Estimation of Current Condition of Undermined Rock Massif with Regard to Thickness of Mining

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ABSTRACT: In this paper, analytical estimation of the condition of constructive elements of worked-out space in terms of thickness of mining is presented on the basis of forecasting attributes (elasticity modulus E and compliance 1/E). These attributes make it possible to determine the relationship of the current condition of the undermined rock massif with the working order by depth, during detailed estimation of surface subsidence on a plan of a studied district, with due account of the mechanical properties of the enclosing rock and the thickness of worked-out ledges. On the basis of actual data of geometrical dimensions of overlapping worked-out spaces at the Zhezkazgan deposit, an informational plan was created with regard to the thickness of mining, the anomalous zones of which are in agreement with the calculated data for geomechanical estimation carried out at the districts studied.

1 INTRODUCTION

In the stage of finishing of ore deposits in market conditions, the running thin of reserves of ores of non-ferrous metals and the general tendency of the decreasing content of useful components in raw ore create more difficult requirements as to the quality and quantity of the mineral raw materials. The increase in volumes of mineral raw material extraction necessitates the mining of ore reserves retained in the undermined rock massif, including supporting pillars.

However, the forming of large working spaces in the rock massif causes an increase in their potential risk. This is related to the fact that the increasing of the worked-out space height causes a decrease in the carrying ability of pillars and also destruction of them. The greater the thickness of mining is, the greater the volume of worked-out space and the scale of cavings. Geomechanical processes take place, complicating mining and causing threats to mine safety.

Therefore, in order to ensure mine safety and increase the effectiveness of mining practice, first of all, it is necessary to know the locations of possible caving and to select mining technology appropriate for the situation. This may be done by preliminary diagnostics of the rock massif containing deposits of useful minerals, and by following systematic liquidation of worked-out space by caving during repeat mining (Yun, 1999). The results of such diagnostics make it possible to determine the priority of liquidation of the worked-out space and increase substantiation of technical decisions when mining retained mineral reserves. At locations of possible caving as revealed by diagnostics, it is necessary to arrange observations by means of monitoring with the purpose of predicting cavings.

The parameters of caving and the time of its development mainly depend on the height of the worked-out areas and the overlying rocks from the boundary of the worked-out space up to the ground surface with due account of the coefficient of loosening. The caving of overlying rocks and fall-through cone depends on me ratio of the volume of overlying rocks and worked-out space.

The geomechanical basis for evaluating the condition of worked-out spaces of deposit areas in terms of the thickness of mining and ratio of undermining is dependent on the deformation of strata in respect of stress and mechanical properties, which in an elemental case for an elastic medium is defined by Hooke's law:

$$\varepsilon = \sigma/E$$

where e - deformation; a - stress; and E - elasticity modulus.

For inhomogeneous strata of enclosing rocks and ores, an equivalent modulus of elasticity may be presented in the form:

$$E_e = \left(\sum_{i=1}^{N} E_i h_i \right) \Big/ \sum_{i=1}^{N} h_i \ . \tag{2}$$

where E_e - equivalent modulus of elasticity; E, - modulus of elasticity of enclosed rocks or ores; and h, - thickness of enclosing rocks or ores.

For overlapping enclosing rocks and ores, the formula (2) may be presented as:

$$E_e = \left(\sum_{i=1}^{N_{rock}} E_i H_i + \sum_{i=1}^{N_{ore}} E_i H_i \right) \Big/ \left(\sum_{i=1}^{N_{rock}} H_i + \sum_{i=1}^{N_{ore}} m_i \right) \tag{3}$$

where E_e - equivalent modulus of elasticity; H, - thickness of enclosing rocks; and n^ - thickness of ore ledges.

Quantity, which is reciprocal to the modulus of elasticity İ/E, is compliance, characterizing medium ability for deformation, and it eventually causes subsidence of the ground surface: the smaller E the more deformation or subsidence. When ledge mining with m, thickness, $E_i = 0$ is given for the corresponding ledge. And E as a whole decreases in proportion to the number of mined ledges with great thickness. Therefore, subsidence above the mined area İs more than that above the non-mined area. Above destroyed roof $\sum_{i=1}^{N} h_i = H_m$, and the equivalent modulus E_e above the roof will be less than its value above pillars. This means that the deformation ability of the rock massif above worked-out space will be more than that above pillars.

