ПРОГНОЗ УСТОЙЧИВОСТИ ВЫРАБОТОК ПРИ ПОДГОТОВКЕ ЗАПАСОВ ВТОРОГО КАЛИЙНОГО ПЛАСТА СТАРОБИНСКОГО МЕСТОРОЖДЕНИЯ НА БОЛЬШИХ ГЛУБИНАХ

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РЕЗЮМЕ. Рассматриваются особенности деформирования подготовительных выработок на II калийном горизонте рудника 4 РУ РУП «ПО «Беларуськалий», заложенных в мелкослоистых соляных породах, содержащих в кровле более 40 % слабых соляных и глинистых прослойков. На основании фактических результатов наблюдений за деформированием этих выработок до глубины 800 м, а также выработок III калийного горизонта на глубинах до 1000 м сделан прогноз времени их устойчивого состояния для условий 2-ой и 4-ой северных панелей.

FORECAST OF MINE WORKINGS STABILITY DURING PREPARATION BY DEEP MINING OF THE SECOND POTASH SEAM'S RESERVES AT THE STAROBIN DEPOSIT

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ABSTRACT. Examined the deformation features of the development workings at the 2nd potash level of the mine of the Production Unit No. 4, JSC «Belaruskali», which are in the fine-seam salt rocks and where the roof contains more than 40% thin salt and clay interbeds. Forecast of the stable life was determined based on actual observation of the deformation of the workings to a depth of 800 m, and of the mine workings at the 3rd potash level to the depth of 1000 m in the 2nd and 4th northern panels.

Introduction

During the next four years mining operations at the 2nd potash level in the north-east area of No. 4 P.U.'s mine will reach the depth of 1000 m. This will be the first time in the history of the Starobin deposit that such a depth has been achieved. At present the longwall and development workings are driven at the 2nd and 4th northern panels. The panels are mined with 250 m longwall faces using the combined method. The panels are developed in stages with short, 500 m, section lengths. It is planned to develop further panels in reverse sequence using part of the entries to panels that have been previously mined. The second potash seam comprises two (top and bottom) sylvinite seams with a thickness of 0,5 - 0,8 m separated by a stone salt seam of thickness 0,45 - 0,5 m. The seam is covered by stone salt layers containing clay partings with a thickness up to 0,3 m. The seam into the north-east inclines by as much as 5º. Thus a panel started at a working depth of 650 m has reached a depth of 1000 m by the end of the seam. It is planned that the panels will be completely mined out within 20 - 28 years.

Deformation of the 2nd level mine workings in this area is of interest because there are unstable 2 m thick clay-salt rocks in the mine roof. These contain in excess of 40% thin salt to a thickness of 30 mm with clay interbeds exceeding 2 mm in thickness. Previous experience when mining with a similar roof type at the 3rd potash level has shown that at depths exceeding 750 m the rheological properties of the saliferous rocks are more intensive and that at depths exceeding 900 m their stability is limited to just a few months unless protective measures, e.g. compensation slots or unloading mining, are employed. The intensive growth of rock pressure in these workings is due to changes in the rheological properties of the saliferous rocks and by most intensive rock lamination and layer separation processes on the weak, clay interbeds, to clay partings [2]. There have been no previous stability problems in the permanent and development workings of the 2nd potash seam which reach a depth of 700 m.

Targets and prospecting methods

Development workings being prospected were cut through the seam, their roof was either under the left protective band of the top sylvinite seam with 0,15 - 0,25 m height or above it at the height of 0,55 - 0,65 m. Mine openings were driven by full-face road heading machine PK 8 with a cutting head diameter of 3 m by one movement of the machine.

Where the prospecting works were carried out, the prospecting holes were drilled with core sampling and subsequent testing for uniaxial compression. The tests showed that the average aggregate strength of side and roof rocks at the development openings located under the top sylvinite layer was 28 MPa. Thus the actual thickness of the bottom protective band is 0,16 - 0,17 m, and its aggregate strength under uniaxial compression is 23 MPa. The clay content of the 2 m thick roof is 24 - 27%. At the development openings roof location above the top sylvinite layer at 0,55 - 0,65 m the average aggregate strength of sides and roof rocks is 26 MPa. Thus the actual thickness of the bottom protective band will be 0,10 - 0,11 m, and its aggregate strength under uniaxial compression is 24 MPa. The clay content in the 2 m thick roof is 27 - 29%.

