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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ИЗВЕСТИЯ

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CONTENTS

Geology

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STABILITY OF WORKINGS OF THE CROSSHAIRS AND DRIFTS TYPE IN THE INCLINED-LAYERED ROCK MASSIF

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Abstract. The article studies the stability of workings of circular cross-sectional profile drifts and crosshairs in inclined layered rock massif. The intact rock massif is represented by a continuous elastic homogeneous transversal-isotropic medium with an inclined plane of isotropy coinciding with the layer-rock layering plane. The initial elastic stress and strain states of the excavation are determined by the corresponding anisotropic body theory equations for flat (drift) and generalized flat (crosshair) deformations, that is, by the generalized Hooke's law equations. Calculations of the initial stability of unanchored mine workings in a sloping layered massif, performed on its anisotropic model, showed that the effect of the slope of the layers and the location of the mine workings relative to their strike is clearly established in the initial elastic stage of deformation of the massif around the mine workings. The crosshair is under relatively favorable conditions not only at medium angles φ, but also at steep bedding of rocks. In a rock massif with vertical layers, the stresses around the crosshair will be the same as in an isotropic massif. The data of multivariate numerical experiments show that, at any angle of incidence, the initial elastic stability conditions are relatively favorable for the crosshair than for the drift. A detailed analysis of the numerical results indicates sufficient completeness of the assumptions of this study and the validity of its results as a theoretical basis for solving various problems of rock pressure when driving horizontal mine workings, the longitudinal axes of which are arbitrarily oriented in a slant-layered array of rocks.

Keywords: rock massif, rock pressure, angle of incidence of layers, stability, crosshair, drift, anisotropy.

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КӨЛБЕУ-ҚАТПАРЛЫ ТАУ МАССИВІНДЕГІ КВЕРШЛАГТАР МЕН ШТРЕКТЕР ТҮРІНДЕГІ ҚАЗБАЛАРДЫҢ ТҰРАҚТЫЛЫҒЫ

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Аннотация. Мақалада тау жыныстарының көлбеу-қатпарлы массивінде өткен дөңгелек көлденең профильдегі штректер мен квершлагтар түріндегі қазбалардың тұрақтылығы зерттелген. Қол жетімсіз тау массиві жыныстардың қабаттасу қабаттарымен сәйкес келетін изотропияның көлбеу жазықтығымен тұтас серпімді біртекті трансверсальды-изотропты ортамен ұсынылған. Бастапқы серпімді кернеулі және деформацияланған күй жазық (штрек) және жалпыланған жазық (квершлаг) деформациялар үшін анизотропты дене теориясының тиісті теңдеулерімен, яғни Гук заңының жалпыланған теңдеулерімен анықталады. Оның анизотропты моделінде

жасалған көлбеу қабатты массивтегі бекітілмеген тау-кен қазбаларының бастапқы тұрақтылығын есептеу қабаттардың көлбеу әсері мен олардың созылуына қатысты қазбаның орналасуы қазбаның айналасындағы массивті деформациялаудың бастапқы серпімді кезеңінде нақты белгіленетінін көрсетті. Квершлаг салыстырмалы түрде әрқашанда қолайлы жағдайда, φ орташа бұрыштарында ғана емес, сонымен қатар тау жыныстарының тік орналасуында да болады. Тік қабаттары бар тау массивінде квершлагтың айналасындағы кернеулер изотропты массивпен бірдей болады. Көп нұсқалы сандық эксперименттердің мәліметтері тау жыныстарының құлауының кез-келген бұрышында бастапқы серпімді тұрақтылық жағдайлары штрекке қарағанда квершлаг үшін салыстырмалы түрде қолайлы екенін көрсетеді. Сандық нәтижелерді егжей-тегжейлі талдау осы зерттеудің алғышарттарының жеткілікті толықтығын және оның нәтижелерінің сенімділігін көлденең тау-кен қазбаларын қазу кезіндегі тау қысымының әр түрлі мәселелерін шешудің теориялық негізі ретінде көрсетеді, олардың бойлық осьтері тау жыныстарының көлбеу-қабатты массивінде еркін бағытталған.

Түйін сөздер: тау массиві, тау қысымы, қабаттардың құлау бұрышы, тұрақтылық, квершлаг, штрек, анизотропия.