The forecasting attributes E or 1/E are used for detailed determination of the subsidence of the ground surface on a plan of the district studied with due account of the mechanical properties of the enclosing rocks and ore ledges, the thickness of mined ledges and the presence of overlapping. It makes it possible to determine the relationship of the current condition of the rock massif and the order of ore mining by depth. Thus, the deformation of inhomogeneous (lumpy-homogeneous) strata takes the form of the following expression:

$$\varepsilon = \sigma_1/E_1 + \sigma_2/E_2 + \dots + \sigma_n/E_{n_1} \tag{4}$$

where e - deformation of strata; σ_i - stress; and E, - modulus of elasticity.

To express stresses in the form of the product of solid weight and depth of bedding of the rock layers, calculations can immediately be performed by the formula:

$$\varepsilon = \gamma_1 H_1/E_1 + (\gamma_1 H_1 + \gamma_2 H_2)/E_2 + \dots + (\gamma_1 H_1 + \gamma_2 H_2 + \gamma_N H_N)E_N \ . \tag{5}$$

where γ_i − solid weight of the i^rock layer; Hj - depth of the i layer bedding; and E! - modulus of elasticity of the i[lh] rock layer.

For a mined ore ledge it is necessary to take y, = 0, preserving H, and E,. It is not difficult to see that the different values of deformation e may be obtained depending on different sequences of ore ledge mining by depth.

On the basis of these behaviours of space changes in the mechanical properties of rocks and stresses, informational plans were drawn up with regard to the thickness of mining and ratio of undermining.

In order to show the effect of this factor on the process of cone forming at the ground surface, data from mine surveys, mining and geological forms and records were studied. Using these data, a plan was drawn showing isolines of the total thickness of the Zhezkazgan deposit, as shown in Figure 1.
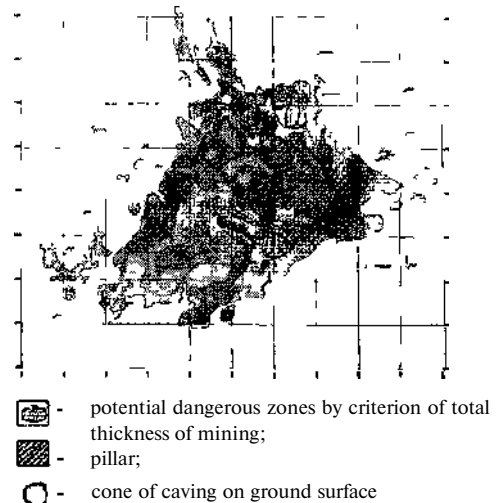

	- potential dangerous zones by criterion of total thickness of mining;
	- pillar;
	- cone of caving on ground surface

Figure *I* Informational plan with regard to thickness of mining.

As can be seen in Figure 1, zones where earlier cavings took place correspond to districts with the maximum values of total thickness.

The presence of tight massifs (pillars) creates particular interest, because knowledge of them is necessary for solving problems in future mining of the deposit From the point of view of prediction, a tight massif is a barrier to the development of large cavings.

The zones of the deposit drawn with regard to the thickness of mining are convincing evidence of the effect of this factor on the parameters of caving.

The drawing of such plans has an influence on the scale studying of the effect of different voids if the worked-out space has different multi-level geometrical structure and section areas at different

heights differing substantially from each other. It is necessary to know this information in order to take account of the full volumes of overlying rocks and worked-out space.

Generalization of the large volume of materials of natural investigations made it possible to identify that the important characteristic of the process of movement in space and time is the value H/m.

Thus, caving of the overlying rocks and cone of fall-through depend on the ratio of the volume of the overlying rocks and the worked-out space. When determining the ratio H/m in a space of the deposit on the plan of the ground surface, we obtain contours of the possible forming of cones.

It has been established (Makarov & et al., 1999) that with due account of the empirical criteria of equivalent span l_e and coefficient of loosening Ki, on the basis of an analysis of cavings carried out at die Zhezkazgan deposit, the conditions of fall-through forming are established by the ratio H/m < 10.

The condition of full caving of overlying strata up to the ground surface is determined by experimental dependence:

$$L = -9 + 1.2H, \text{ m} \qquad (6)$$

where L - equivalent span of worked-out space; and H - depth of mining, m.

