Available online at www.sciencedirect.com
ScienceDirect
Procedia - Social and Behavioral Sciences 195 (2015) 2263 – 2271
Procedia
Social and Behavioral Sciences

World Conference on Technology, Innovation and Entrepreneurship

Stress-Strain State of Two Diagonal Cavities Weighty Inclining Layered Massif System with Slots in Terms of Elastic-Creep Deformations

T.Turymbetov[a], N.Azhikhanov[b], N.Zhunisov[b], Zh.Aimeshov[b,*]

[a]*Caspian State University of Technologies and Engineering, Kazakhstan*
[a]*Bolashak Fellow at Colorado School of Mines, US*
[b]*Kh.Yasavi International Kazakh-Turkish University, Kazakhstan*

Abstract

This paper investigated the stress-strain state of two diagonal cavities of arbitrary cross-sectional shape and the depth of a weighty inclining massif with system slots in terms of elastic and elastic-creep deformation rocks. This study was based on the anisotropic mechanical-mathematical model of inclining multilayer massif with a doubly periodic system of slots studied numerically, the patterns of distribution of elastic-creep stresses, displacements near two diagonal cavities of derived shape, and the depth of the Finite Element Method in generalized plane strain. Calculation algorithm is a designed and compiled software package for the study of the elastic-creep state of adjacent cavities of derived depth and shapes. Multivariate numerical calculation and analysis of the effect on the components of stresses and displacements near the cavities geometrics, physical parameters, and creep properties of rocks were conducted.

Peer-review under responsibility of Istanbul Univeristy.

Keywords: anisotropic; elastic-creep deformation; finite element; slots; stress-strain state.

* Corresponding author. Tel.: +7-729-242-5780; fax: +7-729-242-5780.
E-mail address: turymbetov.ta@kguti.kz

Peer-review under responsibility of Istanbul Univeristy.
doi:10.1016/j.sbspro.2015.06.313

1. Introduction

In the last century, the works of foreign scientists consisted mainly of theoretical research on the stress-strain state of underground cavities in the isotropic massif. Using the symmetry of the biharmonic solutions and based on the special properties of harmonic functions by (O.Müller, 1930, & K.Stocke, 1937). They reviewed the relevant class of problems. In the solution (G.V.Kolosov, & N.I.Muskhelishvili, 1966) of two dimensional problems of the theory of elasticity of an isotropic body, they successfully used the method of the Complex Variable Theory.

Analytic function proposed by Appel considered the state of the one and many related isotropic bodies with a circular hole. (L.A.Filshtinsky, 1967) considered orthotropic structures with doubly periodic systems of circular holes, and a body with elliptical holes by (A.S.Kosmodamiansky, & M.M.Neskorodev, 1970). A.S.Kosmodamiansky investigated the stress-strain state of an anisotropic elastic body with three endless rows of holes, and based on the decisions of (Zh.S.Erzhanov, K.K.Kaydarov, & M.T.Tusupov, 1969), studied the effects of the slots on the static stress state of underground workings. (Zh.S.Erzhanov, Sh.M.Aytaliev, & Zh.K.Masanov, 1971) proposed a computational mechanics and mathematical model of the anisotropic elastic strain of the rock mass with doubly periodic systems slots. This solved the problem by bringing the elastic constants obtained transtropic body, and the equivalent stiffness main massif with slots, depending on the elastic properties and the geometry of the slots. On the basis of this model, they mainly studied static initial elastic state single underground cavities in a deep foundation of analytic and approximate methods subsequent creeping cavities state-based Э-Algebra Operators by (U.N.Rabotnov, 1948), and the theory of Creep of Rocks by (Zh.S.Erzhanov, 1964).

(W.Wittke, 2014) extended Anisotropic Jointed Rock Model (AJRM) and the corresponding analysis methods to a wider spectrum of rock types. His design approach has been applied to many projects in tunneling, dam, and slope design.

(L.Segerlind, 1979, B.Z.Amusin, & A.B.Fadeev, 1975, Zh.S.Erzhanov, & T.D.Karimbaev, 1975, A.D.Omarov, Zh.K.Masanov, & N.M.Mahmetova, 2002 and others) made significant contributions to the theory of Finite Element Method (FEM) and its application to solving complex problems of statics and dynamics of solid mechanics.

