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NATURAL STUDY OF MARGINAL ARRAY ROCK`S STRESS STATE

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НАТУРНЫЕ ИССЛЕДОВАНИЯ НАПРЯЖЕННОГО СОСТОЯНИЯ ПОРОД ПРИКОНТУРНОГО МАССИВА

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Safety working out water-soluble ore fields in many ways depends on the stability of chamber development system`s elements. To monitor the interchamber pillars` status a method of experimental and theoretical evaluation of the geomechanical processes taking place in the array was developed, the essence of which lies in the meaningful results interpretation of mechanical characteristics and the stress state experimental studies of load-carrying structures by mathematical modeling methods.

The article describes the method of estimating the marginal rock array`s stress state. The tension control was made using an acoustic memory effect. The measurements were performed in the wells with the help of a Goodman hydraulic jack. Its feature is the ability to create a load on the borehole array in the same plane, that allows to evaluate the stress magnitude in various directions. During the loading of the measuring borehole walls there is a discontinuous increase in the activity of acoustic emission. The pressure, which is logged in the hydraulic system, was taken at the level of the natural stresses acting in the marginal array.

As a result of complex laboratory and field studies methodological features of stress analysis were identified using memory effects in salt rocks of the Verkhnekamskoie potash salt deposit. The experimental data analysis showed that in the “fresh” interchamber pillars a bearing pressure maximum is located near the contour of exposure and in 1.8-2.0 times higher than the load of of the overlying rocks` weight ($\gamma H$). In the central part of the pillar the vertical stress level is 1.25-1.4 $\gamma H$. With the increase in pillars` service life the marginal array`s stresses magnitude declines to the stress level of the overlying rocks weight. The horizontal stress increases with moving from the pillar contour and are approximately 60-70% of the vertical. These instrumental measurements results are a source data for assessing the long-term sustainability of interchamber pillars in sylvinite layers mining.

Ключевые слова:
соляные породы, камерная система разработки, физико-механические свойства, устойчивость обнажений, деформации, напряжения, методы контроля, акустоэмиссионные эффекты памяти.

Безопасная отработка месторождений водорастворимых руд во многом определяется устойчивостью элементов камерной системы разработки. Для контроля состояния междукамерных целиков разработан метод экспериментально-теоретической оценки геомеханических процессов, происходящих в массиве, сущность которого заключается в содержательной интерпретации результатов экспериментальных исследований механических характеристик и напряженного состояния грузонесущих конструкций методами математического моделирования.

В статье рассмотрена методика оценки напряженного состояния пород приконтурного массива. Контроль напряжений осуществлялся с использованием эффекта акустической памяти. Измерения выполнялись в скважинах с помощью гидродомкрата Гудмана. Его особенностью является возможность создания нагрузки на околоскважинный массив в одной плоскости, что позволяет оценивать величины напряжений по различным направлениям. В процессе нагружения стенок измерительной скважины происходит скачкообразное возрастание активности акустической эмиссии. Давление, регистрируемое в гидросистеме, принималось на уровне природных напряжений, действующих в приконтурном массиве.

В результате выполнения комплекса лабораторных и натурных исследований определены методические особенности расчета напряжений с использованием эффектов памяти в соляных породах Верхнекамского месторождения калийных солей. Анализ экспериментальных данных показал, что в «свежих» междукамерных целиках максимум опорного давления расположен вблизи контура обнажения и в 1,8–2,0 раза превышает нагрузку от веса вышележащих пород (γH). В центральной части целика уровень вертикальных напряжений составляет 1,25–1,4 γH. С увеличением срока службы целиков величина напряжений в приконтурном массиве снижается до уровня напряжений веса вышележащих пород. Горизонтальные напряжения с удалением от контура целика растут и составляют примерно 60–70 % от вертикальных. Полученные результаты инструментальных измерений являются исходной информацией для оценки степени долговременной устойчивости междукамерных целиков при отработке сильвинитовых пластов.

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Introduction

An important condition of safe and efficient recovery of underground resources is adequate management of enclosing rock deformation and disintegration. This is especially true in case of potassium mines, where mining operations imply preservation of waterproof formation integrity as a means of separation of water bearing horizons from mined-out area. Waterproof pillar strength assurance and, consequently, flood protection of mines is achieved by application of chamber system of development employing support of overlying rock masses on belt-type interchamber pillar [1].