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УСТОЙЧИВОСТЬ ВЫРАБОТОК ТИПА КВЕРШЛАГОВ И ШТРЕКОВ В НАКЛОННО-СЛОИСТОМ ГОРНОМ МАССИВЕ

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Аннотация. В статье изучена устойчивость выработок типа штреков и квершлагов круглого поперечного профиля, пройденных в наклонно-слоистом массиве горных пород. Нетронутый горный массив представлен сплошной упругой однородной трансверсально-изотропной средой с наклонной плоскостью изотропии, совпадающей с плоскостью слоев – напластования пород. Начальное упругое напряженное и деформированное состояния выработки определены соответствующими уравнениями теории анизотропного тела для плоской (штрек) и обобщенной плоской (квершлаг) деформаций, т.е. обобщенными уравнениями закона Гука. Расчеты начальной устойчивости незакрепленных горных выработок в наклонно-слоистом массиве, выполненные на ее анизотропной модели, показали, что эффект влияния наклона слоев и расположения выработки относительно их простирания четко устанавливается в начальной упругой стадии деформирования массива вокруг выработки. Квершлаг находится в сравнительно благоприятных условиях не только при средних углах φ, но и при крутом залегании пород. В горном массиве с вертикальными слоями напряжения вокруг квершлага будут такими же, как и в изотропном массиве. Изложенные данные многовариантных численных экспериментов показывают, что при любом угле падения пород условия начальной упругой устойчивости сравнительно благоприятны для квершлага, нежели для штрека. Детальный анализ численных результатов свидетельствует о достаточной полноте предпосылок данного исследования и достоверности его результатов как теоретической основы решения разнообразных вопросов горного давления при проходке горизонтальных горных выработок, продольные оси которых произвольно ориентированы в наклонно-слоистом массиве горных пород.

Ключевые слова: горный массив, горное давление, угол падения слоев, устойчивость, квершлаг, штрек, анизотропия.

Introduction. Development of minerals is usually accompanied by sinking and anchoring of horizontal underground excavations, crossing the layered-forming strata of sedimentary rocks in different directions. These excavations, depending on the orientation of longitudinal axes relative to the strike of rock layers, are divided into drifts and crosshairs, located along the strike and along the strike of rocks. The intermediate position is occupied by relatively rare diagonal excavations, whose axes form an acute angle with the line of strike of the layers - rock stratification surfaces.

The manifestation of rock pressure in the drifts and crosshairs, displacements of rocks and their pressure on the support are largely predetermined by the slope of rock layering surfaces. This is confirmed by field observations. However, until now there has been no sufficiently complete analysis and calculation of such phenomena, characterizing the specifics of the mechanism of stability and work of shields of drifts and crosshairs, as well as diagonal mine workings. The existing calculation schemes of mine workings represent the real rock mass as a mechanically homogeneous medium (isotropic or anisotropic) simulating horizontal layering. They sufficiently reflect the main physical and kinematic features of rock behavior and their interaction with underground structures, do not allow to assess the influence of the spatial position of rock layering surfaces on the rock pressure.

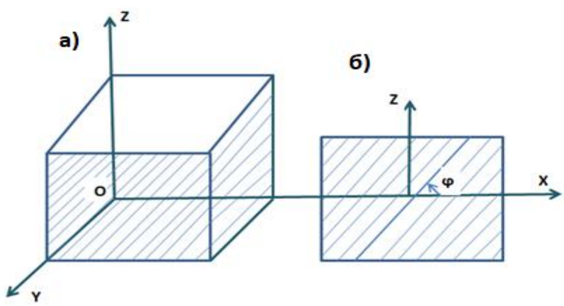
The expediency of taking into account the elastic anisotropy of rocks around workings was first noted by G.N. Savin, who obtained expressions for the coefficient of lateral pressure (Savin, 2014). S.G. Lekhnitsky solved the problem about the stress state of a heavy elastic transversal-isotropic massif with a horizontal isotropic plane, weakened by a mine shaft (Lekhnitsky, 2013).

The influence of elastic anisotropy of rocks on the stress state around adits was considered by G. Sonntag in an approximate way (Sonntag, 2013; Sonntag, 2013). In their works H. Werner and P. Felix touched upon the issues of estimation of layering and elastic anisotropy of rocks (Werner, 2015; Felix, 2013).

There are very few data on the full set of elastic characteristics of rocks as a transversal-isotropic body. The main reason is the lack of experimental data on the shear modulus G_2, which was pointed out by A.S. Kosmadamiansky (Kosmodamiansky, 2013). Researchers K. Wolf and H.A. Lang determined the shear modulus G_2 not from experiment, but by very arbitrary calculations (Wolf, 2016; Lang, 2014).