2. The Task

In this case we investigated the static elastic stress and strain state of two shallow cavities laying in heavy transtropic massif which depended on the degree of discontinuity conforms to small sloping layers at an angle φ when the longitudinal axis of the cavity constitutes an arbitrary angle ψ with the line of the plane of isotropy line coinciding with the plane of the slots. Let H denote the depth of the workings of the distance between their centers $2L$ (Fig. 1).

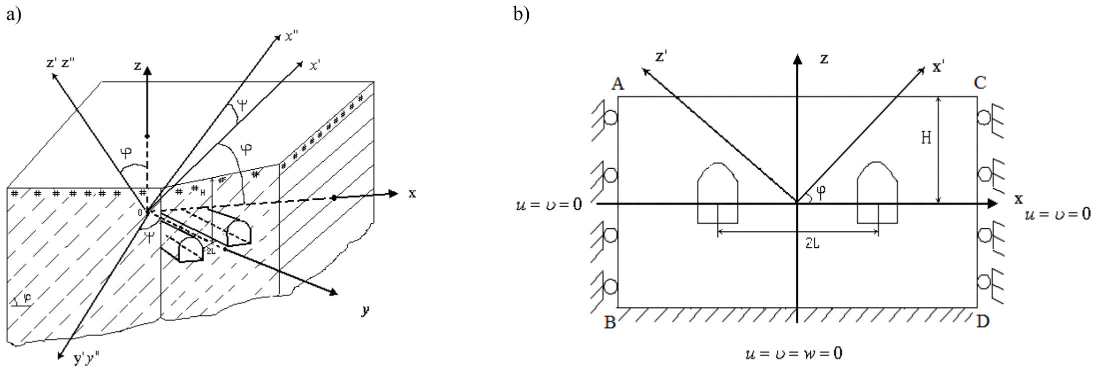

Fig.1.The computational domain (a) three dimensional view; (b) two dimensional view.

Anisotropic doubly periodic massif of slots systems are replaced with a solid transtropic body, equivalent stiffness basic structure, which solves the problem of reduction.

2.1. The task explained

The plane of the cross-sectional areas with anisotropic in plane strain slots; efforts are at infinity (Fig. 2)

$$\sigma_x^{(\infty)} = p,\ \ \sigma_z^{(\infty)} = q,\ \ \tau_{xz}^{(\infty)} = r \tag{1}$$

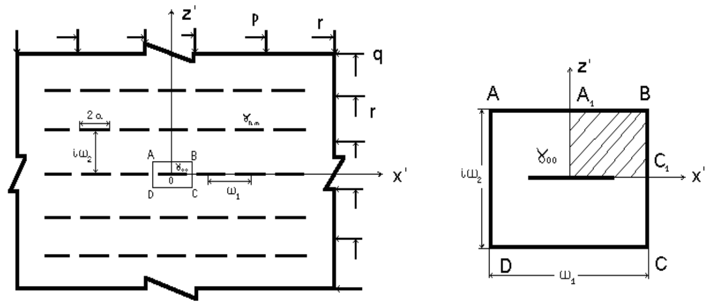

Fig.2. Surface with periodic system of slots.

Here γ_{00} - main slot; $2a$, γ_{nm}- circuits and their length; n,m - indices, $\omega_1, i\,\omega_2$ - periods of slots in the directions of the axes x and z ; circuits are free of external loads. $E_j, \nu_j, G_2\ (j=1,2)$ which represent elastic properties transtropic massif slots. To solve the problem of bringing an anisotropic body with the boundary conditions (1) given elastic parameters $E_i^e, \nu_i^e, G_2^e,\ (i=1,2)$, transtropic solid body, equivalent stiffness anisotropic massif with slots are the following equations:

$$\begin{aligned}
&E_1^э = E_1,\ \nu_1^э = \nu_1,\ \nu_2^э = \nu_2,\\
&E_2^{э^{-1}} = E_2^{-1} + 2\omega^{-1} < 2\operatorname{Re}\sum_{j=1}^{2} q_j \Phi_j\left(x + i\beta_j 0.5\omega, q\right) >,\\
&G_2^{э^{-1}} = G_2^{-1} + 2\omega^{-1} < 2\operatorname{Re}\sum_{j=1}^{2}\left[p_j \Phi_j\left(x + i\beta_j 0.5\omega, r\right) + q_j \Phi_j\left(x + i\beta_j 0.5\omega, r\right)\right] >
\end{aligned} \tag{2}$$