The analysis of mined-out areas inspection results in the mines of Verhnekamskoye potassium mine (VKMKS) shows that in certain areas, in the course of recovery of adjacent sylvinite horizons (KrII and AB) with "hard" pillar of "unlimited" service life, in 20–30 years their massive disintegration occurs. Rock cleavage depth in the pillar walls may achieve 1.5–2.5 m, while in chamber roofs the collapse of arches and partings occurs. The situation may be aggravated by decrease of pillar strength in the geological anomaly areas. All the above mentioned results in gradual deterioration of interchamber pillar and intensification of mined out rock shift. Subsidence rate may achieve 500 mm/year, while the eventual deformation of earth surface may reach 3.0–4.5 m. This is especially relevant for the southern part of the field where massive clay interlayers occur in the roof of the lower sylvinite horizon [2, 3].

The deformation and disintegration nature in the interchamber pillar and roof depends on many variables: geometrical size and shape of excavation, structure and properties of rocks, their behavior under stress etc. [4]. In order to decrease the probability of emergency, a flexible geomechanical control system for mining safety assurance has to be established to reliably reflect the diversity of processes in the rock mass and ensure continuous awareness of local changes in geological and technical mining conditions as a basis of administrative decisions. The system has to be able to assess the changes in mechanical peripheral rock properties and its stress condition during mining operations.

At the present time an extensive experience was accumulated in terms of methods of various subsurface structure elements stability assurance. To analyze the geomechanical processes occurring in the mined-out rock mass, mathematical methods of rock mechanics are widely used [5]. However, despite the growing complexity of mathematical problems, the assessment accuracy depends on the reliability of computation parameters and adequacy of geomechanical models describing the process of stress-deformed state of the rock mass (interchamber pillar, stope roof). Therefore it is necessary to conduct an experimental study of deformation and disintegration nature of the rock mass marginal parts and elements of subsurface structure at various conditions of mining operations.

A comprehensive research of structure, physical and mechanical properties, stress-deformed state and disintegration of salt rocks in the course of sylvinite horizons recovery in VKMKS mines resulted in development of principles for experimental and theoretical assessment of the chamber system load-carrying elements condition (Figure 1). The essence of this method is in-depth interpretation of field observation results by means of mathematical modeling [4].

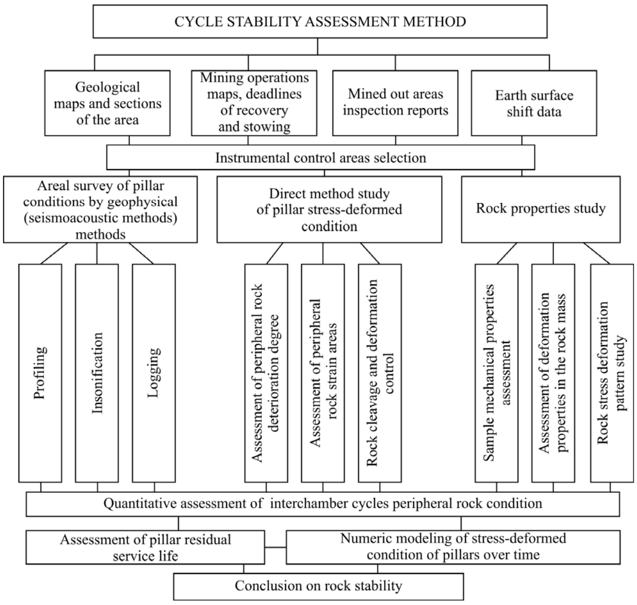

Figure 1. Interchamber pillars stability control scheme

As input data for assessment of interchamber pillar and roof pillar condition, geological survey documentation obtained in the process of exploration and mining of productive horizons was used, along with stope and preparation works reports, and earth surface subsidence data.

Drawing on the results of analysis, potentially hazardous areas were discovered, demanding a more detailed study of their condition. These areas are subjected to research of physical and mechanical properties of enclosing rock, subsurface structural elements strain condition assessment, study of their deformation nature over time. This data is used as a parametrical background for identifying the deformation pattern of the mined out salt rock mass and the criteria of its deterioration.

Reliability of experimental evaluation of stress-deformed state of subsurface structural elements largely depends on the applied method of research which is primarily selected based on the structural properties of the rock mass.