Material and basic methods. The stress-strain state of horizontal mine workings such as drifts and crosshairs, in addition to different orientations, is predetermined by the slope of folded rock layers. Let us define the basic physical equations of the anisotropic (transtropic) model of the rock massif, not weakened by the conduct of underground construction. Let's introduce a rectangular Cartesian coordinate system Oxyz (see Figure 1a, b), where Oz axis is directed vertically upwards, horizontal axes Oy and Ox coincide with the lines along and across the strike of the isotropic plane, respectively. Let us denote the angle of inclination of the isotropy plane to the horizontal plane by ϕ. Then the equations of the generalized Hooke's law for a transtropic massif with the isotropy plane inclined at angle ϕ in the chosen coordinate system Oxyz have the form:

$$\begin{aligned} &\varepsilon_x = a_{11}\sigma_x + a_{12}\sigma_y + a_{13}\sigma_z + a_{15}\tau_{xz}, && \varepsilon_y = a_{12}\sigma_x + a_{22}\sigma_y + a_{23}\sigma_z + a_{25}\tau_{xz}, \\ &\varepsilon_z = a_{13}\sigma_x + a_{23}\sigma_y + a_{33}\sigma_z + a_{35}\tau_{xz}, && \gamma_{yz} = a_{44}\,\tau_{yz} + a_{46}\,\tau_{xy} \\ &\gamma_{xy} = a_{46}\tau_{yz} + a_{66}\tau_{xy}, && \gamma_{xz} = a_{15}\sigma_x + a_{25}\sigma_y + a_{35}\sigma_z + a_{55}\tau_{xz} \end{aligned} \tag{1}$$



a– general scheme; b - cross-section across the isotropic plane
Fig. 1 - Sloped-layered rock massif

where the strain coefficients $a_{\text{ij}}\ (i, j = 1-6)$ are equal:

$$a_{11} = E_1^{-1}\cos^4\phi + 0.25(G_2^{-1} - 2\nu_2 E_1^{-1})\sin^2 2\phi + E_2^{-1}\sin^4\phi, \quad a_{22} = E_1^{-1},$$
$$a_{33} = E_1^{-1}\sin^4\phi + 0.25(G_2^{-1} - 2\,\nu_2 E_1^{-1})\sin^2 2\phi + E_2^{-1}\cos^4\phi,$$
$$a_{44} = 2\,E_1^{-1}(1+\nu_1)\sin^2\phi + G_2^{-2}\cos^2\phi, \tag{2}$$
$$a_{55} = G_2^{-1} + (E_1^{-1}(1+2\,\nu_2) + E_2^{-1} - G_2^{-1})\sin^2 2\phi,$$
$$a_{66} = 2\,E_1^{-1}(1+\nu_1)\cos^2\phi + G_2^{-1}\sin^2\phi, a_{12} = -E_1^{-1}\nu_1\cos^2\phi + G_2^{-1}\nu_2\sin^2\phi,$$
$$a_{13} = -E_1^{-1}\nu_2 + 0.25(E_1^{-1}(1+2\,\nu_2) + E_2^{-1} - G_2^{-1})\sin^2 2\phi,$$
$$a_{15} = [E_1^{-1}(1+\nu_2)\cos^2\phi - (E_2^{-1} + E_1^{-1}\nu_2)\sin^2\phi - 0.5\,G_2^{-1}\cos 2\phi]\sin 2\phi,$$
$$a_{23} = -E_1^{-1}\nu_1\sin^2\phi - E_1^{-1}\nu_2\cos^2\phi, a_{25} = -E_1^{-1}(\nu_1 - \nu_2)\sin 2\phi,$$
$$a_{35} = [E_1^{-1}(1+\nu_2)\sin^2\phi - (E_2^{-1} + E_1^{-1}\nu_2)\cos^2\phi + 0.5\,G_2^{-1}\cos 2\phi]\sin 2\phi,$$
$$a_{46} = -0.5\left(G_2^{-1} - 2\,E_1^{-1}(1+\nu_1)\right)\sin 2\phi,$$

and the remaining strain coefficients are zero.

Here E_1 and E_2- are elastic moduli in the isotropy plane and perpendicular to it; v_1 and v_2 - Poisson's coefficients in the isotropy plane and perpendicular to it during compression-expansion in this plane; G_2- is shear modulus for planes normal to the isotropy plane. The values E_1, E_2, v_1, v_2 are found from uniaxial compression experiments on rock samples parallel and perpendicular to the layering. First, the modulus of elasticity E*a* in compression of the sample at an angle *a* to the layering is determined from the formula:

$$E_\alpha = (E_1^{-1}\cos^4\phi + 0.25\,(G_2^{-1} - 2\,E_1^{-1}\nu_2)\sin^2 2\alpha + E_2^{-1}\sin^4\alpha)^{-1},$$

and then the shear modulus G_2 by the formula:

$$G_2 = \sin^2 2\alpha\,[0.25\,(E_\alpha^{-1} - E_1^{-1}\cos^4\alpha - E_2^{-1}\sin^4\alpha + 0.5\,E_1^{-1}\nu_2\sin^2 2\alpha)]^{-1}.$$

