In 2019 Siberia's largest scientific establishment in mining, the ***N. A. Chinakal Institute of Mining of the Siberian Branch of the Russian Academy of Sciences celebrates its 75th anniversary*** *since it was founded under the auspices of the former West Siberia Division of the USSR Academy of Sciences.*

The Institute has passed the glorious historical path. Established in the years of the Great Patriotic War, the Institute right away made for exploration of Siberian minerals being critical for the Victory. The postwar years and later on period featured great achievements of the Institute in technology and equipment for mineral mining. The N. A. Chinakal Institute of Mining, SB RAS takes the top position in some areas of mining sciences in Russia.

The Institute celebrates its anniversary with the huge creative and professional background and potential for new discoveries, dynamic development and prosperity.

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STABILITY ASSESSMENT OF COAL-AND-ROCK MASS AROUND TEARDOWN ROOM IN THE YALEVSKY MINE

In terms of the mining conditions in longwall No. 52-13 in coal seam 52 in the Yalevsky Mine, the integrated research aimed at geomechanical assessment of rock mass stability around a teardown room is carried out. The stress–strain analysis of the geotechnical structure in the extraction panel was implemented by 3D finite element-based modeling. Owing to this, the geological conditions of the coal occurrence and the structural complexity of geotechnical objects were taken into account to the maximum extent in the calculations, which allowed near-reality results qualitatively and quantitatively consistent with in-situ data.

The forecast maps of stress distribution in the elements of the mining system in the extraction panel are obtained with regard to the earlier mined-out areas, using the gravitational model of the geomedium. The localities and sizes of the post-limiting deformation zones (possible instability zones) are determined in coal-and-rock mass around underground excavations. It is found that safety of the teardown room and the adjacent drainage and ventilation drives is mostly governed by the poor quality and jointing of the coal-and-rock mass.

The predictive estimate of the rock mass stability provides a complete idea on the mechanism of deformation and failure of rocks in the structural elements of the analyzed drive, which enables reasoned design of the support system for the teardown room, as well as the drainage and ventilation drives while combining safety and efficiency of removal of the powered roof support units.

Keywords: *stress–strain behavior, coal-and-rock mass, geomechanical model, longwall, teardown room, stability, mine support, safety.*
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Introduction

Longwall mining of flat-dipping and horizontal coal seams with total roof caving and using powered roof supports ensures high productivity of coal mines while intensity of coal recovery and production performance leaves all known technologies behind. At the same time, the current steady increase in the depth of mining is faced with complication of geological, geotechnical and geomechanical conditions of mineral field development. In case there is no reliable information on the behavior, physical and mechanical properties, deformation and strength characteristics as well as faulting of rock mass, it is possible that wrong decisions are often made in justification of geotechnologies, in particular, in validation of operation and support of underground openings. In longwall mining, specific place belongs to design of a teardown room meant for disassembling of very expensive powered support units before re-employment.

Reliability of the support system design as well as operating safety on the teardown room can be improved by implementing numerical variational evaluations for taking into account all diverse geological features of bedding and the current geotechnical situation govern by the whole mine performance. The efficient numerical modeling greatly supports full-scale experimentation. It allows, in shorter period and at minimal material and labor inputs, solving multi-variant problems on the stress–train behavior and stability of rock mass, as well as underground openings and pillars of any purpose even under uncertainty and incompleteness of geological and geotechnical data [1, 2]. Safe operation of teardown rooms is a very relevant exploration trend as they govern the short- and medium-term performance of productive coal mines.

The aim of this study is prediction of possible damage zones in rock mass and coal around a teardown room at the final construction stage, as well as adjoining drainage and ventilation drives, for the subsequent selection and validation of the type and parameters of a support system.

Features and conditions of geomechanical modeling

The data on geological structure and geodynamic zoning of the Kuznetsk Coal Basin (T. I. Lazarevich, V. P. Mazikin, I. A. Malyi et al) rate the natural field of stresses of this deposit as gravitational (nontectonic mode of loading). In the gravitational model, the vertical stresses are governed by the bulk weight of overlying rock mass and the maximum pressure in the coal-and-rock mass (initial stress field is consistent with the *Dinnik-type* distribution, which is typical of flat bedding) [3–6]:

$$\sigma_y = \gamma g H,\ \sigma_x = \sigma_z = q\sigma_y,\ \tau_{xy} = \tau_{yz} = \tau_{xz} = 0 \qquad (1)$$

where σ_y, σ_x, σ_z и τ_{xy}, τ_{yz}, τ_{xz} are, respectively, the vertical and horizontal normal and shear components of the stress tensor (the y axis is oriented vertically downward); H is the depth of mining; γ is the density of rocks; g is the gravitational acceleration; $q = \mu/(1 - \mu)$ is the lateral earth pressure coefficient; μ is Poisson's ratio.