Regardless of the fact that VKMKS salt rocks consists of homotypic minerals (halite, sylvine), their mechanical properties are extensively variable due to their structural and textural properties [6, 7]. Salt rocks have consertal structure where crystal particle size can vary from 0.5 to 15.0 mm and more. The productive rock mass consists of alternating layers of rock salt, sylvinite (carnallite) and thin interlayers of argillaceous anhydrite. In this case, use of traditional methods of rock mass survey that suggest a limited array of measurements will result in a wide spread of data points of the researched parameters, with subsequently lower reliability of results. Practically in the experimental research of stressed condition of salt rock it is common to use methods excluding the need for model transitions from measured deformations to stresses, with measurement data significantly exceeding the rock inhomogeneity typical size [8, 9]. This requirement was most agreeably met by the jack method using the acoustic memory effect. The idea of using stress control in the rock mass is based on the ability of rock mass to memorize the magnitude of previous load (acoustic-emission Kaiser effect) [10–14]. The stress magnitude is measured by step-like change in the acoustic emission (AE) activity at an excess of previous stress level in the process of repeated loading [15, 16].

Research procedure

To refine the measurement method, a comprehensive laboratory and field research was conducted in order to study the patterns of acoustic emission variation at loading of salt rock.

Laboratory research has shown that salt rock manifest a remarkable memory effect and are able to retain information for an extended period of time. The main sources of acoustic emission in salt rock are strain microfractures that generate on the interfaces of grains and, in the course of sample deformation, grow in the direction of maximum main stress influence [17]. When loading level exceeds the previous strains, fracture generation process activates, tiny fissures merge and form large mainstream fissures which results in sharp acceleration of AE activity level [16].

Peripheral rock mass strain condition assessment in field conditions was performed with the aid of Goodman hydraulic borehole jack produced by Durham Geo Slope Indicator (USA). The jack is a logging tool for well walls deformation measurement as a function from applied load. Unlike pressure meters conducting load to the rock via the rubber shell, in the course of measurement by a jack it applies unidirectional pressure to the walls of the well by means of two adjustable steel plates. The tool is designed for application in 76 mm diameter wells. The equipment package includes a portable device for deformation measurement, a hydraulic pump with high pressure pipeline, cut-off valves and manometer. To control AE parameters during well loading, a piesoceramic sensor with acoustic event frequency measurement range of 0.2–0.5 MHz was attached to the jack casing. AE parameters measurement was performed with AE-USB-1 device. The force to the well contour was applied via semicircular 200 mm steel plates creating pressure in one plane which allows measuring the massive parameters in different directions (Figure 2).

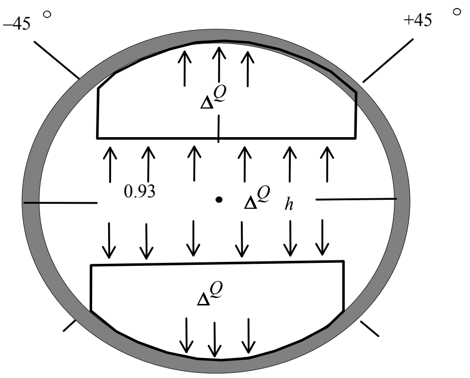

Figure 2. Scheme of well peripheral loading by Goodman hydraulic jack: ΔQ_h – pressure in hydraulic system; ΔQ – load applied to the well walls

To substantiate the received data reliability, the hydraulic jack was used in field conditions to apply load to the walls of a well drilled in a wall of a single production well. During experimental research, the following procedure was used. At the first stage, the peripheral rock mass was locally unstressed by way of drilling of a well, which subsequently accommodated a hydraulic jack at a depth of at least 1.0 m. Using a manual pump, cyclic load was applied to the peripheral rock. Measurements were performed by the ‘loading – unloading’ scheme with pressure increase at each subsequent cycle. Maximum pressure in hydraulic system during the first loading cycle amounted to 15 MPa, second cycle – 20 MPa, third cycle – 25 MPa. During the experiment, results were recorded for the pressure applied to the well walls and quantity of AE impulses. Previous loading level was determined by step-like (by 2–3 times) increase of AE impulses intensity or curve bend in the AE parametric chart in the process of directional cyclic loading of the well walls (Figure 3).

At the initial section of AE activity curve there is a section of relatively intense AE impulses caused by high noise levels related to crumpling of wall irregularities by hydraulic jack at the initial deformation stages. Further on, there is a zone where AE activity is insignificant (remains at background level), which corresponds to the что rock elastic deformation in the well periphery. In the first cycle of loading the step-like increase of AE activity occurs upon achievement of loading magnitude equal to the level of stress the rock was exposed to before the measuring well had been drilled. At further loading sessions, AE intensity is insignificant until the loading level approaches that of the previous cycle. Then the quantity of AE impulses increases in a step-like manner, concordant to the magnitude of well walls loading matching that of the previous cycle. The research has established that the total number of AE impulses is not a universal localization criterion for magnitude of stress in the rock mass. Very often it was impossible to identify the bend point by the curve of AE impulses count. Intensity (emission speed) of AE turned out to be a more informative parameter, measured as a number of AE impulses per unit of time and allowing for a more precise registration of AE impulses number increase.

