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Analytical Investigation of Overburden Rock Strata Movement During Monitoring of Rock Massif at Stage of Finishing of Ore Deposit Mining

Sh.M.Aitaliyev & T.M.Yermekov
National Academy of Sciences of Kazakhstan, Almaty, Republic of Kazakhstan
A.B.Yun & MZh.Satov
"Kazakhmys "Corporation, Zhezkazgan, Republic of Kazakhstan

ABSTRACT: In this paper, new results are presented. They were obtained jointly by scientists - both theorists and practical workers. It is noted that rheology has an effect on die development of deformations of rocks in time and also on mine workings destruction in terms of achieving long-term strength. Creepage of a rock massif is studied on the basis of the hereditary theory of Boltsman-Volterr. Analytical expressions are given, both of subsidence of the clay surface and the rate of subsidence. The possibility of taking account of irregular increasing of working excavation space dimensions at a moment of stability loss (destruction) in support pillars is shown.

1 INTRODUCTION

The Zhezkazgan polymetal deposit (Kazakhstan), the largest in Eurasia, at one time produced up to 45% of all copper output in the world. It has been exploited for more than 70 years, since the end of the 1930s. Now the deposit İs in the final stage of mining. The finish of mining of the deposit İs characterized by complications of the stressed-deformed condition of the rock massif as a result of long-term technical-in-genesis activity. The depth of mining operations increased and ore reserves which remained in pillars were extracted. These processes caused disturbance of the steady-state balance, deterioration of geomechanical conditions, and activated processes of movement and destruction of the rock massif. The large volume of rock movement due to the creation of worked-out space had such negative consequences as caving of the overlying strata up to the clay surface. It can cause great physical and economic damage through destruction of industrial developments and housing, quite often endangering human life. All this necessitates the monitoring of the current condition of the undermined rock massif with a broad analytical information system.

2 ANALYTICAL EVALUATION OF CLAY SURFACE SUBSIDENCE

To determine the current condition of an area of clay surface above worked-out space, we can represent it as extended in horizontal direction ellipse in the vertical plane of cross-section. Then elastic deflection - strata subsidence - at a moment of worked-out space forming may be represented by Muskhelishvili's formula (Muskhelishvili, İ954):

$$\eta = \gamma H_b l_e \frac{1-\nu^2}{E}; \quad m \tag{1}$$

where r\ - deflection value, m; y - specific gravity of rock, kg/m^3; Hb - depth of rock-bridge bedding, m; U - equivalent span, m; v and E - Poisson's coefficient and modulus of elasticity of rock.

Practice shows that deformation of the overlying strata is a process in time. The deformation has two factors. First, properties of creepage of the rock massif take place. Secondly, in the course of time, the effect of long-term strength of roofs and pillars occurs. As a result, the span of worked-out space changes.

In accordance with Volterr's principle, which was formulated by Rabotnov (Rabotnov, 1966), subsidence in time may be obtained from elastic solution (1) by way of replacing the elastic parameters v, E with elastic operator functions v_t, E_t. Taking into account the elastic solid deforming of TOcks and the small variation of Poisson's coefficient in time, subsidence in time takes the form:

$$\eta_t = \gamma H_b l_e \frac{1-\nu_t^2}{E_t}; \quad m \tag{2}$$

where $E_t = E\left[1 - \beta Э_\alpha^*(-\beta)\right]$

Here 3 $_0${-ß) - special operator of Rabotnov.

In accordance with the hereditary theory of rock creepage of Yerzhanov (Yerzhanov, İ964), for simpler two-parameter (a. 6) core of Abel with parameters approximation operator function of modulus of elasticity, we may write:

$$E_t = Ee^{-\omega t\beta^{1-\alpha}} \qquad (3)$$

Then, expression (2) may be written in the form

$$\eta_t = \gamma H_b l_e \frac{1-v_t^2}{E} e^{\omega\beta\, t^{1-\alpha}} \qquad (4)$$

or, more simply,

$$\eta_t = \eta_{t=0}^{y} e^{\omega\beta\, t^{1-\alpha}} \qquad (5)$$

where: $\omega = (1-\alpha)^{1-\alpha}$; $\beta = \delta\Gamma(1-\alpha)$; $0<\alpha<1$.

Here $\eta_{t=0}^{y}$ - elastic subsidence (1) corresponding to the initial moment of time f=0. As is clear, if $\omega>0$, $\beta>0$ with time increase $t\rightarrow\infty$ $e^{\omega\beta\, t^{1-\alpha}} \rightarrow \infty$ and $\eta_t \rightarrow \infty$, then subsidence increases in the course of time.

