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TOOL CONTROL METHOD OF STRAIN-STRESS STATE OF MARGINAL SALT ROCKS*

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To reduce the risks of accidents in underground water-soluble ore deposits, a flexible system of geomechanical monitoring of mine safety is needed. Many years of research experience of physical and mechanical properties, stress-strain state of salt rock during sylvinite layers excavation in VKDPS mines allowed to develop the principles of experimental and theoretical estimation of the bearing elements state of the mining method. The essence of this method is a meaningful interpretation of the results of in-situ studies using mathematical modeling.

In the study of the stress-strain state of the marginal rock the research methods have measuring bases that are significantly higher than the characteristic size of the structure inhomogeneity of the massif. It eliminates the need of model transitions from the measured strains to stresses. These requirements are met by slot discharge methods and methods that are based on the memory effects during deformation of the well walls by Goodman hydraulic jack.

To take into account the structural features of the massif, estimation of physical and mechanical properties of the host rock is undertaken in natural conditions by testing of large-size blocks.

The results of instrumental measurements are used as input information for estimation of steady state of pillars by means of mathematical modeling. During the simulation process, parameters of a model are determined and the diagram of the stress distribution across the width of pillars, calculated for these parameters, and the value of the surface displacement will correspond to the results of experimental studies. Our procedure is used for estimation of structural elements stability of heading-and-stall development method for sylvinite layers.

Key words: *potassium deposit, underground mines, heading-and-stall development method, base constructions, water-proof stratum, stress-strain state, deformation, natural testings, geomechanical processes, mathematical simulation.*

Results of examination of state of empty space at the mines of Verkhnekamsky potassium deposit (VKDPS) show that after 20–30 years after extraction of chamber resources it takes place significant destruction of the pillars at some areas of mining of closed silvinite seams (KrII and AB) with "rigid" pillars. It has been expected "eternal" life of the pillars. Depth of exfoliation of the rock at the pillars walls may reach 1.5–2.5 meters. Falling of roofing and the rock lying between the seams takes place in the roof of the chambers. Situation is aggravated by decrease of strength of the rock in the zones of geological anomalies. Gradual destruction of the pillars between the chambers intensifies processes of moving of the rock adjacent to mined space. Rate of settling may reach 500 mm per year. Final deformation of the earth's surface may be to 3–4.5 meters. It is the most typical situation for south part of the deposit. Roof of the lower silvinite seam includes here thick clay interlayers [1, 2].

Character of deformation and destruction of the pillars between the chambers and the roof depends on many factors: geometrical sizes and forms of mining workings, features of structure and properties of the rock, behavior of the rock under loading and so on. Flexible system of geo-mechanical control is necessary for prognostication and prevention of possible emergency situations. Flexible system has to reflect adequately variety of the processes in the rock massif, to take quickly into account and to estimate change of mechanical properties of the rock near the contour and strain of the rock massif in course of mining.

Today it is accumulated great experience for solution of the different tasks for ensuring of stability of the elements of underground structures. Mathematical methods of the rock mechanics are used widely for analysis of geo-mechanical processes in mined rock massif. But, in spite of complication of mathematical tasks, exactness of estimation depends on trustworthiness of

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parametric providing of calculation and on adequate geo-mechanical models describe the process of stress-strain state (SSS) of the rock massif, pillars, roof of the chambers and so on. It conditions necessity to study, by means of experiments, character of deformation and breaking of the end zones of the rock massif and elements of underground structures of different methods of mining. Examination of features of structure, physical-mechanical properties, SSS and character of breaking of the rock-salt, carried out at the mines of VKDPS, has permitted to work out the principles and method of experimental-theoretical estimation of state of the loaded elements of chamber mining system. Main point of the method is substantial interpretation of results of the field study by means of mathematical simulation [3].

Geological and mining-surveyor documents obtained in course of operational exploration and mining are initial information for estimation of condition of the pillars between the chambers and roofs. The documents are: reports about examination of mining and preparing workings; information about settling of the earth's surface. Potentially dangerous zones are marked on the base of analysis. Zones demand for deeper study of conditions of the rock massif (in particular, physical and mechanical properties), estimation of strain of the elements of underground structures and character of deformation of the last ones in time. Above mentioned information is used as parametrical providing permitting to specify the model of deformation of mined rock-salt massif and criterions of destruction of the last one.

