Forecast and Management of the State of the Mountain Range

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Abstract. This article discusses the safety issues of geomechanical processes in the joint development of oil and potassium salts. The problem is solved by the finite element method. To predict changes in the stress-strain state of a rock mass in the mining area, a method has been developed for calculating the values of rock deflection and reference pressure. On the territory of the Berezniki and Solikamsk districts there are huge areas and valuable salt deposits, and under them - oil fields of industrial importance. Such joint development is unique, and geomechanical processes in this matter are poorly understood. To ensure the safety of mining operations, as well as the safety of ground structures in these conditions, it is necessary to know the stress-strain state of the rock massif and the nature of the manifestation of the movement process during the joint development of oil and potash deposits. Over the ever-increasing excavation space, there is a deflection of rock layers with subsequent subsidence, which both positively and negatively affects the technological processes of production.

1. Introduction

In recent years, geomechanical problems have worsened. This is, first of all, a consequence of the depletion of the subsoil and more complete mining. In this regard, the problem of integrated subsoil development is becoming increasingly important. On the territory of the Berezniki and Solikamsk districts there are huge areas and valuable salt deposits, and under them - oil fields of industrial importance. Such joint development is unique, and geomechanical processes in this matter are poorly understood. To ensure the safety of mining operations, as well as ground structures in these conditions, it is necessary to know the stress-strain state to ensure the safety of rocks and the features of the introduction of displacement in the joint development of oil and potash deposits. Over the ever-increasing excavation space, there is a deflection of rock layers with subsequent subsidence, which both positively and negatively affects the technological processes of production.

The negative effects include rock subsidence during mining, heavy roof movement, dynamic and gas-dynamic phenomena, etc [1].

The intensity of the roof movement largely determines the number of layers of rocks that bend and collapse over the developed space. The more layers are bent, the more intense the movement, the higher the value of the bearing pressure.

2. Relevance

The force of the bearing pressure and the strength properties of rocks largely determine the nature of the destruction and collapse of the roof. Today, the mechanism of deformation, movement and collapse of rocks is as follows. Excavation of the soil to a depth leads to a violation of the natural balance of external
loads and internal resistance of rocks, the resulting gaps cause first elastic, and then inelastic (before collapse) deformation of rocks. Deformation is expressed by movement, movement of rocks until they are completely weakened in the massif or with the formation of a failure on the earth's surface. Foresight of these phenomena during design will significantly increase the safety of the object. Attempts to solve these problems are considered in the works: Konlybaeva Zh.M., Borisov A. A., Andrushko V.F., Lobkov N.I., Popov L.F., Zhelyazko V.Z., Bolgozhin Sh.A., Klinovitsky F.I. and Khokhlov I.V.

3. Statement of the problem
To predict changes in the stress-strain state of the rock massif in the field of production, it is necessary to develop a methodology for calculating the values of rock deflection and reference pressure. The most effective option is the finite element method, which we will try to implement to solve this problem.

4. Theoretical part
According to the roof typing by stability, the rocks of the immediate roof of the class "not stable", "below average stability", destroyed in the bearing pressure zone under the action of shear stresses, penetrate in small fractions into the bottomhole space.

In the presence of rocks of classes of "medium stability", "stable" and "difficult to collapse", "very difficult to collapse" above the seam, on the immediate roof, cracks form in the zone of support pressure that break the roof into blocks. Loads are especially intense during the first planting of the upper boundary.

The above examples of the behavior of the roof rock are typical in the presence of thick and strong layers of rock. These layers can lie directly above the layer and at some distance from it, which greatly complicates the development conditions [2].

The movement of the fracture in the zone of reference pressure also depends on the overlapping layers, the bending over the space of the rock. These layers form the area of movement of the rock, which depends on the thickness of the layers and the strength characteristics of the rock. This position is confirmed by studies [3-7]. Thus, we can talk about the influence of the entire rock mass included in the displacement region on the formation of the reference pressure in the working surface.

Zones differ in the nature of deformation of rock layers within the region of movement [8].

The first zone is the zone of emergency roof collapse, its height is 0.1 ... 1.0 m. In this zone, the immediate roof collapses randomly and is additionally compacted by the weight of the collapsed rocks of the second zone.

The loosening coefficient of the rock in the first zone is in the range of 1.01 ... 1.05 and depends on the strength properties of the rock.

