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OPERATIONAL CONTROL OF RIB PILLAR STABILITY

In room-and-pillar mineral mining, rib pillars should support overlying rock mass for the specified time limit of production. Therefore, one of the mining safety components is monitoring of the behavior of rib pillars in the course of time. For the conditions of the room-and-pillar method of mining, the authors propose a monitoring procedure for rib pillar deformation based on operational measurements of horizontal convergence in stopes. The theoretical and experimental research proves that transverse deformation of rib pillars is an informative parameter suitable for generalized assessment of pillar failure. The obtained ranges of critical transverse deformation rates (50–100 mm/m/yr) in rib pillars can tentatively be used as an indicator of the critical stability of load-bearing structures in room-and-pillar mining. In-situ determination of the integral transverse deformation rates in rib pillars is based on the ratio of the measured horizontal convergence in stopes to the width of pillars. Implementation of the proposed approach in the Upper Kama potash salt mines has proved its applicability to identification of rock mass areas where intense deformation is expected. The comparison of the monitoring data of the transverse deformation rates and their critical values determined makes it possible to predict service life of rib pillars, which is very important in terms of safety of mining operations.

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Introduction

The room-and-pillar method is traditionally widely used in the mining practice worldwide [1–4]. In this method, the overlying rock mass support is ensured by rib pillars within the project-specified period of time. This is achieved through the optimization of the room-and-pillar dimensions (width of rooms and pillars, mining height) in compliance with the effective standards and procedure [5–7], or based on specific research [8–11]. On the other hand, it is quite often the design parameters fail to ensure the target life of the load-bearing elements in the structure of a room-and-pillar mine. In this respect, one of the mining safety aspects is the stability of the rib pillars.

The simplest approach to the mined-out area control is visual inspection. It allows identification of visible cracks in exposures, and enables assessment of schistosity in the roof, floor and sidewalls in development headings and stopes. Such inspection results are subjective and unsuitable for the quantitative assessment of inter-temporal changes.

Rib pillar stability control is possible with the methods connected with the stress–strain analysis, indirect geophysical estimates and instrumental measurement of deformations. The first group methods are based on measurement of unloading deformations and their conversion to stresses, or on recording of force interaction between a sensor and enclosing rocks [12, 13]. The same group methods include compensation techniques such as borehole slotter or overcoring, with subsequent stress recovery using hydraulic jacks and hydraulic cushions [14, 15], and also stress measurement using various memory effects in rocks [16, 17]. Each method has its own advantages and disadvantages. A common feature of such methods is the comparatively high labor content, which complicates their application in operational monitoring of rib pillar stability.

In a sense, the aforesaid is valid for the geophysical studies into the interaction between parameters of physical fields (natural or induced) and effective stresses [18–20]. An undeniable advantage of these methods is their ability to provide an areal control of rock mass behavior. At the same time, the geophysical methods offer ambiguous quantitative data due to considerable influence of various factors on the intensity of stresses being measured.

Thus, the best suitable methods for the operational monitoring of rib pillars are deformation measurements using various design measurement stations [21, 22]. In this case, it is unnecessary to convert the obtain results, measurements are simple, and the on-line control is possible [23].

Another critical task of operational monitoring is evaluation of critical value of a measurement parameter, which defines that geomechanical situation on a specific site is hazardous. In each geotechnical situation, the geomechanical hazard can be interpreted differently. For instance, the hazard connected with possible rock fall and, consequently, with the presence of personnel in a mined-out void. Or the hazard governed by impossibility of process flow accomplishment as per the mining plan, in particular, backfill.

Estimation of critical deformation values in rib pillars

With the deformation monitoring assumed as the main control procedure for rib pillars, we need to find which parameter is the best suitable for the operational evaluation. A priori, this parameter is apparently the longitudinal or transverse deformation of rib pillars. As a matter of principle, these characteristics are equivalent as there is a well-balanced interrelation between them.