Trustworthiness of experimental examination of SSS of the elements of underground structures depends in many cases on the used method of investigation. Selection of the method first of all depends on features of structure of the rock massif. Rock-salt of VKDPS are presented by halite and sylvite, but mechanical properties of the minerals vary within wide range. It is conditioned by structure and texture features of the rock, including grains of different size. Size of the crystals may vary from 0.5 to 15 mm and more. Productive rock massif is characterized by alternation of rock-salt layers, silvinite (carnallite) and thin clay-anhydrite dirt bands. Usage of traditional methods of study of the rock massif based on small number of measurements gives in this case considerable scatter of the particular means of investigated parameters and decreases trustworthiness of results.

Experimental investigations have demonstrated that for study of SSS of the rock-salt massif it is necessary to use the methods without simulating transition from measured values of deformation to the strains and with basis of measurements considerably exceeds typical size of the rock non-uniformity. Methods of compensation with usage of different loading devices (hydraulic jacks, hydraulic bags and so on) are the most suitable ones in this situation. They ensure renewal of initial strained conditions in preliminarily unloaded rock massif. Method of compensation in case of slot unloading is the most tried. It permits to estimate SSS of the rock massif on the contour of outcrop (walls of mining working). Principle of measurement is based on compensation of strains of preliminary unloaded by the flat slot rock layer near the contour by means of hydraulic bag. Usage of above mentioned method in the rack-salt is easier thanks to low laboriousness of the work for forming of the slot and thanks to low level of the loads necessary for compensation of unloading. Flat hydraulic jack is used as loading device. Laboratory tests have shown that the device permits to create pressure up to 25 MPa with coefficient of pressure gear $k_n = 0.92$. Mineral oil is used as the working liquid. Pressure in hydraulic system is created by the hand pump BN-3 (constructed by Research institute of mountain geomechanics and surveying business — Intersectoral scientific center (VNIMI) and measured by the exemplary manometer (Fig. 1).

Partial unloading of the rock massif near the contour is carried out by means of semi-circular slot ($R = 300$ mm) that is formed by drilling of the holes 45 mm diameter in accordance with templet with subsequent dilation of the holes up to 85 mm diameter for liquidation of the crosspieces between the holes. Templet in form of the flat semicircle is placed in the slot for creating of smooth surface. Empty space in the slot is filled by the salt-content mixture. After hardening of the mixture (2–3 days) the templet is replaced by the flat hydraulic jack forming pressure. Moment of strains compensation is determined by renewal of unloading deformation. Last one is measured by the indicator of the watch type (to within 0.01 mm) between the contour bench-marks (on the basis 300 mm), placed before forming of the slot. Value of pressure in hydraulic bag in the moment of renewal of unloading deformation near the slot determines strain value in the end area of the rock massif perpendicular to the slot.

Strains field disturbance is formed on the basis about 1.5 meters. It is much more than size of heterogeneities of the rock-salt and it fully satisfies demands for measurements in coarse-grained rocks. Combine driving of the workings favors effective usage of the method. Combine driving is characterized by minimum breaking of the rock in the zone near the contour and by the form similar to the circular one. So, arising of the zones of local concentration of the strains is excluded. Investigations, carried out at the mine SKRU-2 in the pillars between the chambers in different conditions of exploiting, have shown good correlation of the results of measurements obtained by different methods: deviation of measured strains from calculated ones does not exceed 10 %.