Here < > - symbol averaging values, β_j – anisotropy parameters;

$$\Phi_j\left(z_j\right) = \left(B_j + iC_j\right)z_j + \sum_{k=1}^{\infty} a_{2k-1,j}\zeta_j^{-(2k-1)} + \sum_{k=1}^{\infty}\sum_{k=1}^{\infty} a_{2k-1,j} B_{jik}\left(\zeta_j^{2k-1} + \zeta_j^{-(2k-1)}\right),$$

$$B_1 = 0.5\left(p + \beta_2^2 q\right)\left(\beta_2^2 - \beta_1^2\right)^{-1},\ B_2 = 0.5\left(p + \beta_1^2 q\right)\left(\beta_2^2 - \beta_1^2\right)^{-1},\ C_1 = 0,\ C_2 = 0.5 r \beta_2^{-1}; \tag{3}$$

2.2. The solving problem

Hooke's law of anisotropic massif with cavities with generalized plane strain are relative to the Cartesian coordinate system $Oxyz$ (see Fig. 1):

$$\{\sigma\} = \left[\overline{D}\right]\{\varepsilon\}; \tag{4}$$

were $\{\sigma\} = \left(\sigma_x, \sigma_z, \tau_{yz}, \tau_{xz}, \tau_{xy}\right)^T$, $\{\varepsilon\} = \left(\varepsilon_x, \varepsilon_z, \gamma_{yz}, \gamma_{xz}, \gamma_{xy}\right)^T$, $\left[\overline{D}\right] = \left[d_{ij}\right]$, $(i, j = 1,2,...,5)$; - deformation coefficients as defined by the (Zh.S.Erzhanov, Sh.M.Aytaliev, & Zh.K.Masanov, 1971) equations:

$$d_{11} = a_{11}\cos^4\psi + (2a_{12} + a_{66})\sin^2\psi\cos^2\psi + a_{22}\sin^4\psi,\ d_{22} = a_{33},\ d_{33} = a_{44}\cos^2\psi + a_{55}\sin^2\psi,\ d_{44} = a_{44}\sin^2\psi + a_{55}\cos^2\psi,$$
$$d_{55} = (a_{11} + a_{22} - 2a_{12} - a_{66})4\sin^2\psi\cos^2\psi + a_{66},\ d_{12} = a_{13}\cos^2\psi + a_{23}\sin^2\psi,$$
$$d_{13} = a_{25}\sin^3\psi + (a_{15} - a_{46})\sin\psi\cos^2\psi,\ d_{14} = a_{15}\cos^3\psi + a_{25}\cos\psi\sin^2\psi,$$
$$d_{15} = 2(a_{11} - a_{12})\cos^3\psi\sin\psi + 2(a_{12} - a_{22})\sin^3\psi\cos\psi - 0.5a_{66}\cos 2\psi\sin 2\psi,$$
$$d_{23} = a_{35}\sin\psi,\quad d_{24} = a_{35}\cos\psi,\ d_{25} = 2(a_{13} - a_{23})\cos\psi\sin\psi,\quad d_{34} = (a_{44} - a_{55})\cos\psi\sin\psi,\tag{5}$$
$$d_{35} = a_{46}\cos^3\psi + (2a_{15} - 2a_{25} - a_{46})\sin^2\psi\cos\psi,\ d_{45} = a_{46}\sin^3\psi + (2a_{15} - 2a_{25} - a_{46})\cos^2\psi\sin\psi.$$
$$a_{11} = \frac{1}{E_1}\cos^4\varphi + \frac{1}{4}\left(\frac{1}{G_2} - \frac{2\nu_1}{E_1}\right)\sin^2 2\varphi + \frac{1}{E_2}\sin^4\varphi,\ a_{22} = \frac{1}{E_1},\quad a_{33} = \frac{1}{E_1}\sin^4\varphi + \frac{1}{4}\left(\frac{1}{G_2} - \frac{2\nu_1}{E_1}\right)\sin^2 2\varphi + \frac{1}{E_2}\cos^4\varphi,$$
$$a_{44} = \frac{2(1+\nu_1)}{E_1}\sin^2\varphi + \frac{1}{G_2}\cos^2\varphi,\ a_{55} = \frac{1}{G_2} + \left(\frac{1+2\nu_2}{E_1} + \frac{1}{E_2} - \frac{1}{G_2}\right)\sin^2 2\varphi,$$
$$a_{66} = \frac{1+2\nu_1}{E_1}\cos^2\varphi + \frac{1}{G_2}\sin^2\varphi,\quad a_{12} = -\frac{\nu_1}{E_1}\cos^2\varphi - \frac{\nu_2}{E_1}\sin^2\varphi,\ a_{13} = \frac{\nu_2}{E_1} + \frac{1}{4}\left(\frac{1+2\nu_2}{E_1} + \frac{1}{E_2} - \frac{1}{G_2}\right)\sin^2 2\varphi,$$
$$a_{15} = \left(\frac{1+\nu_2}{E_1}\cos^2\varphi - \left(\frac{1}{E_2} + \frac{\nu_2}{E_1}\right)\sin^2\varphi - \frac{1}{2G_2}\cos 2\varphi\right)\sin 2\varphi,\ a_{23} = -\frac{\nu_1}{E_1}\sin^2\varphi - \frac{\nu_2}{E_1}\cos^2\varphi,\ a_{25} = -\frac{\nu_1 - \nu_2}{E_1}\sin 2\varphi,$$
$$a_{35} = \left(\frac{1+\nu_2}{E_1}\sin^2\varphi - \left(\frac{1}{E_2} + \frac{\nu_2}{E_1}\right)\cos^2\varphi + \frac{1}{2G_2}\cos 2\varphi\right)\sin 2\varphi,\ a_{46} = -\frac{1}{2}\left(\frac{1}{G_2} - \frac{2(1+\nu_1)}{E_1}\right)\sin 2\varphi$$