Determination of the stress components in an intact continuous rock massif, from now on referred to as the main ones, is hypothetical in nature. A.N. Dinnik's hypothesis about the absence of horizontal displacements in an intact thickness under the action of its own weight only, which is equivalent to the absence of expansion of the rock massif in the horizontal directions, is widely used. Then, taking $\sigma_z = -\gamma H$ and using (1), we obtain

$$\sigma_x = \lambda_x\,\sigma_z, \sigma_y = \lambda_y\,\sigma_z, \tau_{xz} = \lambda_{xz}\,\sigma_z, \tau_{yz} = \tau_{xy} = 0.$$

Here λ_x, λ_y - coefficients of lateral pressure across and along the isotropy plane; γ, H - volumetric weight of the rock mass and depth of the point in question. At horizontal layering (isotropy plane), when $\phi = 0$, we have:

$$\lambda_x = \lambda_y = \nu_2\,(1-\nu_1)^{-1};\ \lambda_{xz} = 0\cdot \tag{3}$$

For an isotropic medium ($E_1 = E_2 = E, G_2 = G, \nu_1 = \nu_2 = \nu$) we obtain the well-known A.N. Dinnik's coefficient:

$$\lambda_x = \lambda_y = \nu\,(1-\nu)^{-1};\ \lambda_{xz} = 0. \tag{4}$$

For an incompressible medium at $\nu = 0.5$ we come to a hydrostatic stress distribution

$$\lambda_x = \lambda_y = 1, \lambda_{xz} = 0. \tag{5}$$

Results and discussion. An unanchored deep underground mine working in a transversally isotropic rock massif arbitrarily oriented relative to the rock strike line is considered. First, the stress state of the transversally isotropic rock massif is found. The stress state of the undisturbed rock massif, in which no underground excavation has yet been carried out, is determined by its elastic properties, assuming that only vertical movements are possible according to the hypothesis of A.N. Dinnik. Then we studied the mechanical state of circular drifts and crosshairs caused by the anisotropic elasticity of the rock mass, as well as the influence of the angle of incidence of rocks on the distribution of stresses on the contour of loose drifts and crosshairs.

It should be noted that the values of the modulus of elasticity allow us to estimate the degree of elastic anisotropy of the rock massif only qualitatively. For a complete analysis of such anisotropy of a rock massif, it is necessary to have values of the anisotropy parameters for the flat problem introduced by S.G. Lekhnitsky:

$$k^2 = \frac{(E_1/E_2)-\nu_2^2}{1-\nu_1^2}, \quad n = \sqrt{2k+m}, \quad \text{где} \quad m = \frac{(E_1/G_2)-2\nu_2(1+\nu_1)}{1-\nu_1^2} \tag{6}$$

In other words, they can be found using the values of all five elastic constants of the rock mass: E_1 and E_2 - modulus of elasticity in the isotropy plane and perpendicular to it; ν_1 and ν_2 - Poisson's ratio in the isotropy plane and perpendicular to it (in tension-compression in this plane); G_2 - shear modulus for planes normal to the isotropy plane.

Values E_1, E_2, ν_1, ν_2 are determined by compression experiments on rock samples parallel and perpendicular to the layering, and G_2 is calculated by the formula

$$G_2 = \left(\frac{4}{E_{\varphi=45^0}} - \frac{1-2\nu_2}{E_1} - \frac{1}{E_2}\right)^{-1}, \tag{7}$$

where $E_{\varphi=45^0}$ - is the value of the modulus of elasticity in compression of the rock sample in the direction which is 45^0 with the plane of isotropy (stratification).

In the generalized planar deformation (the crosshair stress problem), in addition to the parameters *k* and *n* we need the parameter *l* defined by the expression

$$l = \sqrt{E_1/2\,(1+\nu_1)G_2}. \tag{8}$$

The degree of anisotropy is estimated by the deviation of the values of these parameters from the values for isotropic medium: *k=1*, *n=2*, *l=1*.

Evaluation of the stability of mine workings is given taking into account the influence of technological irregularities of the rock contour. The analysis is based on multivariate numerical experiments using formulas 1-8. For the numerical analysis, the authors developed an algorithm and a package of applied programs for the problem of the stress state of underground structures (Guang-Chuan Liang, et. al., 2016), **(Mandal,** et. al., 2018; **Jianguo Zhang,** et. al., 2019; **Liu Hao,** et. al., 2020; **Pleshko,** et. al., 2021).

Calculations were performed using a set of elastic parameters of siltstone as an example: *k=1,43*; *n=3,32*; *l=1,78*. The calculations are performed for the cases when the stress distribution in the intact massif:

1) nonhydrostatic (according to A.N. Dinnik), i.e. $\lambda_x = \lambda_x(\varphi)$, $\lambda_y = \lambda_y(\varphi)$, $\lambda_\tau = 0$;
2) hydrostatic, i.e. $\lambda_x = \lambda_y = 1$, $\lambda_\tau = 0$.