Figure 1a presents measurements of vertical and horizontal convergence in stopes. The measurement stations were equipped with systems of deep-seated and perimeter plugs

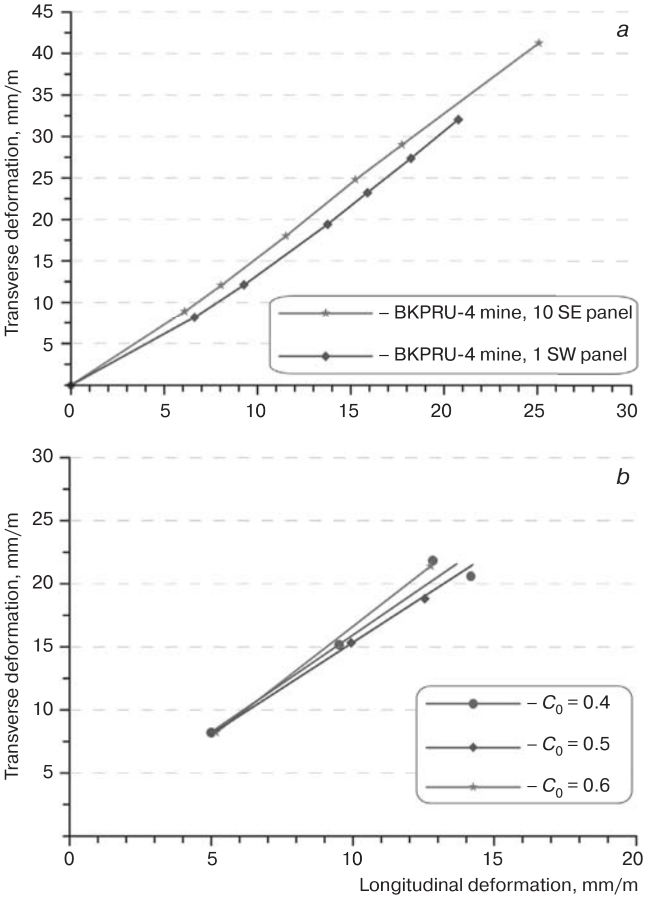

Fig. 1. Relationship of longitudinal and transverse deformations in rib pillars:
(*a*) – in situ measurement; (*b*) – modeling

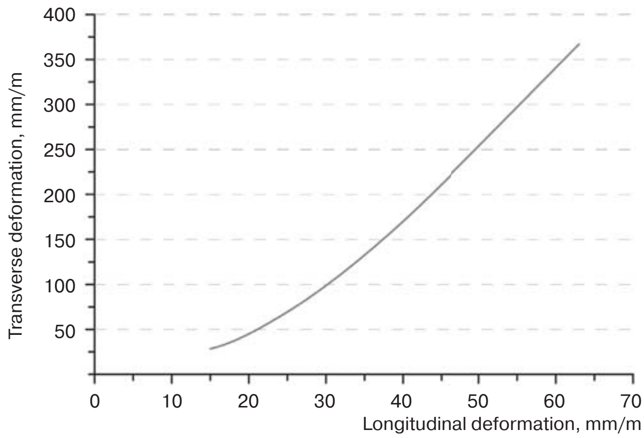

Fig. 2. Relationship between longitudinal and transverse deformations of rib pillars in case of plasticity localization in their edge areas

installed in various sites of mine fields of the Upper Kama Potash Salt Deposit for more than 5 years. The linear correlation between the longitudinal or transverse deformations is obvious. The transverse/lateral deformation ratio is 1.6.

The similar estimates were obtained in mathematical modeling of deformation and fracture of rib pillars. The calculations were performed at different initial loading rates C_0 of rib pillars. The loading rate of rib pillars was determined using the modified Turner–Shevyakov approach with regard to the experimental studies implemented in the Upper Kama Deposit [5].

The mathematical modeling set is in full described in the work [24]. The resultant transverse/lateral deformation ratio in rib pillar at the pre-limiting deformation stage (See Fig. 1b) quantitatively totally agrees with the in-situ measurements and equals 1.6. During activation fracture process in a pillar and localization of the plasticity zones in its edge areas, the transverse deformations jump (**Fig. 2**) and their ratio to the longitudinal deformations reaches and exceeds 3.

The transverse deformations exceed considerably the longitudinal deformations of rib pillars, which makes the former somewhat more preferable in terms of the rib pillar control. Furthermore, the horizontal convergence of stopes is easier measurable as against the vertical convergence, and the results are free from impairment connected with roof rock schistocity and fall.