Estimation of the strains in virginal rock massif may be carried out on the base of results of measurement of the strains in the contour

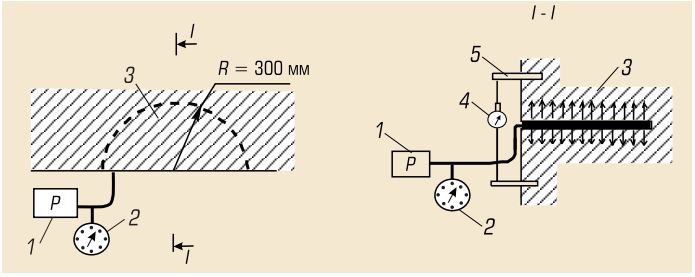

Fig. 1. Scheme of measurement of SSS of the rock massif at the contour of uncovering by the compensation method
1 — pump; *2* — manometer; *3* — hydraulic bag; *4* — deformation meter; *5* — bench-mark; $R = 300$ mm

of mining workings (Fig. 2). Dependence of secondary field of strains near mining workings in the natural strained state of non-disturbed massif is determined by means of geo-mechanical calculations. Method of estimation of the strains in virginal massif includes numerical simulation of the natural strained condition in the massif that ensures obtain of calculated strains in the contour of the workings corresponding to results of the field measurements on the outcrop. Investigations, carried out at the mine fields SKRU-2 and SKRU-3, have shown that field of the natural strains, in case of normal structure of rock-salt massif, differs from hydrostatic field: horizontal strains are 0.5–0.8 of the strains, conditioned by weight of above-lying rock, and difference between the strains does not exceed 15–30 %.

For control of stability of the elements of underground constructions, besides of estimation of the strains, it is recorded parameters of deformation of the constructions. Study of deformation of the pillars and roofs in the time is carried out with application of contour and deep bench-marks. Study of moving of the mined rock massif is carried out by means of leveling of the earth's surface along the profile lines. In case of considerable deformations of the rock-salt massif and relatively small dimensions of the mining workings control of deformations of their contour has been carried out with electronic telescopic ruler with maximum length 5 meters and with precision of measurement 5 mm. Control of deformations of the roofs and floors of the mining chambers at the seam KrII of the mine BKPRU-2 has shown that in the areas with increased content of clay removal of material of the contour reaches 200 mm during first 1–2.5 months after passing of the combine. After that it takes place intensive forming of the splits with subsequent suspension of great rock pieces or with caving of the rock lied between the seams.

It is necessary to know physical-mechanical properties of the rocks of the massif and its structural-texture features for geometrical calculations. Definition of the last ones is carried out by the methods of loading of the blocks in the rock layer near the contour by means of hydraulic loading devices (crushing device, holes Goodman's hydraulic jack). Contoured blocks with the edge size up to 500 mm in the walls of the mining workings were loaded by the set of hydraulic jacks. Every jack ensures the load to 100 tons. Loads and deformations have been measured during of experiments. They have been used for calculation of mechanical parameters. As a result of investigations it has been found that module of deformation of the rock-salt, determined on the base of the field measurements, varies within the range from 0.5 to 2.7 GPa and depends on level of the strains. Increase of the strains in the rock massif leads to increase of module of deformation. Module of elasticity exceeds module of deformation 4–5 times (in average). The values well correlate with deformation properties of the rock-salt determined in laboratory. It testifies to insignificance of influence of the scale factor in the rock-salt [4].

Deformation properties of the rock massif near the contour have been determined by means of loading of the holes walls by Goodman's hydraulic jack. The last one is the logging sound intended for measurement of deformation of

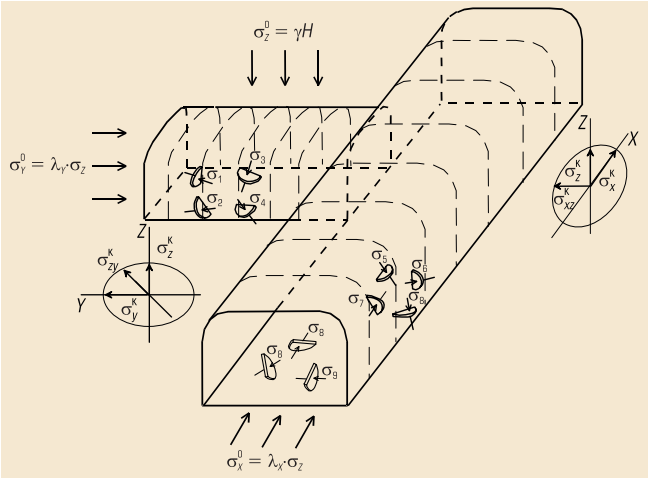

Fig. 2. Scheme of location of measuring slots in the walls and floor of mining workings for estimation of the strains in the natural rock massif