Values of lateral pressure coefficients for rock massifs with drifts and crosshairs are summarized in Table 1.

Table 1 - Values of side pressure coefficients

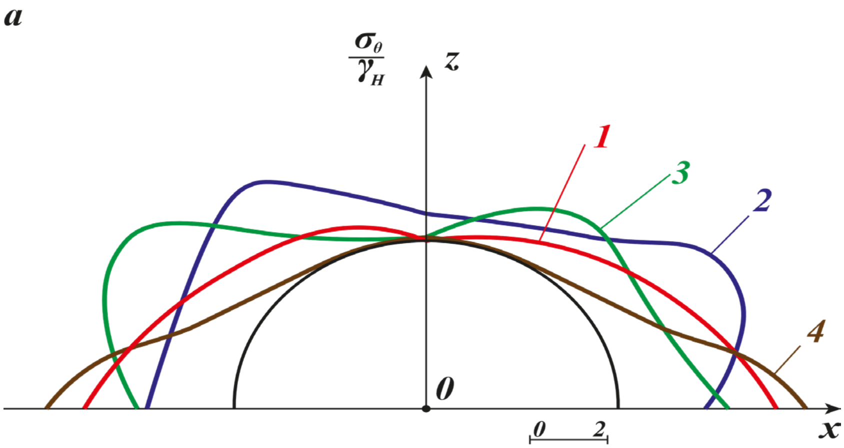
φ, degree	0	10	20	30	40	50	60	70	80	90
λ_x	0.337	0.398	0.549	0.692	0.705	0.578	0.404	0.258	0.169	0.139
λ_y	0.337	0.364	0.436	0.520	0.566	0.556	0.517	0.476	0.456	0.441
λ_τ	0	-0.031	-0.039	0.104	0.239	0.314	0.300	0.224	0.118	0

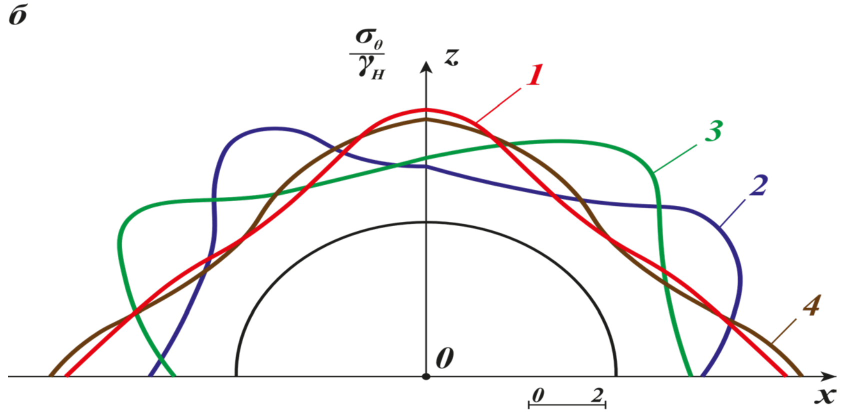
The initial stability of the mine workings of the drift and crosshair type has been studied. On the contour of loose circular workings $\sigma_r = \tau_{r\theta} = 0$. Circumferential stresses σ_θ for the drift are calculated in points with coordinates θ from 0 to 180^0, and for the contour of the crosshair, whose vertical and horizontal axes are axes of symmetry, - only in one quadrant because of symmetry. The angle of incidence of rocks φ varies from 0 to 90^0.

Based on the developed proprietary algorithms and stable numerical analysis schemes combined with the finite element method, multivariate numerical experiments were carried out to study the stress state of the circular mine workings of the drift and crosshair type (Solonenko, et al., 2017; Makhmetova, et al., 2019; Solonenko, et al., 2022). The stresses on the drift's contour changed with the increase of rock dip angle and underwent not only quantitative but also qualitative changes. The results of numerical experiments on the law of stress distribution along the contour of the circular drift depending on the angle of incidence of rocks are shown in Table 2. The corresponding diagrams of circumferential stresses σө, built on the contour of the drift type excavation, are shown in Fig. 2a,b. The stresses are shown in fractions of γH both for nonhydrostatic $\lambda_x = \lambda_x(\varphi)$, $\lambda_y = \lambda_y(\varphi)$ and hydrostatic $\lambda_x = \lambda_y = 1$. With a steep fall of rocks, the distribution of these stresses becomes inhomogeneous: tensile stresses appear in the top and bottom of the excavation. The epiures have symmetry axes for horizontal and vertical bedding, with the maximum stresses at the lateral points and the minimum ones at the top. At $\lambda_x = 1$, the maximum stresses, remaining constant in value at any inclination angle of the layers, are concentrated at the point of the rock contour along the normal to the layering plane. The track is in favorable conditions at medium angles $\varphi = 30^0$-50^0, when the circumferential stresses are distributed relatively evenly and least intensely.