Measuring point represented planimetric bench marks were installed in the roof, sides and floor of openings. Measurements of the openings' contour convergence (sides and roof with floor) were made using VNIMI measuring tape (accuracy ± 0,1 mm), or PD-32 laser ranger (accuracy ± 1 mm). Roof shift measurements were carried out by means of caprone thread fixed horizontally at the sides' bench marks and VNIMI measuring tape. Using this method the accuracy of shifts measurements is ± 1 mm.

Measuring point installation was made at a distance of 1 to 8 m from the shut- down face. This allowed the detection of deformations at the moment of face moving from them. Determined empirical dependence (1) between measuring point up to the face of working and "lost" convergence of its sides for the first twenty-four hours of its deformation after driving:

$$U_{áá} = 9,836 \cdot \exp(-0,23(12 - L)), \quad (1)$$

where U_{66} is "lost" convergence of working's sides for the first twenty-four hours by measuring point's installation at the distance L, mm, from face; L is the distance from measured cross-sections to working's face, m.

Rock creeping was monitored at over 70 points and more than 200 measurements were taken at 13 points in the development workings at depths of 700 - 800 m. To protect workings compensation slots were cut 10 - 70 days after their driving. Apart from these data results of previous tests were used in the data analysis carried out at the 3rd potash level (at the depths of 700-1000 m) [2].

Research [2] indicates that when determining the creep parameter δ under field conditions it is better to use side convergence data as they are more stable than "roof – floor" convergence data. Papers [3, 4] describe the technique used for establishing the rock mass creep parameter δ using field measurement of the radial movement of rock mass points in the area of horizontal working based upon T_0 which is the elapsed time from the moment of working drivage to the installation of measuring points. According to this technique workings sides convergence $U_{t_1} - U_{t_2}$, caused by rock creeping within time intervals [0, t_1], [0, t_2], is calculated as follows:

$$U_{t_2} - U_{t_1} = 3 \cdot R \cdot \frac{t_2^{1-\alpha} - t_1^{1-\alpha}}{1-\alpha} \cdot \frac{\delta \gamma H \cdot K_B}{E}, \quad (2)$$

where

R = average radius of working in metres (for PK 8 R = 1,5 m);

t_1 = elapsed time from the moment of working drivage to the moment of measuring point installation, $t_1 \geq T_0$; t_2 = time of last measurement; α = dimensionless parameter of creep kernel (α = 0,7), $c^{\alpha-1}$ = dimensional parameter of creep kernel; γ = average specific weight of overlying rocks, *γ* = 0,021 MH/м³; *H* = depth in metres; *E* = roof flexibility modulus, *E* =1,5·10⁴ MPa; K_B = working interaction factor (for single workings K_B = 1).

Research results

The least squares method was used to determine that the dimensionless parameter of creep kernel for different conditions of working location in seam changes in a flat interval of values (from 0,6 to 0,89), and the parameter δ for fixed values α changes within single-order. The given parameter was determined in the form of the complex aggregate $\delta\gamma HE^{-1}$, as was its dependence on the level of the loaded rocks condition $\gamma H / \sigma_{сж}$ ($\sigma_{сж}$ is aggregate rock strength, MPa). The level index of the loaded rock condition for investigated sections changes from 0,45 to 0,62.

Fig. 1 is a graph plotting the deformational and rheological parameter $\delta\gamma HE^{-1}$ against load level $\gamma H / \sigma_{сж}$. The data is drawn from previous research [2] and newly obtained measurements. The graph clearly shows that the new data correspond well with earlier results. It permits the use of previously obtained generalizations for the third potash layer to forecast the workings stability at the second potash layer (for example, dependence (3) [2, 5]).