the holes walls under influence of the load. Pressure is passed to surface of the hole through two semi-circle traveling plates 200 mm length ensuring loading in the single plane. Maximum pressure created by hydraulic jack is 70 MPa. Two sensing elements for deformation permit to measure sum displacement of the plates with precision 0.01 mm. Sound has been designed for usage in the holes 76 mm diameter. Equipment involves portable device for measurement of deformation, hydraulic pump with high-pressure pipe-line, locking accessories and high-pressure sensing element. Electronic recorder Metran-901 is used for continuous recording of pressure.

Experimental investigations have been carried out in horizontal holes drilled in the pillars and in vertical holes drilled in the roof of mining chambers. Loading has been carried out by the steps by 5 MPa with subsequent unloading. Measurements have been fulfilled through every 0.3 meters with moving off from the contour of the mining workings. Maximum depth of the holes was 3.5 meters. Results of investigations have been used for drawing of the diagrams of deformation in coordinates "strains — radial deformation". Deformation parameters of the rock massif have been determined on the base of above mentioned diagrams. Thus, study of dependence of change of the module of deformation of the rock-salt along width of the pillar in the mined space of the first western panel of the mine BKPRU-2 has shown (Fig. 3) that deformation module of the rock in

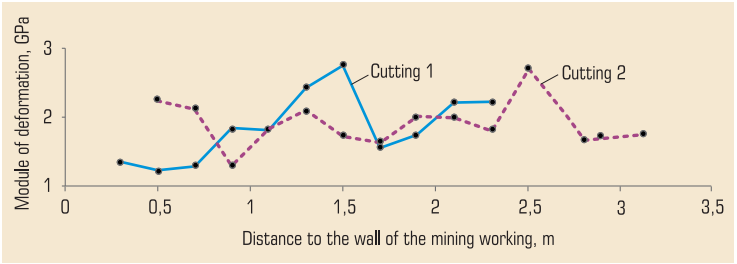

Fig. 3. Distribution of module of deformation of the rock-salt in section of the pillars between the chambers at the seam AB in mined space of the first western panel at the mine BKPRY-2

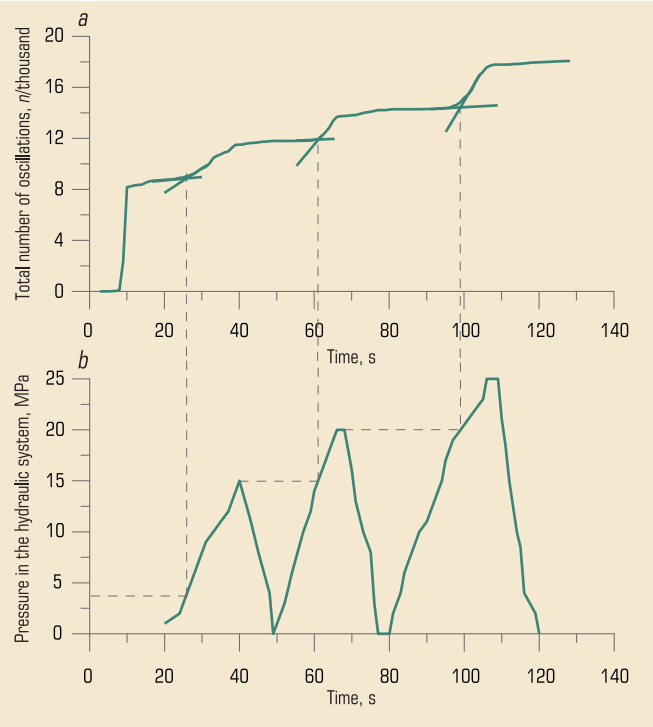

Fig. 4. Change of total number of the impulses (oscillations) AE (*a*) and pressure (*b*) in process of cyclic loading of the walls of the hole

the pillar at the seam AB along the hole N1 increases from 1.2 to 2.7 GPa at the depth 0.3–1.5 meters. After that module stabilizes at the average level 2 GPa. Deformation module of the rock-salt in the hole N2 in average is 1.9 GPa.