The authors earlier discussed the approaches to theoretical estimation of limiting conditions of rib pillars [24]. From the multi-variant mathematical modeling, averaged rates of transverse deformation of pillars were determined at various rates of initial lading of the pillars (**Fig. 3**). The analysis of the data shows that as soon as the transverse deformation rate reaches the value of 50–100 mm/m/yr, it starts soaring, which can be reflective of instability of the pillars and their transition to progressive creep. Consequently, the interval of the transverse deformation rates of 50–100 mm/m/yr can be used as the indicator of critical stability of pillars in a room-and-pillar mine. The calculations should be adjusted using the in-mine control data on deformation and failure of rib pillars in the course of time.

Underground measurement procedure

The simplest method to determine the rate of transverse deformations in rib pillars is the measurement of the horizontal convergence rate in stopes (**Fig. 4**). The integral rate of transverse deformation is found as a ratio of time change of the horizontal convergence to the width of pillars.

The width control in stopes can use laser distance measures with a precision of 2 mm. Such precision is, as a rule, sufficient to identify geomechanically hazardous areas, and, due to low labor content, the scope of the control can embrace more stopes. Check points are set on opposite sidewalls of a stope as wooden plugs or paint marks. Such measurement stations can be arranged either on a local scale (based on the visual inspection outcome) in the zones of potential instability of pillars, or in all stopes at a certain interval. At high deformation rates, the first measurement cycle data should be compared with the design cross-section of a shearer. This makes it possible to assess convergence from the very beginning of stoping.

From the numerical calculations of deformation patterns at the boundaries of stopes, irrespective of the stope shape, the highest transverse deformations develop in a pillar at a height of the mining half-height. It is possible that in multipass stopes, in the area of overlap of the passes, local plastic strain zones appear. For the instrumental control results to be more reliable, the horizontal convergence is measured in the widest part of a stope, at a height of 1.5–1.7 m from the floor (**Fig. 4**).

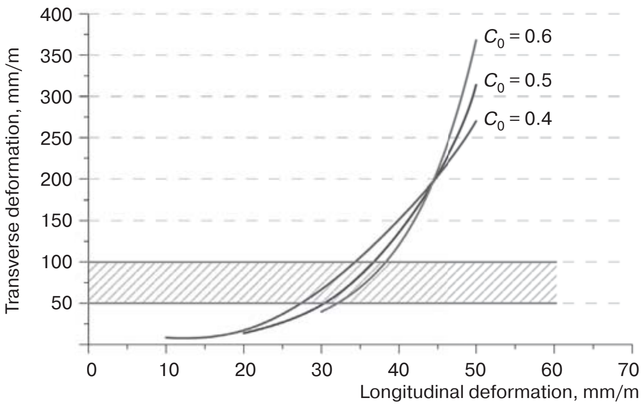

Fig. 3. Variation in relative transverse deformation rate in pillars under different initial loading rates

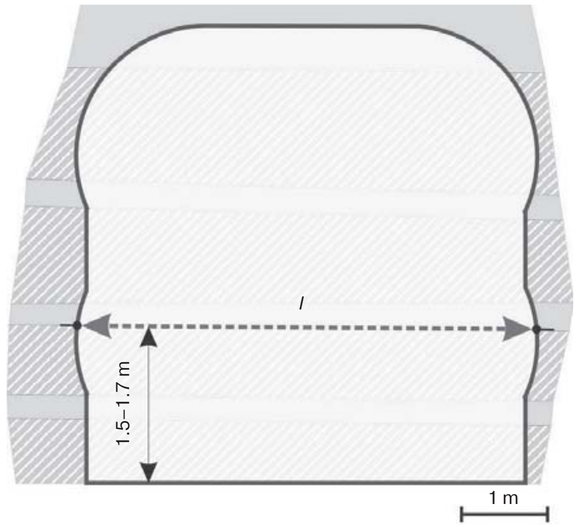

Fig. 4. Horizontal convergence measurement in stope

At the early stages of rib pillar stability control, the horizontal convergence in stopes is measured not less than once in 3 months. Later on, periodicity of measurements is adjusted subject to the pillar deformation rate.

Rib pillar stability control results

The trails of the rib pillar stability control were carried out in two mined-out sites of an underground mine of Usolye Potash Plant, Upper Kama Potash Deposit. To that end, 13 measurement stations were arranged, including 7 stations in the first site and 6 stations in the second site.

In the selected test sites, the productive strata feature varied clay content, which considerably governs stability of stopes. Mining operations were carried out by shearer Ural-20 with cutter drum width of 5.5 m in the first site and by shearer Ural-61 with cutter drum width of 3.2 m in the second site.