Table 1. Physical and mechanical properties of jointed rock mass assumed in calculations

Material	Reduced Young's modulus, GPa	Poisson's ratio	Cohesion, MPa	Internal friction angle, deg	Density, kg/m^3
Alluvium	0.1–1.0	0.38	0.1	27	1700
Transition to rocks	3.5	0.33	0.8	30	2500
Medium grain sandstone	16.0	0.25	3.5	42	2500
Siltstone	10.0	0.23	2.5	37	2500
Alternating siltstone and sandstone	11.0	0.23	3.0	38	2500
Fine grain siltstone	7.0	0.25	2.0	36	2500
Coaly siltstone and clay rock	6.0	0.22	2.0	35	2000
Coal	3.0	0.15	1.2	33	1320
Caved rocks	0.03	0.42	0.1	25	1500–1800

The stress–strain modeling and analysis were implemented using a 3D finite element-based linear model [7–12]. Stability of underground rooms was assessed by the Mohr–Coulomb criterion using the strength factor [13, 14]:

$$K_y = \frac{2C\cos\varphi + (\sigma_1 + \sigma_3)\sin\varphi}{(\sigma_1 - \sigma_3)}, \qquad (2)$$

wheree σ_1 and σ_3 are the maximal and minimal principal stresses in rock mass (assumed based on the elastic solution), MPa; C is the cohesion of rocks, MPa; φ is the internal friction angle, deg. When $K_y < 1.0$ rocks are estimated as unstable.

In the numerical solutions, coal and enclosing rocks were modeled as solid isotropic materials with physical and mechanical properties of a jointed (poor quality) rock mass compiled in **Table 1**.

Figure 1 shows the analytical model with basic parameters and problem formulation (boundary conditions). In the center of the model, there is the geotechnical structure of mined-out extraction panel No. 52-13 with constructed teardown room.

The geomechanical calculation results are presented as the distribution zones of the maximal principal stress σ_1 (compression with plus sign), minimal principal stress σ_3 (tension with minus sign) and maximal shear stress τ_{max} (MPa), as well as the instability zones in the element of the geotechnical structure.

The problems assumed that caved rocks in the mined-out space bear a certain side pressure and have cohesion with enclosing rock mass (conditions of continuity of the model geomedium is fulfilled). The latter made it possible to simulate the mined-out void by the low-modulus material, which was governed by the required maximal approximation of the model to the full-scale conditions. When the longwall approached the teardown room, the mined-out void along the extraction panel was modeled as an open stope to the length equal to 1.5–2-fold step of caving but not less than 60 m. As a consequence, it was possible to reproduce the limit case of the geotechnical structure (the worst stress state situation).

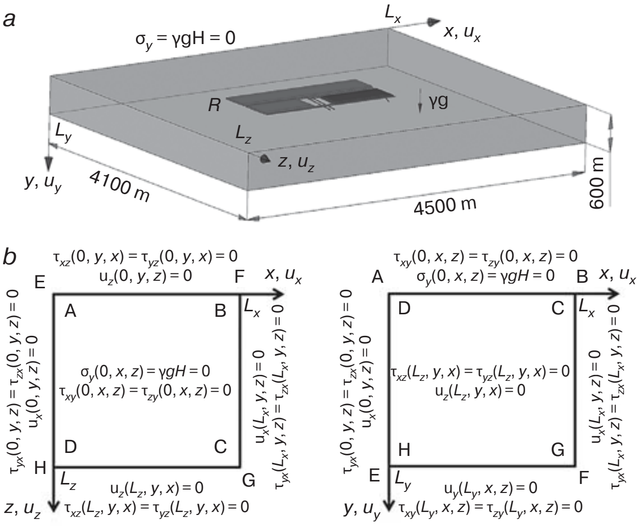

Fig. 1. Analytical model:
a — 3D representation; *b* — plane representation

The input data analysis, including the details of the teardown room construction and the technology of removal of the powered roof support units dictated consideration of the mining modeling variant conformable with completion of the powered roof support removal when the width (span) of the teardown room across the roof had the maximum value of ≈7 m. Such geotechnical structure is the geomechanically limiting (worst) case of stability of the room.

The model structure diagram of the mining situation, the stress–strain behavior and the general spatial orientation of the cross-sections under analysis are described in **Fig. 2.** The extraction panel and the longwall are 2900 and 260 m long, respectively, the mining depth is 330 m.