In these equations $E_k^e, \nu_k^e, G_2^e (k = 1,2)$ represent effective elastic constants transtropic massif equivalent stiffness anisotropic massif with slots, which depends on the elastic constants of the last $E_k, \nu_k, G_2 (k = 1,2)$ and the geometry of the slots $a, \omega, i\omega$.

2.3. The use of numerical methods

The cross-section in plane *ABCD* diagonal cavities under generalized plane strain is meshed using n units to m isoparametric calculation elements (Fig. 1b).

By constituting the basic resolution of the system of algebraic equations Finite Element Method's $3n$-order relative to the projections of displacements points, it can be solved with the following boundary conditions:
base *BD* calculation area *ABCD* non-deformable –

$$u = v = w = 0;\tag{6}$$

sides *AB* and *CD* under the weight of rocks displacement only in the vertical direction due to a lack of influence of cavities-

$$u = v = 0,\quad w = w(z).\tag{7}$$

The study estimated that the area with cavities is automatically meshed into isoparametric elements using program FEM_3D in object-oriented environment Delphi (Fig. 3).

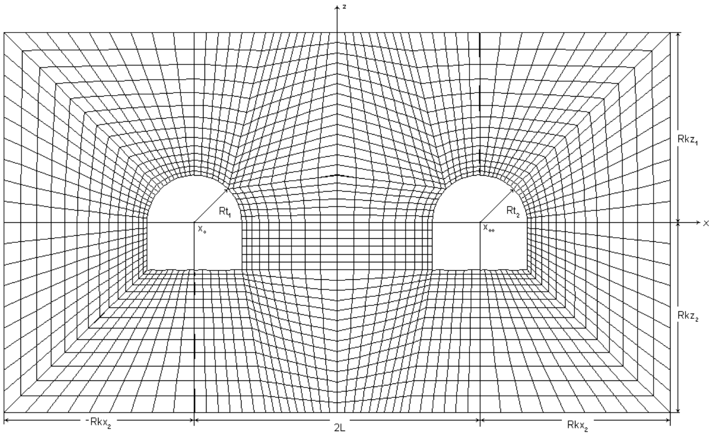

Fig.3. A layout of the estimated area for isoparametric elements

Each point acts as the vertical force of the weight:

$$f_{z_i} = -\frac{\gamma S}{4};\ (i = 1,2,3,4) \tag{8}$$

2.4. Suggested procedure

According to (Masanov, Zh.K., Azhikhanov, N.T., Turymbetov, T.A., & Temirov, B.M., 2009), the fundamental system of equations with the Finite Element Method's displacement components with the boundary conditions (6) and (7) analytic methods are difficult; therefore it can be solved in an iterative method of Gauss-Seidel-relaxation factor with a given accuracy:

$$\{F\} = [K]\{U\} \tag{9}$$

here $[K] = \sum_{i=1}^{n}[k^e]_i$ – stiffness matrix of the system; $\{U\} = (u_1,...,u_R, w_1,...,w_R, v_1,...,v_R)^T$ – displacement vector; $\{F\} = (F_{x_1},...,F_{x_R}, F_{z_1},...,F_{z_R}, F_{y_1},...,F_{y_R})^T$ – force vector.

An attractive feature of this method is as follows: firstly it was prepared only once and the system stiffness $[K]$ was matrix used when iterating its elements and column elements of the matrix $\{U\}$; secondly, when $k+1$- iteration for unknown u_{m+1}, $(m = 1,2,...,3n)$, need values $u_1, u_2,..., u_m$ when $k+1$- iteration, and for $u_{m+2},..., u_{3n}$ - their values for k-iteration.

2.5. Testing the program

To verify the correct operation of the developed algorithms and software systems, problem of elastic stress state circular cavity in an anisotropic massif with the horizontal plane of isotropy $(\varphi = 0)$ in the plane strain and hydrostatic stress distribution in a virgin ground environment was tested. Because of the symmetry of the problem, a quarter of the area of the cavity is divided into 342 isoparametric elements with the help of 380 points. The basic system of equations is solved with 1000 iterations. Unlike values of displacements at characteristic points of contour obtained by iterative and known analytic methods, when tested by (T.Turymbetov, 2014) it was no more than 1-2%

(Table 1).

Table 1. Comparative solution of the test problem for cavity.

θ, deg	$-\sigma_\theta^{cont}/\gamma H$			
	$-\sigma_\theta^{anal}/\gamma H$ Precise method (test)	$-\sigma_\theta^{FEM}/\gamma H$ FEM	$\lvert\sigma_\theta^{anal}/\gamma H-\sigma_\theta^{FEM}/\gamma H\rvert$	$\frac{\lvert\sigma_\theta^{anal}-\sigma_\theta^{FEM}\rvert}{\lvert\sigma_\theta^{anal}\rvert}$
0	3.079	3.040	0.039	0.01
30^0	1.510	1.493	0.017	0.01
60^0	1.706	1.694	0.012	0.007
90^0	2.692	2.631	0.061	0.022

2.6. Application examples

Calculating the components of displacements and stresses near diagonal cavities ($\psi = 0, 30^0, 45^0, 60^0, 90^0$) of varying depth ($H = 5m, 10m, 20m$), occurred when the shape of the profile in slots transtropic massif had discontinuous layer coupling ($\omega / a = 2.5, 3, 4, 6, \infty$), inclined plane isotropy ($\varphi = 0, 30^0, 45^0, 60^0, 90^0$), and the study area was divided into 2064 elements with 2189 points.

The results of calculations are presented in the form of graphics and isolines. The impact of input parameters on the elastic state of underground structures were analyzed in detail.

Figure 4a shows the variation of the vertical elastic stress values $-\sigma_z / \gamma H$ on the between the cavities strain profile depending on the ω/a (Fig. 4b) and depending on the value of the vertical displacement of $w(mm)$ on the between cavities diagonal and the angle of incidence of cavities plane isotropy.