Table 2 - Stress distribution along the contour of the circular drift

ө, degree	$\sigma_ө/\gamma H$ *(drift)*					
	$\varphi=30^0$		$\varphi=45^0$		$\varphi=60^0$	
	$\lambda_x = \lambda_x(\varphi)$	$\lambda_x=1$	$\lambda_x = \lambda_x(\varphi)$	$\lambda_x=1$	$\lambda_x = \lambda_x(\varphi)$	$\lambda_x=1$
0	1.967	1.706	1.750	1.420	2.152	1.610
10	2.288	2.077	1.833	1.572	1.861	1.403
20	2.582	2.493	2.025	1.877	1.731	1.476
30	2.583	2.692	2.250	2.292	1.700	1.706
40	2.183	2.493	2.319	2.638	1.698	2.077
50	1.633	2.077	2.045	2.638	1.605	2.493
60	1.183	1.706	1.542	2.292	1.297	2.692
70	0.890	1.476	1.079	1.877	0.834	2.493
80	0.734	1.403	0.767	1.572	0.430	2.077
90	0.712	1.510	0.599	1.420	0.184	1.706
100	0.885	1.875	0.562	1.431	0.074	1.476
110	1.402	2.570	0.699	1.653	0.076	1.403
120	2.126	3.079	1.165	2.187	0.222	1.510
130	2.233	2.570	2.101	2.926	0.657	1.875
140	1.926	1.875	2.739	2.926	1.688	2.570
150	1.710	1.510	2.453	2.187	3.084	3.079
160	1.657	1.403	2.035	1.653	3.295	2.570
170	1.746	1.476	1.805	1.431	2.671	1.875
180	1.967	1.706	1.750	1.420	2.152	1.510



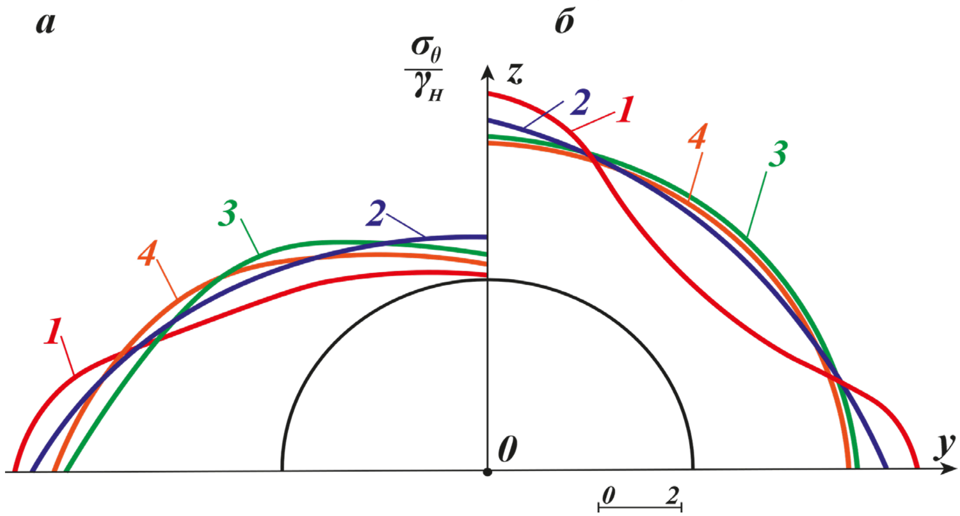


a - when $\lambda_x = \lambda_x(\varphi)$, б – when λ_y=1; 1- φ=0, 2- φ=30⁰, 3- φ=60⁰, 4- φ=90⁰
Fig. 2 - Circumferential stress diagrams on the contour of the circular profile drift