The analyzed domains 1 and 2 (Fig. 2a) represent slightly inclined cuts in the plane of extraction longwall No. 52-13 of seam 52, in the influence zone the teardown room, at the height of 1.8–2.1 m from the floor of the main roadways. Site 1 — influence zone of the drainage drive and teardown room intersection; site 2—influence zone of the ventilation drive and teardown room intersection. Cross-section 3 is a vertical cut made across the strike of the extraction panel along the teardown room (Fig. 2a).

The proposed method of 3D stress–strain modeling helps understand general geomechanical situation and creates background for the objective prediction of geomechanical phenomena and their inclusion in the mining safety assessment in local areas of mineral deposits.

Stress–strain analysis of coal-and-rock mass in the influence zone of teardown room

The geomechanical calculation results in the limits of the teardown room are depicted in **Figs. 3** and **4**.

The maximal principal stresses σ_1 in the structural element of the mining system at the coal seam level have the values below:

- sidewalls of mined-out void in the extraction panel — more than 25 MPa;
- teardown room — 25–33 MPa;
- rocks adjoining the teardown room, open drives and intersections — more than 20 MPa.

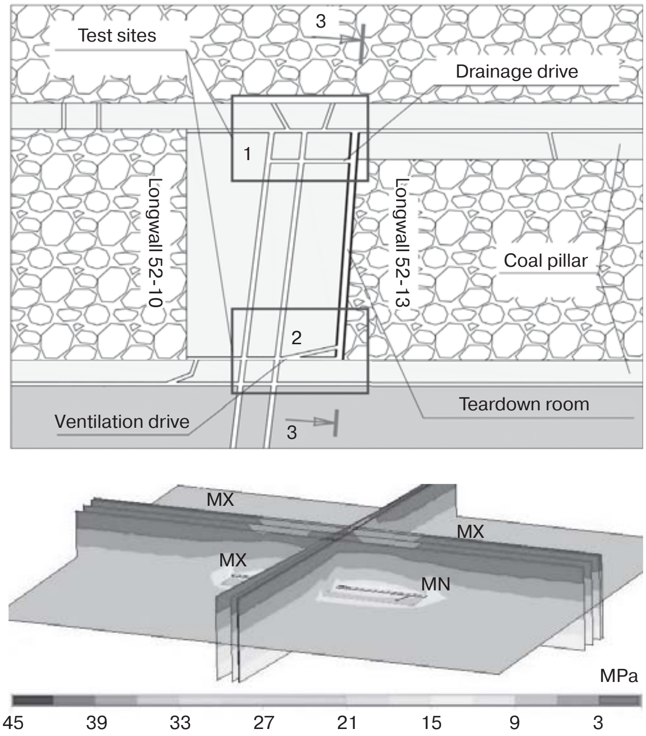

Fig. 2. Geotechnical situation diagram (*a*) and cross-sections under analysis (*b*)

The minimal principal stresses σ_3 have the values:

- sidewalls of mined-out void in the extraction panel — ≈ 8–10 MPa;
- teardown room—from 5 to 12 MPa (roof and sidewalls), which conditions the absence of the tensile stresses and the presence of the triaxial compression; the latter means that coal-and-rock mass fails under the shear stresses (viscous failure owing to growth of plastic straining);
- drives adjoining the teardown room and mined-out void experience rock pressure not higher than the initial stress state and acting in the respective directions.

As mentioned above, the tensile stress zones are absent in the study section of the teardown room. The latter mean that the geotechnical structure is subjected to the triaxial compression. On the other hand, the essential difference between the absolute values of σ_1 and σ_3 conditions high probability of instability in sidewalls of the drives and teardown rooms due to the maximal shear forces. On the whole, stresses in the coal-and-rock mass in view of its poor quality tend to its limiting deformation and strength characteristics by the compression, tension and shear, which governs the worst situation.

At the final stage of removal of the powered roof support units, when the width of the teardown room across the roof reaches 7 m, in the range of the structural weakening coefficient K_c = 0.12–0.20, the instability zone is predicted along the whole length of the room sidewall and inside adjoining coal mass to a depth up to 4.0–4.5 m and more.