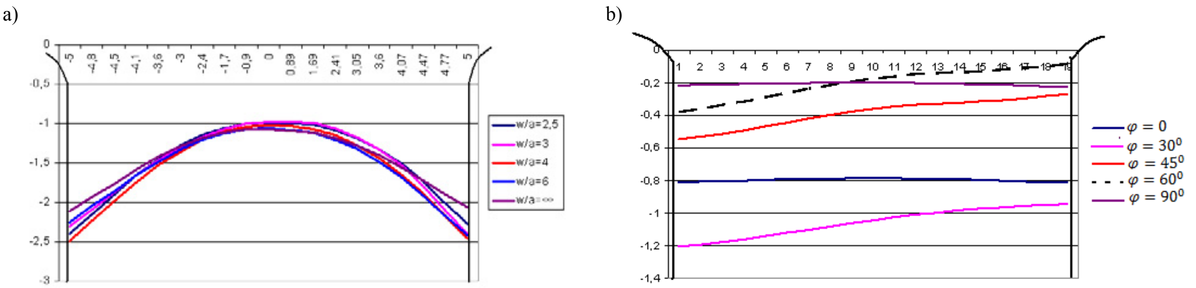

Fig. 4. (a) changing the value of the stress $-\sigma_z / \gamma H$ on the between cavities depends on ω/a (ψ=45^0; φ=90^0; L=10M; H=5M); (b) depending on the values of the vertical displacement w on the between cavities of the angle φ of incidence of the plane of isotropy rocks (ψ=45^0; ω/a=4; L=10M; H=5M).

From these figures it can be seen that the parameter slots ω/a, and the angle of incidence of the plane of isotropy φ has significant impact on the stress and strain state of cavities: with decreasing values ω/a strain varies considerably and angle φ equates to an asymmetric distribution of vertical displacement w. Other things being equal ω/a significantly affects the displacements near the cavities of various forms; with a decrease in the value of its recent increase (Fig. 5a,b).

a) b)

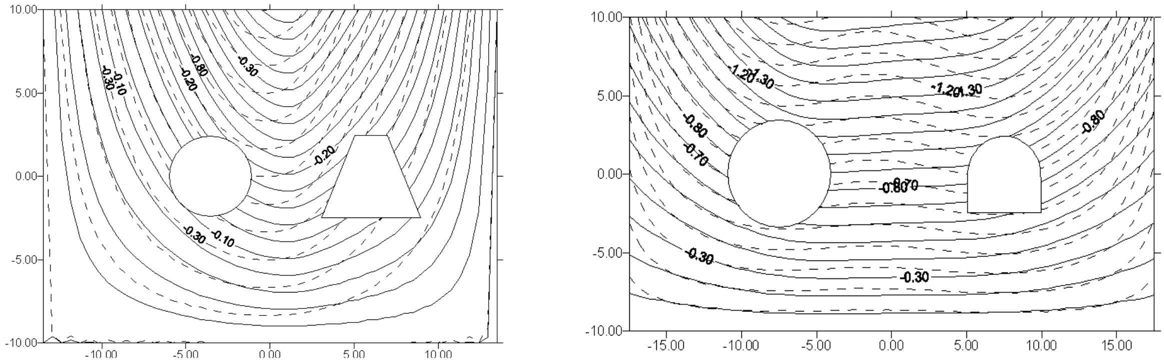

Fig. 5. (a) Isolines displacements $10^6 u\,(mm)$ around the cavity in different shapes (H=10M; L=5M; ψ=45^0; φ=0; —— ω/a=6.0; - - ω/a=2,5); (b) Isolines of vertical displacements $10^6 w(mm)$ around the cavity in different shapes (R_1=3,5M; R_2=2,5M; H=10M;L=10M; ψ=90^0; φ=30^0; ω/a=6.0; - - ω/a=2.5).

3. Stress-strain state of the diagonal cavities in rocks creep

Using the theory of creep of rocks by (Zh.S. Erzhanov, 1964) and the Finite Element Method in terms of the generalized plane strain the patterns of distribution of creeping stresses and displacements near the diagonal pair of cavities in weighty creeping transtropic massif were studied.

Temporal processes (for t> 0) occur near the underground cavities due to the manifestation of creep properties of the around rocks. For their study, involving the basic principles of the theory of creep of rocks by Zh.S.Erzhanov, (5) the given elastic constants $E_1^e,\ E_2^e,\ G_2^e$ and Poisson's ratios $\nu_1^e,\ \nu_2^e$ are replaced with temporary operators

$$\widetilde{E}_1^e,\ \widetilde{E}_2^e,\ \widetilde{G}_2^e,\ \widetilde{\nu}_1^e,\ \widetilde{\nu}_2^e\ ,\ \widetilde{E}_n^{e^*} = E_n^e\left(1-E_n^*\right),\ \left(\widetilde{E}_3^e = \widetilde{G}_2^e\right),\quad \nu_k = \nu_k^e\left(1+\nu_k^*\right),\ (k=1{,}2;\ n=1{,}2{,}3)\,, \qquad (10)$$

$$E_n^* f = \int_0^t M_n(t-\tau) f(\tau) d\tau, \qquad \nu_k^* f = \int_0^t L_k(t-\tau) f(\tau) d\tau\,;$$

here $M_n(t-\tau)$, $L_k(t-\tau)$ - the core of heredity.