Module of deformation changed within wide diapason (from 1 to 2.5 GPa) in the rocks between the seams KrII–AB. It has increased from 1.2 to 3 GPa at the depth 0.5–1.5 meters. It was impossible to measure deformation parameters in the middle of the hole at the depth 1.5–2.7 meters because of loose structure of the rock-salt. Further increase of module of deformation (to 2.5 GPa) has been observed at the depth 2.7–3.2 meters. After that it decreases to 0.9 GPa with approaching to the floor of above lying seam AB. Fulfilled investigations of deformation properties of the rock massif near the contour have shown that the pillars are disturbed to depth 1–1.2 meters. Besides, it is observed exfoliation of the rock of the roof between the seams. Above mentioned results have been confirmed by telemetering examination of the walls of the holes.

Simultaneously with estimation of deformation properties in zone near the contour it has been measured the strains with usage of the method of acoustic-emission effects of memory. The effects are well observed in quasi-plastic rock-salt [5]. Above mentioned method of control is based on ability of the rock to "remember" level of influence of previous loads (Kaizer's effect). Strains, acted in the rock massif before drilling of experimental hole, are considered as previous (initial) loads. Renewal of initial strains in the rock massif near the hole is carried out by means of loading of the walls of the hole by Goodman's hydraulic jack. Level of the strains, influenced on the rock, is determined by spasmodic change of activity of acoustic emission (effect of memory) in the moment of exceeding of pressure on the walls of the hole over level of initial strains. Piezoceramic sensing element with working frequency 0.2–0.5 MHz is set into the body of the jack for measuring of the signals of acoustic emission (AE). Record of the signal of acoustic emission has been carried out by the device AEC-USB-8.

For basing of trustworthiness of obtained information it has been carried out laboratory and mine investigations of character of change of intensity of AE with loading of the rock-salt. Investigations have shown that spasmodic increase of number of AE impulses takes place in case of reach in the second cycle of value of pressure equal to the last one in the first cycle. Level of previous loading is estimated by the extreme of curve on the diagram of total number of the impulses AE or by sharp increase (2–3 times) of intensity of the impulses AE [6].

Experimental investigations of the strains in the pillars of the seam KrII within 11-th eastern panel of the mine BKPRU-2 have shown that vertical strains in the middle zone of the pillar are 10–11 MPa (Fig. 5). Vertical strains conditioned by weight of the rock lying above the pillar were 8.4 MPa. Maximum of the zone of bearing pressure is located at distance 1.3 meters from the wall of mining chamber. Maximum vertical pressure reaches 18 MPa. It confirms that the pillar does not lose its bearing capacity, but zone of bearing pressure has moved deep into the pillar because of deformation of the rock near the contour.

Examination of the strains in the rock between the seams KrII–AB has shown that horizontal strains change from 5 to 7.5 MPa in middle zone and decrease to 1.5 MPa near the roof of the seam KrII and in the floor of the seam AB. It witnesses destruction of the rock near the contour and confirms results of study of deformation and destruction of the rock between the seams in case of high content of clay [2].

Thus, results of instrumental measurements are the initial information for estimation of stability of the pillars between the chambers by the methods of mathematical simulation. Numerical simulation of SSS mined by room-and-pillar system of mining of the rock massif is carried out at the stage of theoretical generalization of experimental data for concrete mining-technical situation. The stage involves definition of parameters of the model. Calculated diagram of distribution of the strains along width of the pillars and

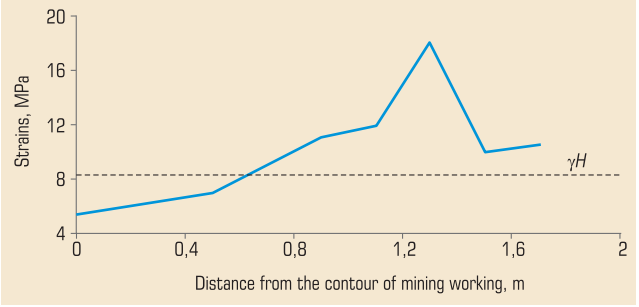

Fig. 5. Distribution of the strains in section of the pillar between the chambers at the seam KrII within 11-th eastern panel of the mine BKPRU-2

value of moving of the Earth's surface will correspond to results of experimental measurements. Offered method of investigations is used in system of ensuring of stability of constructive elements of chamber mining of silvinite seams of VKDPS.