Research has determined that the previously obtained empirical relationship:

$$\delta\gamma HE^{-1} \times 10^7 = \begin{cases} 1,5c^{\alpha-1} \quad \text{by} \quad 0,3 < \gamma H / \sigma_{ñæ} \leq 0,4; \\ 1,5 \cdot \exp(6,15(\gamma H / \sigma_{ñæ} - 0,4))ñ^{\alpha-1} \end{cases} \quad (3)$$

by $\gamma H / \sigma_{ñæ} > 0,4$

adequately describes the deformation behavior of workings situated in the northeast part of the 2nd level mine field of the 4th PU's mine. Fig.1 clearly shows that the complex parameter $\delta\gamma HE^{-1}$ at the interval $\gamma H/\sigma_{сж} \in$ [0,3; 0,5] does not in practice depend upon the rocks load level and that its nonlinear dependence on this factor occurs above this interval. The interval top level by aggregate rock strength $\sigma_{сж}$ = 28 MPa corresponds to a depth of 650 m. This proves the earlier drawn conclusion [2] that the deformation speed of workings sides increases in proportion to depth growth in the interval $H \in$ [400; 650] m and that once H > 650 m (or $\gamma H/\sigma_{сж}$ > 0,5) this parameter grows faster than depth. According to this dependence for single workings of the second potash seam located in the rocks with aggregate strength $\sigma_{сж}$ = 28 MPa, increase in depth H from 400 m to 650 m does not change creeping parameter δ′ which is 0,003 $c^{\alpha-1}$.

When the depths H_1 = 800 m and H_2 = 950 m are achieved by invariable aggregate rocks strength $\sigma_{сж}$ = 28 MPa, the creeping parameter will be accordingly 800 m δ_1 = 0, 0036 $c^{\alpha-1}$, δ_2 = 0, 0092 $c^{\alpha-1}$ that exceeds δ´ accordingly in 1,2 and in 3 times. It specifies development of nonlinear deformations of circuit creeping. Speeds of sides' deformation of workings at these depths will increase 2 and 6 times accordingly against a depth of 650 m.

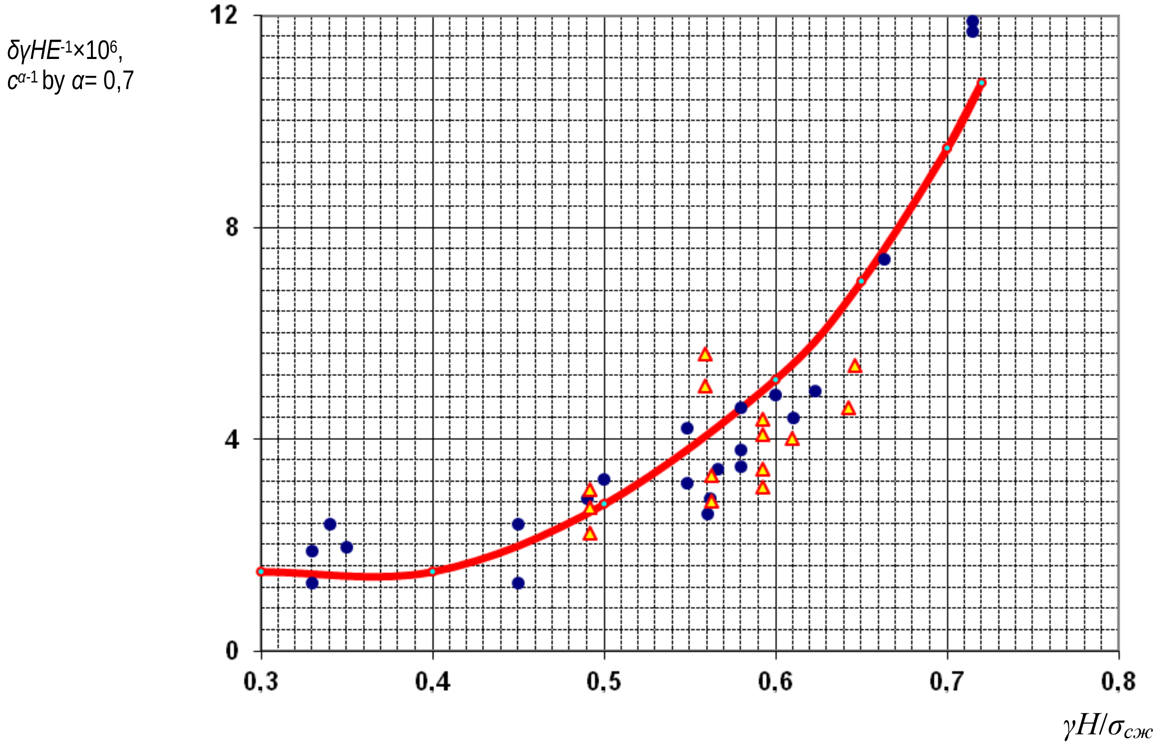

Fig. 1 – Dependence of deformational and rheological parameter ***δγHE***$^{-1}$ on load level ***γH***/$\sigma_{сж}$:

● – Research data for the 3rd level [2]; △ – Research data for the 2nd level:; – approximation given by the formula (3)

Approach suggested in paper [5] was used to investigate the influence of delamination and lamination factors on the strength of openings on weak clay partings. Its main idea is determination of connection between convergence of the roof sides $U_{бб}$, with the floor $U_{КП}$ and roof displacement $U_К$. The form of this connection as coefficient of variation of circuit displacement $K_{КП}$ and $K_К$ was determined using the formulas:

$$K_{КП} = \frac{U_{КП}}{U_{бб}}; \quad K_К = \frac{2U_К}{U_{бб}}. \qquad (4)$$

Roof convergence with floor $U_{КП}$ and roof displacement $U_К$ were determined taking into account coefficients $K_{КП}$ and $K_К$, and as well as convergence of sides $U_{бб}$, realized at the cost of rocks creeping, specified using calculation or actually for a specified time.

It is found that coefficients of variation of circuit convergence in unprotected workings driven in seam change in intervals: $K_{КП} \in [0{,}92;1{,}65]$, $K_К \in [1{,}46;2{,}1]$. In the workings driven partly above sylvinite seam, coefficients of variation of circuit convergence change in intervals: $K_{КП} \in [0{,}96;1{,}25]$, $K_К \in [1{,}5; 2{,}1]$. Both alternatives of workings' drivage in the 2nd seam according to their figures correspond to alternatives of workings' drivage in the 3rd seam with roof stability [2] of types II and III. Change in $K_{КП}$ is connected with composition and structure of rocks left in the roof and the floor of working, and change in $K_К$ characterizes these figures for the rocks left in the roof. Paper [5] proposes to calculate composition and structure of rocks using universal geological parameter $\sum m_i/n$, (where $\sum m_i$ - total thickness of clay partings, located in the roof (floor) of working within pressure envelope; n - thickness of the most stabile "protective" band which is closer to the working circuit). Their influence on irregularity of circuit deformation is quite well described by empirical dependence:

$$K_К = 1 + (\sum m_i / n)^{1{,}63}. \qquad (5)$$

Fig. 2 is a graph plotting dependence of coefficient $K_К$ upon figure $\sum m_i/n$, and as well as the actual research data.

The graph clearly shows that experimental points characterizing the relation of roof displacement to displacement of working's side for the 2nd potash level are located in the left bottom part of an empirical curve. It testifies that influence of geology factor on intensity of working's roof deformation is insignificant. Deformations of the latest are caused by creeping of peripheral rocks. Changes in $K_{КП}$ and $K_К$ for these workings with depth growth were not noticed.

It is determined that cutting compensation slot in the roof of workings reduces coefficients of variation $K_К$ on 20-40%, and besides the maximum permissible roof deformations increase, and system «working - rock mass» attains larger stability factor.

Taking into account these results the following conclusion was made: main factor which has influence on stability of mine workings of the 2nd potash level, driven at great depth, is rock creeping occurring in their constantly displacement inside the working.