As shown by laboratory testing by (A.A.Sarsembayev, A.Y.Sinyaev, V.P.Matveev, & E.F. Kudashov, 1965) creeping parameters anisotropic rocks slightly vary in different directions.

Therefore, in the temporal operators $\widetilde{E}_1^e,\ \widetilde{E}_2^e,\ \widetilde{G}_2^e,\ \widetilde{\nu}_1^e,\ \widetilde{\nu}_2^e$ are defined as

$$\widetilde{E}_n^e = E_n^e\left[1-\aleph Э_\alpha^*(-\beta)\right],\ \widetilde{\nu}_k^e = \nu_k^e,\quad \widetilde{E}_i^e / \widetilde{E}_j^e = E_i^e / E_j^e = const,\ (n,i,j=1{,}2{,}3;k=1{,}2)\,.$$

Then creeping parameters of rocks with Abelian kernel creep defined by the equations:

$$E_{k,t}^e = E_k^e\left(1+\Phi_t\right)^{-1},\ \nu_{k,t}^e = 0.5-(0.5-\nu_k)\left(1+\Phi_t\right)^{-1},\ \Phi_{k,t} = \delta(1-\alpha)^{-1} t^{1-\alpha}\,;$$

$\alpha, \delta -$ creeping parameters of rocks, $t -$ time.

When calculating the stress state of the diagonal cavities under isotropic manifestations, creep properties of rocks transtropic use the time units for t=120h and t=600h given by (Zh.S.Erzhanov, Sh.M.Aytaliev, & Zh.K.Masanov, 1980).

In accordance with the developed algorithms and programs in creep stress-strain state of the diagonal cavities studied by variable modules, when numerical values per component stresses and displacements are caused by isotropic creep anisotropic rocks, Finite Element Method used elastic software systems, which are appropriate geometrical and physical parameters under the same Finite Element discretization study area with holes and method for solving the basic system of equations (Fig. 6).

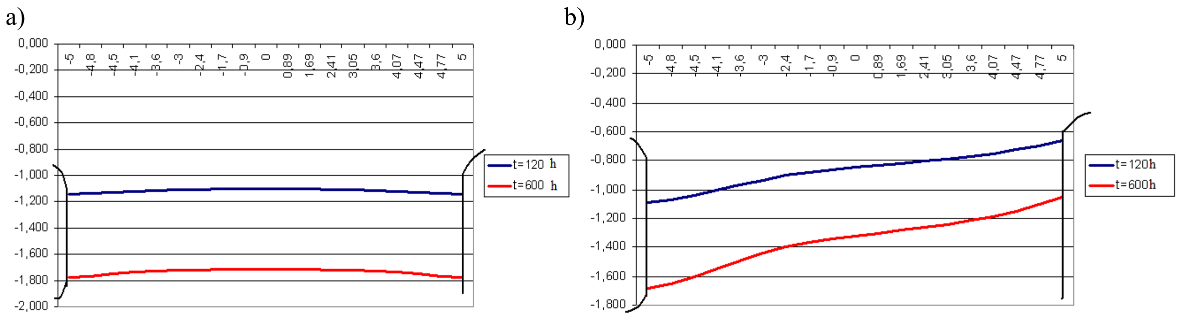

Fig.6. (a) In situation H=10M; L=5M; φ=0; ψ=45^0; $\omega / a = 6.0$ changing the vertical $10^6 w(mm)$ displacements; (b) In situation H=10M; L=5M; φ=60^0; ψ=45^0; $w/a = 3$ changing the vertical $10^6 w(mm)$ displacements.