References

1. Shiman D. I. *Predotvrashchenie zatopleniya kaliynykh rudnikov* (Avoiding of flooding of potassium mines). Moscow : Nedra, 1992.
2. Asanov V. A., Toksarov V. N., Evseev A. V., Beltyukov N. L. *Osobennosti povedeniya krovli vyrabotok na yuzhnom flange Verkhnekamskogo mestorozhdeniya kaliynykh soley* (Peculiarities of mine roof behavior on Southern flank of Verkhnekama potassium salts deposit). Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh – Journal of Mining Science, 2012, No. 1.
3. Baryakh A. A., Asanov V. A., Samodelkina N. A., Pankov I. L., Telegina E. A. *Matematicheskoe modelirovanie napryazhenno-deformirovannogo sostoyaniya gornykh porod na Verkhnekamskom mestorozhdenii kaliynykh soley* (Mathematic modeling of deformation mode of rocks at Verkhnekama potassium salts deposit). Gornyi Zhurnal – Mining Journal, 2008, No. 10.
4. Baryakh A. A., Asanov V. A., Toksarov V. N., Pankov I. L., Kirisyuk M. A. I*zuchenie masshtabnogo effekta v solyanykh porodakh* (Research of a scale effect in salt rocks). Gornyy Informatsionno-analiticheskiy Byulleten – Mining Informational and Analytical Bulletin, 2010, No. 10.
5. Lavrov A. V., Shkuratnik V. L., Filimonov Yu. L. *Akustoemissionnyy effekt pamyati v gornykh porodakh* (Acoustic-emissive memory effect in rocks). Moscow : Publishing House of Moscow State Mining University, 2004.
6. Asanov V. A., Toksarov V. N., Evseev A. V., Beltyukov N. L. *Opyt izucheniya akustoemissionnykh effektov v solyanykh porodakh s ispolzovaniem skvazhinnogo gidrodomkrata Gudmana* (Experience of research of acoustic-emissive effects in salt rocks with usage of Gudman downhole hydraulic advancing cylinder). Gornyy Informatsionno-analiticheskiy Byulleten – Mining Informational and Analytical Bulletin, 2010, No. 10.

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SEISMIC MONITORING IN POTASH MINES: OBSERVATION RESULTS AND DEVELOPMENT ASPECTS*

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Seismological observations in potash mines of Verkhnekamskoe deposit are carried out since 1995. Their start trigger was earthquake situated in mine field of SKRU-2 mine. Exploration of the mine after event was under the treat. As result of the situation, a modern seismic control network covering area of 120 км^2 has appeared. At present the network consists of 35 seismic stations providing representative instrumental data about all seismic events of magnitude $M > 0.3$ for all operating mines. Local seismic subsystems providing information about very small events ($-3 < M < 0$) are working as well. The latter are used to monitor sinkholes appearance above flooded mine. Observation results for years show the natural seismicity may be sensed good and happens very rarely. Induced seismicity is weaker but being under influence of rock conditions (physical-mechanical properties) and technology of extraction (mining, backfilling, blasting) it needs constant attention. Seismic monitoring had made clear many factors affecting seismicity in all operating mines and allowed to determine its relation to deformation processes in undermined massif. Investigation of seismicity due to sinkholes had showed the way to control effectively sinkhole development and help to minimize risk of accidents related to them.

Key words: *seismological monitoring, potassium mine, induced seismicity, triggered seismicity, aftershock, magnitude, sinkhole, prediction of events.*

Verknekamsky potassium salt deposit (VKDPS) is mined for few tens years. But examination of the problem of seismic activity of the area over the mined rock massif has been begun comparatively recently. First seismic investigations at the mines of the deposit

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