The visual inspection of the mined-out voids and the experimental data analysis shows that despite reduced width of stopes in the areas of rocks mass with high clay content, deformation processes have higher rates: mining-induced fractures appear in roofs, roof falls take place and floor buckling is observed.

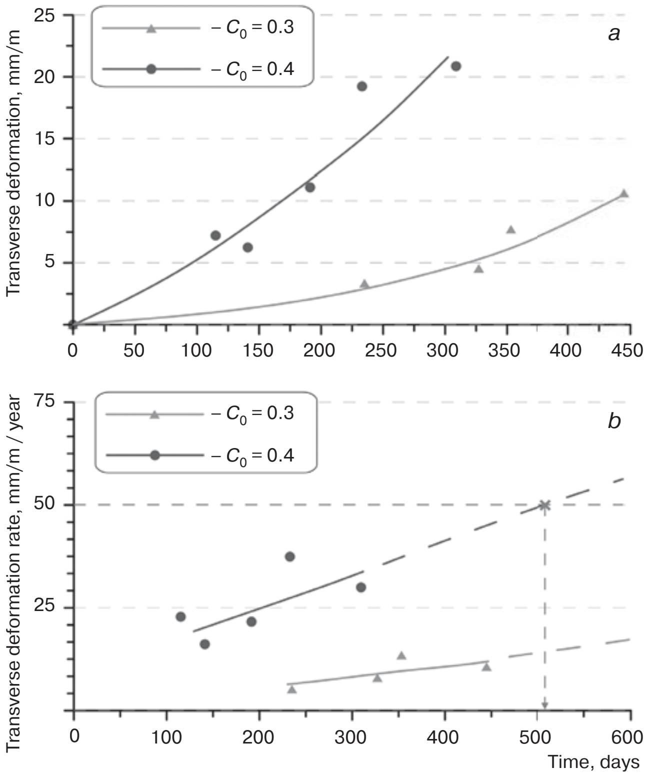

Fig. 5. Time change of (*a*) transverse deformation and (*b*) deformation rate of pillars at different loading rates

The experimental measurements in the first trial site, at the calculated loading rate C_0 = 0.4 show that transverse deformation rates of pillars persist at the same level of 5–10 mm/m/yr.

In the second site, at the same calculated loading rate C_0 = 0.4, deformations have higher rates: transverse deformation rates grow with time and reach 22–37 mm/m/yr. Indirectly, this means that the calculation of the loading rate of the rib pillars incorrectly takes into account the influence of clay material on the load-bearing capacity of the pillars.

The generalized results of the in-situ deformation control of rib pillars subjected to different-rate loading are depicted in **Fig. 5** as the transverse deformation–deformation rate–time curves (zero time defines the time of actual mining). The influence of the loading rate on the deformation rate in the same geological conditions of room-and-pillar mining is distinct in **Fig. 5**. The quantitative experimental data reasonably agree with the mathematical modeling (**Fig. 3**) in the initial branch of the transverse deformation curve at the loading rate C_0 = 0.4.

In the conditions of high clay content of salt rocks, irrespective of the loading rate of rib pillars, the transverse deformation rate of the pillars increases with time (**Fig. 5b**). At C_0 = 0.4 the assumed lower limit of the critical transverse deformation (50–100 mm/m/yr) can be reached in 1.5 years. This trend is generally proved by the overall condition of the mined-out area in the test sites.

Thus, the implemented in-situ research has proved feasibility and efficiency of operational stability control of rib pillars by the rate of change in horizontal convergence of stopes. The research findings can be used in detection of potentially hazardous areas due to higher rate deformations of load-bearing components of the room-and-pillar mine structure.

Conclusions

It has been found that transverse deformation of rib pillar is an informative parameter providing a generalized characteristic of the rib pillar stability. The operational control procedure proposed by the authors for the transverse deformation of pillars is based on the measurement of horizontal convergence in stopes. The primary trials of the control procedure in a mine have proved its applicability to detection of potentially hazardous areas of deformation in undermined rock mass. The obtained test results can be used for the predictive estimates of service life of rib pillars, which is of high concern in terms of safety of mining operations. Wide introduction of this control system in potash salt mining can enable prompt implementation of reasonable flooding precautions in mines [25].

Finally, it should be pointed at potential modernizability of the proposed control system to be operated online [25], which can allow wider area monitoring in mined-out voids.

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