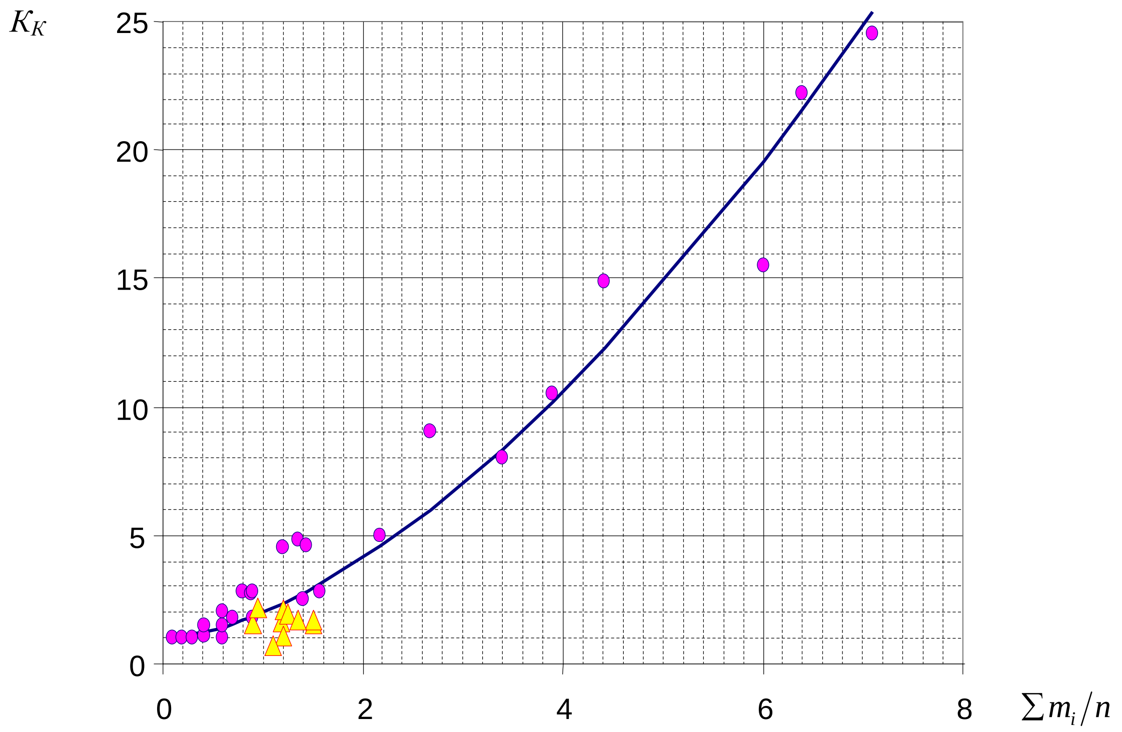

Fig. 2 - dencendence of figure K_K on a geological figure $\sum m_i/n$, characterizing increase of roof displacement against side:

● – Research date for the 3rd level [2]; △ – empirical curve; —— – Research date for the 2nd level

Production workers usually classify as critical the depths, by which development openings fail before, than it is foreseen by mining technology. If to consider that development opening service life makes 2-3 years, and its deformations in the area of pillar mining are similar to the deformations which have been accumulated out of them within 2 years, the minimum time of stable workings condition without additional protection measures should make 5 years.

With notice the variation of circuit displacement and using dependence (2) it is possible to determine the time of stable condition of the working's roof, by which the accumulated deformations do not exceed maximum permissible deformations. For workings without any protection measures ultimate strains make 3% from width of working, they increase double by cutting slots in the roof or by use of unloading workings. And when the slots are cut in the roof and sides using both protection methods, compensation slots and unloading workings, deformations increase in 3 times. Considering that and using dependences (2) and (3) it was determined that deformations of workings' roof will be close to critical figures by the end of the fifth operation year, when for $\sigma_{сж}$ = 28 MPa critical depth is N_k = 900 m, and for $\sigma_{сж}$ = 26 MPa - N_k = 840 m. Thus the level of rocks loading is $\gamma H/\sigma_{сж}$ = 0,65.

Regulatory document [1] do not permit to obtain prognostic deformations and time of stable workings' condition at the depth exceeding 900 m, and as for smaller depths, where $\gamma H/\sigma_{сж} \geq 0{,}65$, there are divergences between them and actual data. It demands correction of the technique for forecast of workings' stability taking into account progressing rock creeping round them. Empirical dependences of time T_p to stable condition were suggested for such correction with application functions of exponential mode dependences as approximating. For unprotected workings of a width 3 m time of their stable condition T_p can be determined by the following dependence:

$$T_p = 1500 \cdot \exp(-8{,}6\gamma H/\sigma_{сж}), \text{ years.} \quad (6)$$

For the workings of a width 4-4,5 m protected by unloading workings or by the combined way (unloading workings and compensation slots in the roof or in the sides), T_p is:

$$T_p = 763 \cdot \exp(-6{,}3\gamma H/\sigma_{сж}), \text{ years.} \quad (7)$$

For the workings of a width 3-3,5 m protected by compensation slots (whether in the roof or in the roof and the sides), T_p is:

$$T_p = 900 \cdot \exp(-5{,}8\gamma H/\sigma_{сж}), \text{ years.} \quad (8)$$

The given dependences are presented in fig. 3.

The figure clearly shows that, the temporal values of stable workings condition T_p, obtained by means of mine researches are being collected in three special areas. And it is possible to select an empirical curve for each area.