4. Conclusion

At an angle of inclination of the plane of isotropy $\varphi = 0, 90^0$ (and the plane of the slots) slots massif with cavities, both stress and displacements are distributed symmetrically around the vertical axis Oz and increase with the depth of emplacement of structures, which reduces stress, increasing displacement with reduction *ω/a*; when $\varphi \neq 0, 90^o$, both the stress and the displacement are asymmetric about vertical axis Oz. In the case of $\varphi = 0, \psi \neq 0$ stress and strain state structures remain unchanged. When the length of the between cavities are *5D* or more, and *D*-cavities are of the largest diameter, interference structures is negligible.

Multiple calculations set: with increasing time t creeping displacement components increase in character being distributed similarly elastic; at $\omega / a = 2.5$ displacement is increased almost twice the corresponding value, at $\omega / a = 6.0$; over time changing stress low are general.

Acknowledgement

I would like to thank Special Programs and Continuing Education (SPACE) staff, Instructors, and Professors of Mining Engineering at the Colorado School of Mines, for their suggestions and advice.

References

Müller, O. (1930). Untersuchungen an Karbongesteinen zur Klärung von Gebirgsdruckfragen. *Glückauf.* #47. (pp. 1601-1612).

Stöcke, K. (1937). Für das Gebingsdruckproblem wichtige Begriffe aus der technischen Mechanik. *Zeitschrift für des Berg-Hütten und Salinenwesen.* Bd. 84, H. 11. (pp. 465-467).

Muskhelishvili, N.I. (1966). *Some basic problems of the mathematical theory of elasticity.* M .: Science.

Wittke, W. (2014). *Rock Mechanics Based on an Anisotropic Jointed Rock Model (AJRM).* Germany.

Filshtinsky, L.A. (1967). Stress in the correct doubly periodic grids (lattices). *Engineering magazine. Mechanics of Solids,* #1. (pp. 20-28).

Kosmodamianski, A.S., & Neskorodev, M.M. (1970). Doubly periodic problem for an anisotropic structure weakened elliptical holes. *Reports of the Academy of Sciences URSR Ser. A.* # 7. (pp. 31-42).

Erzhanov, Zh.S, Kaidarov, K.K., & Tusupov, M.T. (1969). *Mountain range with a discontinuous layer coupling (plane problem).* Mechanical processes in the rock mas. Alma-Ata, Nauka.

Erzhanov, Zh.S, Aytaliev, Sh.M., & Masanov, Zh.K. (1971). *Stability of horizontal caves in the pan-layered massif.* Alma-Ata, Science.

Rabotnov, U.N. (1948). Some problems in the theory of creep. *Vestnik MGU.* #10.

Erzhanov, Zh.S. (1964). *The theory of creep of rocks and its application.* Alma-Ata, Nauka.

Segerlind, L. (1979). *Application of the Finite Element Method.* Moscow, Mir.

Amusin, B.Z., & Fadeev, A.V. (1975). *The finite element method for solving mining mechanics.* Moscow: Nedra.

Erzhanov, Zh.S., & Karimbayev, T.D. (1975). *The finite element method in problems of rock mechanics.* Alma-Ata: Science.

Omarov, A.D., Masanov, Zh.K., & Makhmetova N.M. (2002). *Static and seismic stress state transport of underground structures in anisotropic nonlinear geometric massif.* Almaty, Bastau.

Masanov, Zh.K., Azhikhanov, N.T., Turymbetov, T.A., & Temirov, B.M. (2009). The stress state of the two shtreks of a weighty obliquely layered massif system with cracks of elastic deformation of rocks. *L.N. Gumilyov Eurasian National University.* (pp. 150-154). Vestnik ENU, #4. Astana.

Turymbetov, T. (2014). The stress-strain state of the two shtreks of cross-sectional shape and the depth of a weighty obliquely layered massif system with slits in terms of elastic deformation of rocks. *International Journal of Latest Research in Science and Technology.* (pp. 29-32). Vol 3, Issue 6. India.

Sarsembayev, A.A., Sinyaev, A.Y., Matveev, V.P., & Kudashov E.F. (1965). On determination of elastic deformation and time for layered samples. *Proc. Research on rock mechanics.* Alma-Ata, Nauka.

Erzhanov, Zh.S., Aytaliev, Sh.M., & Masanov, Zh.K. (1980). *Seismic stress state of underground structures in anisotropic layered massif.* Alma-Ata, Science.