Study of the causes and effects of previous caving made it possible to connect the limiting-permissible value of subsidence Ti by a correlation relationship to the ratio of undermining H/m:

$$\eta_l = 3.95(H/m)^2 - 21.28(H/m) + 55.17, \text{ mm} \qquad (7)$$

where rii - limiting-permissible value of subsidence, mm; and H/m - ratio of undermining. The correlation relationship describing the parameters of worked-out space and ground surface movement is presented in Figure 2.
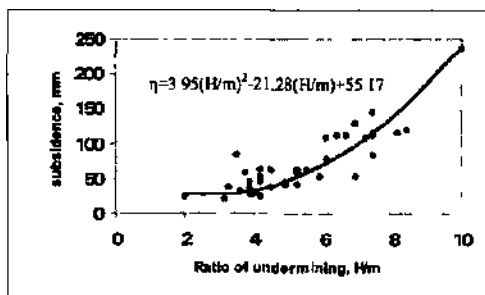

Figure 2. Graph of ground surface subsidence as a function of ratio of undermining.

The criterion H/m < 10 under a conventional assumption of pillars supporting worked-out space

that have lost their carrying ability makes it possible to perform diagnostics of the final condition of the undermined rock massif.

Physical simulation of the final condition of the worked-out space with artificial extraction of supporting pillars will allow: evaluation of the consequences of deposit mining on the ground surface; preparation of preventive measures of protection; an opportunity to finish remaining reserves, including supporting pillars; the selection of technology for carrying out mining operations; and mine planning.

The open-stop system is widely used in the mining of underground ore deposits. The use of self-propelled machines of high capacity for drilling, loading and transport of ore ensures a high production capacity. At the same time, significant losses of useful minerals in inter-chamber pillars, which increase constantly together with the depth of mining, are its major disadvantage.

It has been noted (Airuni et al., 1985) that an increase in the intensity of mining useful minerals causes the deposit to run thin, rises in price to occur and mining to decrease. In such conditions, the preservation of pillars is not acceptable because of the high level of ore losses in pillars, inasmuch as both dimensions of pillars and non-covered expenses for the opening-up and development of reserves increase when the depth of mining increases (Airuni et al., 1985).

Use of the results of preliminary diagnostics helps solve this problem, which İs important in the industry.

Use of the obtained relationship makes it possible to take account of such factors as the extracting thickness m and depth of mining H, and permissible rate of subsidence q, and these factors determine the conditions and location of cones forming on the ground surface. The reliability of the results was confirmed by the fact that all cavings which took place at the deposit were located in zones determined by the criteria mentioned above.

The obtained correlation relationship makes it possible to predict limiting-permissible deformation of the ground surface as a function of the depth of mining H/m. It also solves opposite problems, that is, the choice of parameters of voids, ensuring that deformations of the ground surface not will be greater than the limiting-permissible deformation for undermined objects. It will enable a substantial increase in the coefficient of recovery of useful minerals under built-up areas.

When H/m>10, catastrophes are prevented and caving may appear on the ground surface in the form of terraces, smooth deflections, secant fractures, and negligible movements. In these conditions, it is possible to fill in such caving and to use constructive measures of protection for surface constructions.

For practical use of the identified behaviour of the changing of the effect of undermining depending on the geometrical parameters of the worked-out space, a method was developed to determine zones on the ground surface which are potentially dangerous due to caving during underground mining of ore deposits (Satov, 1999).

The solid anomalies of total thickness are superimposed on the plan of mining operations of the deposit. The most dangerous zones are those with maximum values of the total thickness of deposit mining. Then, using the values of total thickness and depth, the ratio of total depth H to total thickness m is determined. With these results, isolines of the ratio of undermining H/m are drawn by extrapolation. The value H/m <10 is taken as a criterion of the prediction of cavings. The solid anomalies revealed by the criterion above, the ratio of undermining, are presented in Figure 3. Dangerous districts are zones where isolines show H/m<10.