The above presented curves and formulas permit to calculate time of their stable condition T_p without taking into account influence of pillar mining and that is appropriate for permanent workings. For development workings the influence of pillar mining can be calculated by subtraction of three years from T_p: $T_{роч} = T_p - 3$, years.

In order to forecast time for stable workings condition it is necessary to know measures used for workings protection, their depth H and average aggregate strength of enclosing rocks $\sigma_{сж}$.

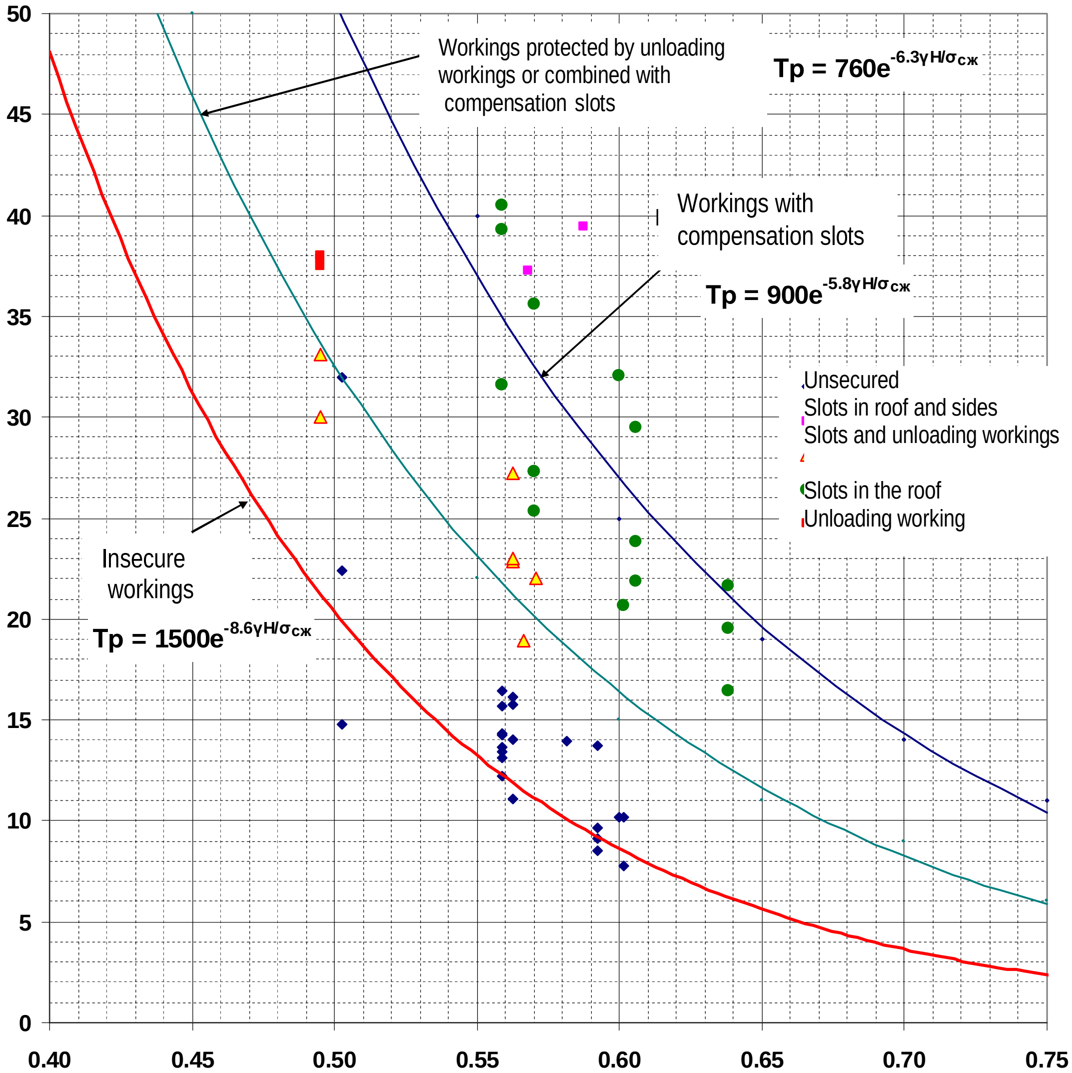

Fig. 3 – for determination of time of stable condition T_p for the workings of the second level

The last figure should be determined taking into account tests of rocks strength properties in the sides and in the roof of working, at the distance from the circuit which is equal to the height of possible roof caving h. For an arched working of a radius of curvature R and an equivalent span $b_{ЭКВ}$ height of possible roof caving h can be determined by formula:

$$h = 0{,}7(b_{ЭКВ} + l_{ПЛ}) = (4R/3 + l_{ПЛ}) \text{, m,} \qquad (9)$$

where $l_{ПЛ}$ - width of flat roof part in m.