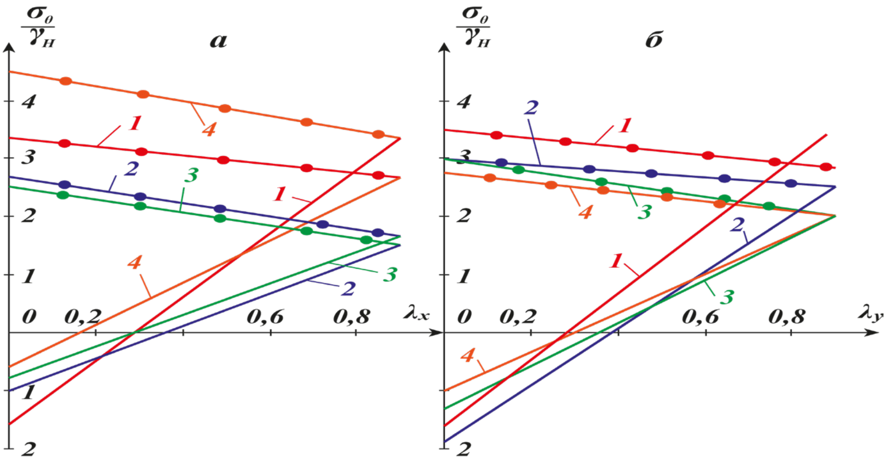
The diagrams of circumferential stresses σ_θ, built on the contour of the crosshair type excavation, are shown in Figure 3a,b. Stresses on the crosshair, on the contrary, in all cases are symmetrical relative to the vertical and horizontal axes and are homogeneous everywhere - compressive. The minimum stresses are concentrated strictly in the middle of the roof, the maximum - in the side points of the crosshair, reaching the highest and lowest values in the horizontal bedding of rocks. The results of numerical experiments on the law of distribution of stresses along the contour of the circular crosshair, depending on the angle of incidence of rocks are shown in Table 3. Naturally, in this case, the stress state of the drift and the crosshair coincide. When λ_y=1, the maximum and minimum stresses at the contour of the crosshair tend to the same value as the rock dip angle increases. The dependence of circumferential stresses on lateral pressure coefficients is shown in Figure 4 for the drift (a) and the crosshair (b), where the solid lines refer to the top of the excavation and the dotted ones to its sides. Curves 4 at $\varphi = 90^0$ for the crosshair coincide with the results for isotropic massif

Table 3 - Stress distribution along the contour of the circular crosshair

φ, degree	Crosshair					
	λ_y=0.2		$\lambda_y = \lambda_y(\varphi)$		λ_y=1	
	$\sigma_{\theta.max}/\gamma H$ *при* $\theta=0^0$	$\sigma_{\theta.min}/\gamma H$ *при* $\theta=90^0$	$\sigma_{\theta.max}/\gamma H$ *при* $\theta=0^0$	$\sigma_{\theta.min}/\gamma H$ *при* $\theta=90^0$	$\sigma_{\theta.max}/\gamma H$ *при* $\theta=90^0$	$\sigma_{\theta.min}/\gamma H$ *при* $\theta=45^0$
0	3.206	-0.631	3.118	0.006	3.079	1.404
10	3.162	-0.653	3.058	0.080	2.927	1.443
20	3.051	-0.678	2.902	0.302	2.652	1.537
30	2.915	-0.669	2.711	0.561	2.412	1.655
40	2.800	-0.630	2.551	0.680	2.256	1.780
50	2.728	-0.585	2.456	0.624	1.132	1.884
60	2.724	-0.513	2.453	0.454	2.047	1.943
70	1.749	-0.457	2.495	0.395	2.012	1.989
80	2.784	-0.416	2.540	0.338	2.001	1.999
90	2.800	-0.400	2.559	0.322	2.000	2.000



a - when $\lambda_y = \lambda_y(\varphi)$, б – when λ_y=1; 1- φ=0, 2- φ=30⁰, 3- φ=60⁰, 4- φ=90⁰.
Fig. 3 - Circumferential stress diagrams on the contour of the circular profile crosshair



1- φ=0, 2- φ=30⁰, 3- φ=60⁰, 4- φ=90⁰.
The solid line refers to the roof, the solid line with a circle refers to the sides.
Fig. 4 - Diagrams of the dependence of circumferential stresses on the contour of the drift (a) and the crosshair (b) on the coefficient of lateral pressure

Analysis of the numerical results shows:

1. For the drift with a change in the angle of rock dip, the minimum stresses are confined to the top of the drift, and the area of maximum stresses visibly changes its position on the contour of the drift from the direction along the layering rocks to the direction across their layering;

2. The crawlspace is in relatively favorable conditions not only at medium angles, but also at a steep bedding of rocks. At any rock dip angle, the initial elastic stability conditions are comparatively more favorable for the croslag than for the drift.

Conclusions: In general, for the drift at $\lambda_x = \lambda_x(\varphi)$, with a change in the rock dip angle, the minimum stresses are confined to the top of the drift, and the area of maximum stresses visibly changes its position on the drift contour from the direction along the rock overlay to the direction crossing their overlay. The initial elastic stability of the drift deteriorates with a steep fall of rocks, when stresses in the lateral points reach the greatest value, and tensile stresses appear in the roof.

The crosshair is in relatively favorable conditions not only at medium angles φ, but also at steep bedding of rocks. In a rock massif with vertical layers, the stresses around the crosshair will be the same as in an isotropic massif. The above data from theoretical studies and multivariant numerical experiments show that, at any angle of rock incidence, the initial elastic stability conditions are relatively favorable for the crosshair rather than for the drift.