For Zhezkazgan rocks İn laboratory conditions, parameters of elasticity and creepage ($\alpha \approx 0.7$, $\delta \approx 10^{-3}$) were established. As shown by Aitaliyev (Aitaliyev et al., 1966), in natural conditions near isolated mine workings natural values of parameter So are by an order of magnitude greater than laboratory value 5/, that is S/r=108j. Near extracting mine workings this effect is built up, that is $\delta_H \approx 10^n \delta_l$, n=2-3.

3 EVALUATION OF RATE OF SUBSIDENCE OF CLAY SURFACE

The main source of information about processes of rock and clay surface deformation as the result of underground mining operations are instrumental observations. Important parameters of the process of movement of the rock massif are the maximum values of subsidence η_{max} and rate of subsidence $\dot{\eta}_{max}$.

In analytical terms, determination of the rate of subsidence is a more difficult problem. The point is that subsidence is a complex function of time, depending both on creepage and on irregular changing span of extracting mine workings. Limiting of constant span l_e = const may be obtained from (5):

$$\dot{\eta}_t = \frac{d}{dt}\eta_t = \eta_{t=0}^{y} \frac{d}{dt}\left(e^{\omega\beta\, t^{1-\alpha}}\right) = \eta_{t=0}^{y}\omega\beta \frac{e^{\omega\beta\, t^{1-\alpha}}}{t^{\alpha}} \qquad (6)$$

İt is clear that when $t\rightarrow\infty$ and $e^{\omega\beta\, t^{1-\alpha}} \rightarrow \infty$ and $t^{\alpha}\rightarrow\infty$, thore *is* uncertainly in the form ∞/∞. This uncertainty is evaluated by the Lapital rule:

$$\frac{\left(e^{\omega\beta\, t^{1-\alpha}}\right)'}{\left(t^{\alpha}\right)'} = \frac{\omega\beta}{\alpha}\frac{e^{\omega\beta\, t^{1-\alpha}}}{t^{2\alpha-1}} \qquad (7)$$

At the n step, this will be:

$$\frac{\left(e^{\omega\beta\, t^{1-\alpha}}\right)^{n}}{\left(t^{\alpha}\right)^{n}} = \left(\frac{\omega\beta}{\alpha}\right)^{n} \frac{1}{(2\alpha-1)\ldots(n\alpha-n+1)} \frac{e^{\omega\beta\, t^{1-\alpha}}}{t^{n\alpha-n+1}} \qquad (8)$$

When

$$n\alpha - n + 1 < 0,\ n > 1/(1-\alpha) \qquad (9)$$

Uncertainty occurs, showing the growth of the rate of subsidence in time.

Thus, for determination of the extreme value of time t_{ext}, after which increase in the rate of subsidence is unlimited, İt is necessary to take:

$$\frac{d}{dt}(\dot{\eta}_t) = 0 \qquad (10)$$

Then, from (6) can be obtained:

$$\ln t_{ext} = \frac{1}{1-\alpha}\ln\frac{\alpha}{\omega\beta} \qquad (11)$$

However, the formulae above should be used with great care. Their accuracy depends on the accuracy of approximation (3). It may not work absolutely accurately much of the time. More reliable results may be obtained with due account of the ability to injure and use of the approach of Aitaliyev and Iskakbayev (Aitaliyev et al., 1990).

4 EFFECT OF WORKED-OUT SPACE SPAN CHANGE ON CLAY SURFACE SUBSIDENCE

The geomechanics of change of the worked-out space span in time and its effect on the process of subsidence of overlying strata may be represented as an approximation as follows.

In spite of the fact that the long-term strength of pillars, and roofs takes place continuously, the worked-out space span changes irregularly in a moment of pillars and roofs destruction. Write these moments of time as $t_1, t_2, \ldots,$ U and the corresponding increments of span as $\Delta l_{e1}, \Delta l_{e2}, \ldots \Delta l_{ei}$. The value of the total span may be written in the form:

$$l_e = l_{e0} + \Delta l_{e1} + \Delta l_{e2} + \ldots + \Delta l_{ei} + \tag{12}$$

Here l_{e0} is an initial equivalent span.

Increment of the span takes place in conditions of creepage of the massif. It is very difficult to describe analytically the combination of such processes, but we may show one possible procedure.