⬤ - potential dangerous zones by criterion of ration of undermining;

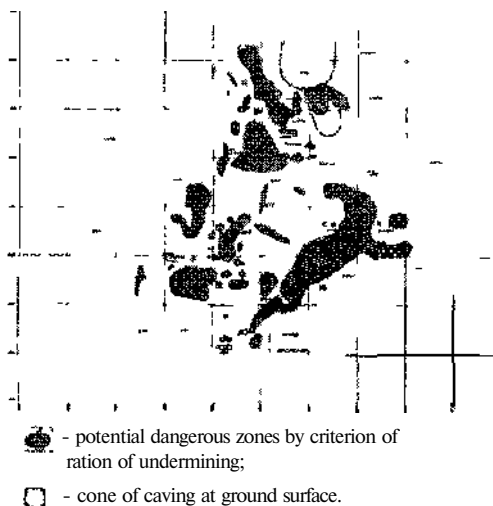◻ - cone of caving at ground surface.

Figure 3. Informational plan of deposit on ratio of undermining

By superimposing drawn plans with isolines of tbe criteria on the plan of mining operations, anomalous zones which are potentially dangerous due to caving are determined. Dangerous zones are taken as those where the isolines of values by criteria m and H/m fall in the same interval. These districts have the greatest risk of caving İn comparison with other parts of the deposit, and this is confirmed by previous cavings which occurred at the deposit

When further mining operations are carried out, the mining and geomechanical situation changes, and the values of m and H/m also change. In such districts, for every cycle of winning operations changes are introduced in corresponding plans, and the identification of potential caving zones on the ground surface is carried out again. Zones on the ground surface determined by this method, are fenced off, and protective measures are taken: depending on economic expediency, dangerous volumes of voids are filled in, engineering constructions are moved from the ground surface, or voids are liquidated by controlled caving of overlying rocks. Therefore, knowledge of such zones allows protective measures to be taken İn good time, preventing possible catastrophes which have taken place at the Zhezkazgan deposit.

The introduction of new methods of evaluation of the current condition of districts of the deposit in terms of the thickness of mining enables preliminary diagnostics of the rock massif to be carried out by established criteria, and the locations of possible catastrophic occurrences such as caving up to the ground surface to be predicted long in advance. The introduction of these methods also allows protective measures to be taken in good time, and effective and safe mining operations to be carried out in hard geological conditions.

Diagnostics of the final condition of worked-out space facilitates ore extraction at mines and the methods and order of liquidation of potentially dangerous voids, and shows the necessity of moving surface constructions.

Practical use of this method ensures safe conditions of mining operations and prevents damage due to possible cavings, especially in conditions where there is,a high concentration of protecting buildings and constructions.

The result of this investigation is: the current evaluation of districts of the Zhezkazgan deposit was carried out in terms of the thickness of mining, and the geomechanical situation at this deposit and dangerous caving zones were determined.

Owing to the methods developed, the locations of possible cavings were identified in good time, and the long-term forecast ensured that corresponding protecting measures were taken.

Current evaluation of the districts with regard to the thickness of mining helps solve an important problem - liquidation of worked-out space - or liquidation of volumes of voids which were formed over previous decades. In the future, with successful liquidation of the existing volumes of voids, such dynamic occurrences of rock pressure as sudden caving will be practically non-existent.

For this purpose, schemes of districts for immediate liquidation of worked-out space by means of rock caving have been established at some ore mines. For districts which contain dangerous caving zones as revealed by diagnostics, designs for

worked-out space liquidation have been prepared, and operations for the liquidation of existing dangerous volumes of voids have been begun.

As a result of these investigations, data of geomechanical forms and records were generalized and current evaluation of districts of the deposit in terms of thickness was carried out.

2 CONCLUSIONS

The mam scientific and practical results are the following:

1. The volume of worked-out space is a cause of the process of caving, and the volume of undermining of the ground surface İs an outcome. The conditions, dimensions and location of cones formed are determined at the end *of* mining by the geometrical dimensions of the worked-out space.

2. A correlation relationship was obtained for the limiting-permissible value of subsidence of the ground surface as a function of the ratio of undermining, which may be used for evaluation of the value of the zone of destruction in the undermined massif.

3. Methods were developed for identifying anomalous zones which are potentially dangerous due to caving during underground mining of ore deposits. These methods allow current evaluation of the condition of districts.

4. The diagnostics of the undermined massif enable locations of possible caving to be determined at the stage of design and planning of mining operations so that measures can be taken to prevent caving, enabling ore extraction and determination of the order of liquidation of dangerous volumes of voids.

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