The second zone is the zone of ordered collapse of the roof and deflection of layers with loss of bearing capacity, its height is 20 ... 60 m and depends on the thickness and strength of the rocks. In this zone, the rock layers are divided into blocks by vertical, curvilinear and homogeneous cracks of separation and sliding. Under the influence of their own weight and overlying layers, the blocks are tightly pressed against each other. The loosening coefficient of rocks in this zone does not exceed 1.05 ... 1.1.

The third zone is the zone of deflection of layers without loss of bearing capacity. The height of this zone largely depends on the thickness and strength of the layers, as well as on the size of the space developed. The movement of rock layers without loss of continuity (within elasticity) plays an important role in the formation of reference pressure, which limits the area of movement.

Layers with high bearing capacity, bending over the developed space, withstand not only their weight, but also the weight of the layers with less stability. Using the method of constructing the area of movement [8], it is possible to divide the array into groups of layers, where the lower layer, which is load-bearing, carries a load to the collapsed upper layer.

Arrays of individual powerful layers, represented by clay, sandy, sandy-clay shales, limestones and sandstones, in the vast majority of cases can be considered continuous within the production field [9-17].
Field observations of the displacement of formations, performed using benchmarks laid in wells drilled from the surface [3, 6, 7] and in the laboratory, on models made of equivalent materials [5], show the following. As mining develops, the immediate roof layer bends over the mined area. The greatest deviation is observed in the middle part of the surface goaf, in the interval from the middle part to the border with the previously surface goaf and in the center on both sides, next to the surface goaf [18-19]. For this work, the following physical and mechanical properties of rocks were selected (table 1) [20].

### Table 1. Physical and mechanical properties of rocks.

| №  | Breed type                                      | Layer power, (m) | Modulus of elasticity (MPa) | Poisson coefficient | Volumetric weight, (MN(m)⁻¹) |
|----|------------------------------------------------|------------------|----------------------------|---------------------|-----------------------------|
| 1  | Quaternary deposits                            | 60               | 500                        | 40                  | 0,018                       |
| 2  | Salt-marl and terrigenous-carbonate strata     | 140              | 1800                       | 40                  | 0,024                       |
| 3  | Halite                                         | 300              | 4500                       | 30                  | 0,022                       |
| 4  | Clay-anhydrite stratum, Philippi horizon, Art in deposits | 600              | 3000                       | 30                  | 0,025                       |
| 5  | Carbonate rocks                                | 3000             | 6000                       | 26                  | 0,027                       |
| 6  | Collectors                                     | 4–12             | 2000                       | 0,22                | 0,020                       |

The deflection of the layer initially occurs within the elasticity of the rock. The amount of deflection depends on the cylindrical stiffness of the layer and the distributed load on the layer (table 2). The cylindrical stiffness of the plate can be calculated by the formula:

\[ D = \frac{Eh^3}{12(1-\nu^2)}, \text{Nm} \]  \hspace{1cm} (1)

where: \( D \) - is the cylindrical stiffness of the plate, Nm, \( E \) - is the modulus of elasticity of the rock, MPa; \( h \) - is the power of the rock layer, m; \( \nu \) - is the Poisson coefficient.

### Table 2. Cylindrical rigidity of the plate.

| №  | Stiffness value (N(m⁻¹)) |
|----|--------------------------|
| D1 | 10714285,71               |
| D2 | 490000000                |
| D3 | 11126373626              |
| D4 | 59340659341              |
| D5 | 14478800000             |
| D6 | 302648,17                |

By imagining the roof rock as an elastic body that complements the layer as a distributed load under its weight, the sediment of the rock layer can be calculated as the deflection of a thin plate. The repulsion of such a plate is described by the famous Sophie Germain-Lagrange equation:

\[ \left( \frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} \right) = \frac{q(x,y)}{D}, \text{m} \]  \hspace{1cm} (2)
where: $w$ – deflection of the layer at a point, m; $x, y$ – coordinates of the point.

By solving equation (3), it is possible to determine that the maximum deflection will be in the center of the plate [8] and can be defined as the deflection of a beam rigidly pinched on both sides (table 3). Technologically this is the span of the layer $l$.

$$\omega = \frac{ql^4}{2Eh^3}, M$$

(3)

Where: $\pi$ - is the maximum deflection of the beam, m; $q$ – distributed load per layer, MPa.