For the single-track drift driven by the full face road heading machine PC 8 with the radius R = 1,5 m, the height of possible roof caving is:

$$h = 0{,}7\left(\frac{4 \cdot 1{,}5}{3}\right) = 1{,}4 \text{ m.}$$

It is obviously that aggregate rock strength should be timely determined (either in laboratory or in underground conditions using express method) to be used in the technique for forecasting of development workings stability in relation to the 2nd potash level. By panel development it is recommended to drill holes from the seam floor each 500 m with the depth no less than 5 m, with core sampling and conducting tests for its unixial compression for determination of the aggregate rock strength in laboratory conditions.

On the basis of technique for determination of workings stable condition T_p, adapted for conditions and character of the 2nd level workings' deformation, the forecast of stability of permanent and development workings was carried out. Forecast results for panel entries taking into account pillar mining are presented in the table.

The table clearly shows that the time of workings stable condition of T_p even in the most severe conditions (at depth of 980-1050 m) exceeds the set service life of working. However such stability is obtained when compensation slots are used for workings' protection.

The proposed forecast method is designed for application in the medium (similar to the 2nd and the 4th northern panels) mining and geological conditions and does not take into account their possible changes to the worst at the separate local sections. Sections with local changes of geological structure and strength seam properties can occur within extraction pillars of northern panels. For such sections (and primarily with decrease of layer thickness is more than 10%) it is recommended to reduce the figure of aggregate rock strength by 20-30% (i.e., till 20-22 MPa).

Table – *Forecast results of time for stable conditions of panel workings of the fourth northern panel, level - 440 m*

№ of panel (technological breakthrough)	Year of workings driving	Year of panel development	Average depth, m	Service life $T_{сл}$, years	Time of stable conditions of workings T_p, years		
					Panel workings under 0,15-0,25 m t.s.l..*	Panel air roadway over t.s.l. at 0,55-0,65 m	Technological breakthrough under 0,15-0,25 m t.s.l.
1	2006	2030	650	24	50	40	50
2	2007	2029	670	22	46	36	46
3	2007	2028	700	21	40	31	40
4	2008	2027	720	19	36	28	36
5	2008	2025	740	17	33	25	33
6	2009	2024	760	15	30	23	30
7	2010	2023	810	13	24	17	24
8	2011	2022	860	11	18	13	18
9	2012	2021	910	9	14	10	14
10	2013	2020	940	7	12	8	12
11	2014	2019	980	5	10	6	10
12	2015	2018	1050	3	5	3	5
*t.s.l. – top sylvinite layer							

Taking into account that mining operations at the 2nd level were not carried out deeper 800 m, and the given technique for the level workings was approved noncompletely, the forecasting figures of time for stable workings condition, obtained using this technique, are preliminary and need additional pilot and commercial check at depths exceeding 800 m.

The calculations have shown that by using compensation slots and development with short panels as protection measures, the time of stable development workings condition at the 2nd and the 4th northern panels of the No 4 PU's mine will not exceed their specified service life.

Conclusions

Review of underground investigations results permits to draw conclusions, that the main form of rock pressure manifestation in the workings of the 2nd potash seam is rock creeping influenced either by the depth of workings *H* or their aggregate strength on uniaxial compression $\sigma_{сж}$. For practice it is convenient to present these two factors in the form of aggregate - level of rocks loading $\gamma H/\sigma_{сж}$. For quantitative assessment of saliferous rock creeping was suggested to use parameter δ, being constant for the workings in the seam with rocks loading $\gamma H/\sigma_{сж} < 0,5$ (or for depths to 550-650), and by $\gamma H/\sigma_{сж} \geq 0,65$ this figure passes into the stage of progressing creep with breaking. Dependence between roof displacement and sides' convergence was determined, that allowed monitoring breaking process of the most important element of the working circuit, i. e., roof. Empirical dependences of time for stable workings condition T_p on $\gamma H/\sigma_{сж}$ were suggested, taking into account progressing rock creeping around them.

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