Up to moment t_1 subsidence in time is determined by formulae (4) and (5), and in a moment of time t_1 it is equal to:

$$\eta^{\Pi}_{t=t_1} = \gamma H_b l_{e0} \frac{1-\nu^2}{E} e^{\omega\beta t_1^{1-\alpha}} \tag{13}$$

At this moment, because of increment of span l_{e0} by Δl_{e1}, there is an immediate growth in subsidence by the value:

$$\eta^{y}_{t=t_1} = \gamma H_b \frac{1-\nu^2}{E}\left(l_{e0} + \Delta l_{e1}\right) \tag{14}$$

Then, total subsidence at time moment t_1 will be:

$$\begin{aligned} \eta^{общ}_{t=t_1} &= \eta^{\Pi}_{t=t_1} + \eta^{y}_{t=t_1} = \\ &= \gamma H_b \frac{1-\nu^2}{E}\left[l_{e0} e^{\omega\beta t_1^{1-\alpha}} + \left(l_{e0} + \Delta l_{e1}\right)\right] \end{aligned} \tag{15}$$

Following this, subsidence is described by the following expression in comparison with formulae (4) and (5):

$$\begin{aligned} \eta^{\Pi}_{t>t_1} &= \eta^{общ}_{t=t_1} e^{\omega\beta (t-t_1)^{1-\alpha}} = \\ &\left\{\gamma H_b \frac{1-\nu^2}{E}\left[l_{e0} e^{\omega\beta t_1^{1-\alpha}} + \left(l_{e0} + \Delta l_{e1}\right)\right]\right\} e^{\omega\beta (t-t_1)^{1-\alpha}} \end{aligned} \tag{16}$$

At time moment t_2, at the expense of rock creepage, subsidence will be:

$$\eta^{\Pi}_{t=t_2} = \left\{\gamma H_b \frac{1-\nu^2}{E}\left[l_{e0} e^{\omega\beta t_1^{1-\alpha}} + \left(l_{e0} + \Delta l_{e1}\right)\right]\right\} e^{\omega\beta (t_2-t_1)^{1-\alpha}} \tag{17}$$

Subsidence at this moment because of the increase of span $(l_{e0} + \Delta l_{e1})$ by Δl_{e1} instantaneously increases by value:

$$\eta^{y}_{t=t_2} = \gamma H_b \frac{1-\nu^2}{E}\left(l_{e0} + \Delta l_{e1} + \Delta l_{e2}\right) \tag{18}$$

Total subsidence at a time moment t_2 will be:

$$\begin{aligned} \eta^{общ}_{t=t_2} &= \eta^{\Pi}_{t=t_2} + \eta^{y}_{t=t_2} = \\ &= \left\{\gamma H_b \frac{1-\nu^2}{E}\left[l_{e0} e^{\omega\beta t_1^{1-\alpha}} + \left(l_{e0} + \Delta l_{e1}\right)\right]\right\} \\ &* e^{\omega\beta (t_2-t_1)^{1-\alpha}} + \gamma H_b \frac{1-\nu^2}{E}\left(l_{e0} + \Delta l_{e1} + \Delta l_{e2}\right) \end{aligned} \tag{19}$$

Hereafter, subsidence in time, in contrast to (4), (5) and (16), is described by the expression:

$$\begin{aligned} \eta^{\Pi}_{t>t_2} &= \eta^{общ}_{t=t_2} e^{\omega\beta (t-t_2)^{1-\alpha}} = \\ &= \left[\left\{\gamma H_m \frac{1-\nu^2}{E}\left[l_{e0} e^{\omega\beta t_1^{1-\alpha}} + \left(l_{e0} + \Delta l_{e1}\right)\right]\right\} * \right. \\ &\left. * e^{\omega\beta (t_2-t_1)^{1-\alpha}} + \gamma H_m \frac{1-\nu^2}{E}\left(l_{e0} + \Delta l_{e1} + \Delta l_{e2}\right)\right] \end{aligned} \tag{20}$$

Continuing the procedure above, we may write the most general formula of subsidence in time, when $t>t_i$ in the form-

$$\eta^{\Pi}_{t>t_i} = \eta^{общ}_{t=t_i} e^{\omega\beta (t-t_i)^{1-\alpha}} \tag{21}$$

5 CONCLUSIONS

In the limits of the hereditary mechanics of rocks, an attempt was made to describe analytically the clay surface subsidence above worked-out space. Imposition of the development of creepage and long-term strength of rock massif in first approximation was studied. Evaluation of the rate of subsidence of the clay surface was developed analytically to the end; however, ite accuracy depends on the approximation of operator functions. Other approaches of one of the authors are offered with due account of the ability to injure of the rock massif and the immediate fractional-exponential function of Rabotnov. The reliability of the analytical expressions proposed must be established by means of carrying out observations of rock movement and clay surface subsidence.

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