### Table 3. Maximum beam deflection.

| № | Beam deflection value (m) |
|---|--------------------------|
| №1 | 1,89 |
| №2 | 0,66 |
| №3 | 0,33 |
| №4 | 256 |
| №5 | 2,46 |
| №6 | 7,68 |

Substituting instead of $l$ the step of the initial planting of the roof, taking into account the loading of weaker layers of $\Sigma h$, we get the value of the deflection of the layer at which the rock will collapse (table 4).

$$\sigma = \frac{q}{2Eh^3} \left[ h \left( \frac{\sigma_o h^2}{7\sigma_p (h + \Sigma h)} \right)^2 + \frac{\sigma_o - 2\lambda y H}{\gamma (h + \Sigma h)} \right]^{1/2} - \frac{\sigma_o h^2}{7\sigma_p (h + \Sigma h)}$$

(4)

where: $\sigma_o$ and $\sigma_p$ - is the tensile strength of the rock for uniaxial compression and stretching, MPa; $\lambda$ – coefficient of lateral spacer, $\gamma$ – volumetric weight of rocks, MPa, $H$ – depth of layer occurrence, m.

### Table 4. Layer deflection.

| № | Layer deflection value (m) |
|---|--------------------------|
| №1 | 3,08 |
| №2 | 2,75 |
| №3 | 3,56 |
| №4 | 2,97 |
| №5 | 6,7 |
| №6 | 8,65 |

### 5. Proposals and implementation results

Expression (4) is used to determine the maximum deflection value of each carrier layer before collapse in the area of rock movement, the height of the random and ordered collapse zones, and the height of the layer deviation zone without breaking the continuity. By specifying the intensity of displacement and determining the number of layers involved in the displacement, you can calculate the value of the reference pressure.
To construct a zone of displacement of roof rocks, as well as to determine the primary planting of the roof, taking into account the angles of inclination of the lines of deflection and collapse, equation (2) can be used. Determining the expected values of the reference pressure and displacement of the roof in the field of extraction, after the initial planting, requires clarification of the pressures on the collapsed layers.

6. Conclusion
Based on the analysis of the results of the study of the movement of roof rocks in the working space, the following is determined:
- the deviation of the layers along the underworked space occurs alternately in ascending order from the immediate roof to the last layer in the movement zone;
- in the process of creating mountain pressure and moving the upper boundary at the base, layers of rocks are taken that are in the displacement space.

7. References
[1] Trumbachev V 1955 Investigation of rock pressure in mining workings by optical method (Moscow: Ugletehizdat) p 98
[2] Andrushko V, Saratikjane S and Spicyn Ju 1985 Roof management in difficult mining and geological conditions ed K F Sapickogo (Kemerovo: Tehnika) p 128
[3] Konlybaeva Zh 1968 Regularities of rock displacement in the massif (Moscow: Nauka) p 108
[4] Borisov A 1980 Mechanics of rocks and massifs (Moscow: Nedra) p 360
[5] Andrushko V, Lobkov N, Popov L and Zheljazko V 1981 Development of mineral deposits (Kemerovo: Tehnika) pp 12-15
[6] Bolgozhin Sh and Klinovickij F 1982 Geomechanical conditions for the protection of development workings during the development of coal seams (Almaata: Nauka) p 88
[7] Hohlov I 1986 Comprehensive study of the rock mass (Moscow: Nauka) p 163
[8] Bubnov I 1953 Works on the theory of plates (Moscow: State ed. in technical and theoretical literature) p 423
[9] Li W, Sun W, Yan T, Li Y, Ji Z and Tang P 2017 Tianranqi Gongye B 37 22-27
[10] Khalkechev R and Khalkechev K 2017 GIAB B 11 220-226
[11] Kazikaev D, Kozyrev A, Kasparyan E and Iofis M 2016 Management of Geomechanical Processes in Mineral Development: Training Manual (Moscow: Mountain Book Publishing House)
[12] Jun Q, Liang X, Wang G, Xian C, Zhao C and Wang L 2017 Unconventional Resources Technology Conf. vol 33 (Austin: Texas/USA) pp 2626-2637
[13] Kochurov A, Radzhabova L and Borodkin P 2018 GIAB B 4 21-28
[14] Khalkechev K 2016 GIAB B 8 190-194
[15] Sidelnik A 2017 Procedia Structural Integrity B 6 316-321
[16] Wang L, Wei J, Di B, Huang P and Zhang F 2018 Applied Geophysics B 15 2 240-252
[17] Khalkechev K 2019 UGOL B 10 1123
[18] Gorbunova N and Mirkushov O 2021 IOP Conference Series: Earth and Environmental Sciencethis 720 1 012088
[19] Gorbunova N, Kapitonova I and Mirkushov O 2021 IOP Conference Series: Earth and Environmental Sciencethis 720 1 012080
[20] Gladyshev S, Popov S and Shustov D 2008 PNRPU Bulletin Geology. Oil and gas and mining 3