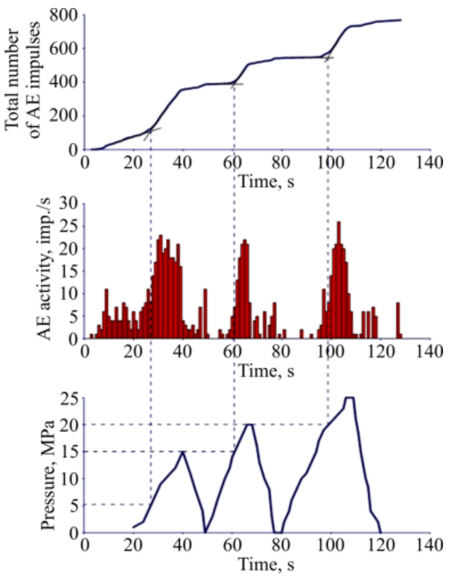

Figure 3. Typical loading and acoustic emission variation charts in the process of cyclic loading of the well walls

Based on the experiment results, the method of stress study using the rock memory effect was elaborated:

– the research should be performed immediately after the well drilling and cleaning of its contour; in 2–3 days the memory effect will dwindle significantly;

– stress level control should be determined by measuring AE intensity;

– bend point on the curve of AE intensity corresponds to the level of stress that existed in the loading plane before the experiment;

– measurement of stress magnitudes in different planes should be performed in wells detached from one another by at least 0.5 m.

Experimental research results

The stress research was conducted in the interchamber pillars of KrII horizon and KrII–AB interlayer rocks within the territory of the 11th eastern panel of the Second Berezniki Mine of Verhnekamskoye potash salt deposit. The horizon recovery is performed using a chamber system consisting of left out hard belt-type pillars 6.1 m wide and chambers 5.3 m wide. Mining operations depth is 320.0 m. Experimental wells were drilled in the pillars located in the panel center. In the process of experiment, the following measurements were made: pressure in hydraulic system, deformation of well walls in the direction of loading, AE intensity parameters.

Goodman hydraulic jack can create a load on the peripheral rock in a single plane, enabling the assessment of stress magnitudes in various directions. Figure 4 shows the distribution of vertical and horizontal stresses across the section of interchamber pillar of KrII horizon with service life over 30 years.

The analysis of experimental data has shown that over distance from the pillar contour to the depth of 2 m the vertical stress grows from 3 to 8 MPa, concordant with the load from the overlying rock. Horizontal stress also grows over distance from the pillar contour, constituting about 60–70 % of the vertical stress.

For comparison, similar measurements were performed over a section of a ‘fresh’ interchamber pillar. The research has shown that bearing pressure maximum is located at a depth of 1.3 m and is equal to 18 MPa. In the central part of the pillar, vertical stress level constitutes approximately 10–11 MPa, which is 25–40 % higher than the weight of overlying rocks.

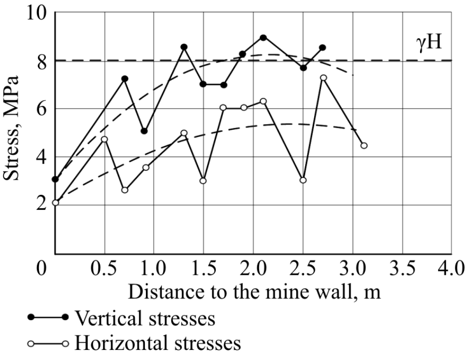

Figure 4. Stress distribution in the interchamber pillar over distance from the contour

Summary

Overall, the comprehensive study enabled the method development and conduction of stress assessment in salt interchamber pillars. The experimental data analysis has shown that in the “fresh” interchamber pillars the bearing pressure maximum is located next to the contour and exceeds the load from the weight of overlying rock (γH*)* by 1.8–2.0 times. In the central part of the pillar the vertical stress level is 1.25–1.4 γH. As the pillar service life increases, the stress magnitude in the peripheral rock mass goes down to the level of the stress from the weight of the overlying rocks. Horizontal stress grows over distance from the pillar contour, constituting approximately 60–70 % of the vertical stress. The field research results are used for assessment of chamber system structural elements stability in the course of VKMKS sylvinite horizons development.

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