A detailed analysis of the numerical results shows sufficient completeness of the assumptions of this study and the reliability of its results as a theoretical basis for solving various problems of rock pressure when driving horizontal mine workings, the longitudinal axes of which are arbitrarily

References

Felix P. (2013) Felsmechanik in Tunnelbau. Schweiz Bauzeitum, Germany (In German).

Guang-Chuan Liang, Xing Huang, Xing-Yu Peng, Yuan Tian, Yu-Hang Yu (2016) Investigation on the cavity evolution of underground salt cavern gas Storages, Journal of Natural Gas Science and Engineering. 2016. Vol. 33. -P. 118-134. DOI: 10.1016/j.jngse.2016.05.018 (In English).

Jianguo Zhang, Wei Yang, Baiquan Lin, Jinjing Zhang, Man Wang (2019) Strata movement and stress evolution when mining two overlapping panels affected by hard stratum, International Journal of Mining Science and Technology. 2019. Vol. 29. Issu. 5. -P. 691–699 (In English).

Kosmodamiansky A.S. (2013) Inzhenernyy zhurnal [Engineering Journal] 2(3):35-46 (In Russian).

Lekhnitsky S.G. (2013) Opredeleniye napryazheniy v transversal′no-izotropnom massive vblizi tsilindricheskoy vyrabotki tipa kvershlaga [Determination of stresses in a transversally isotropic massif near a cylindrical working of the crosshair type]. Leningrad, VNIMI Publ., Russia. (In Russian).

Lang H.A. (2014) The affine Transformation for Orthotropic plane-stress and plane-strain problems, Journal of Mechanics, 23(1): –P.19-32 (In English).

Liu Hao, Zuo Yu-Jun, Sun Wen-Ji-Bin, Wu Zhong-hu, Zheng Lu-Jing (2020) Reasonable Width of Narrow Coal Pillars Along Gob-side Driving Entries in Gas Outburst Coal Seams: Simulation and Experiment, IOP Conference Series: Earth and Environmental Science. 2020. Vol. 570. No. 5. 052042. DOI: 10.1088/1755-1315/570/5/052042 (In English).

Mandal K.P., Das A.J., Kumar N., Bhattacharjee R., Tewari S., Kushwaha A. (2018) Assessment of roof convergence during driving roadways in underground coal mines by continuous miner, International Journal of Rock Mechanics and Mining Sciences. 2018. Vol. 108. -P. 169–178 (In English).

Makhmetova N., Solonenko V., Musayev J., Bazanova I. (2019) Stressed-deformed condition of escalator tunnels under the action of static and seismic loads. Scientific journal of the Modern Education & Research Institute, on the results of the scientific conference "Modernization of the teachers profession: approaches, best practices, challenges", Brussels, Belgium. - P.37-41 (In English).

Pleshko M.S., Pankratenko A.N., Pleshko M.V., Nasonov A.A. (2021) Assessment of stress–strain behavior of shaft lining in bottomhole area during sinking by real-time monitoring and computer modeling data. Eurasian Mining. 2021. No. 1. - P. 25–30. DOI: 10.17580/em.2021.01.05 (In English).

Sonntag G. (2013) Spannungsoptische und theoretische Untersuchungen der Beanspruchung der dichteter Gebirgskorper in der Umgebung einer Strecke. Forschungsberg, Germany (In German).

Sonntag G. (2013) Ein der Anisotropic und die Beanspruchung des Gebirges in der Umgebung von Stollen. Springer Verlag, Germany (In German).

Savin G.N. (2014) Vliyaniye krepleniya na raspredeleniye napryazheniy vozle uzkikh podzemnykh vyrabotok [Influence of fastening on stress distribution near narrow underground workings]. AN USSR Publ., Ukraine (in Russian).

Solonenko V.G., Bekzhanova S.E., Makhmetova N.M. (2017) Modern technologies in the construction of subways. LAP LAMBERT Academic Publ., Germany. ISBN: 978-3-689-86944 (In English).

Solonenko V. G., Musayev J. S., Makhmetova N.M. (2022) Assessment of ground surface fluctuations during shield tunneling of subway tunnels. The Bulletin of KazATC, 1(120):19-30. DOI: 10.52167/1609-1817 (In English).

Werner H. (2015) Beitrage zur Anwendung der Naturgestre im geschicteten Gebriqe. Bergfreiheit, Germany (In German).

Wolf K. (2016) Ausbreitung der Kraft in der Halbene und in Halbaum bei anisotropen Material. Ingenieurwissenschaftliche Forschungsarbeiten. Springer Verlag, Germany (In German).

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