Generalization of the research data on the main roof and floor of the coal seam show that in the roof of the drainage and ventilation drive, relaxation from the maximal principal stresses is observed as their values are less than 10 MPa. In

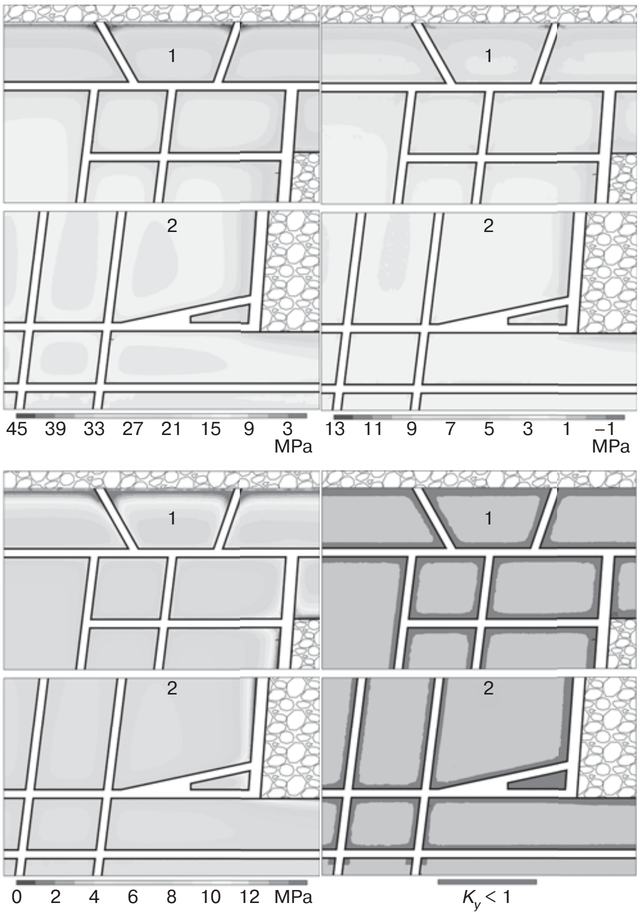

Fig. 3. Maximal principal stress σ_1 (*a*), minimal principal stress σ_3 (*b*), maximal shear stress τ_{max} (*c*) and instability zones (*d*) in plan view of analyzed sites 1 and 2

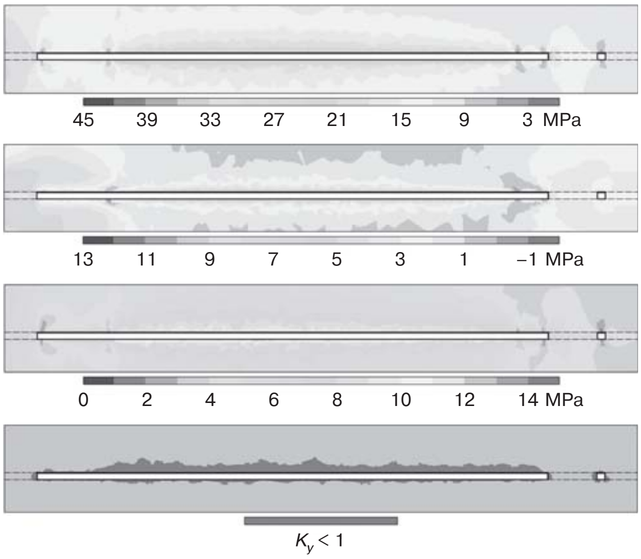

Fig. 4. Maximal principal stress σ_1 (*a*), minimal principal stress σ_3 (*b*), maximal shear stress τ_{max} (*c*) and instability zones (*d*) across the strike of extraction panel along the teardown room—cross-section 3

Table 2. Predicted parameters of vertical displacement and probable fall zones in coal-and-rock mass

Analysis domain	Vertical displacement Y, mm		Instability zone, m		
	Roof	Sidewall*	Roof	Sidewall*	Floor
Teardown room	210.0–240.0	to 200.0	6.8–8.1	4.0–4.5	1.0–1.5
Teardown room and drainage drive intersection	190.0–230.0	180.0–230.0	2.2–2.5	2.5–3.0	to 1.0
Teardown room and ventilation drive intersection	200.0–230.0	to 210.0	2.8–3.5	2.4–2.8	to 1.0

*Weighted mean linear value in two horizontal mutually perpendicular directions in analysis of intersection of teardown room and drives

the meanwhile, the extensive additional loading is observed in the side rock where σ_1 reach values above 20 MPa (the shear stresses τ_{max} range from 6 to 15 MPa and higher).

The higher stress state is in the teardown room roof and corners which experience the compressive stresses $\sigma_1 > 25$ MPa, and even reach 30 MPa in the sidewalls. It should be emphasized that geomechanically, in terms of qualitative and quantitative changes in the stress state of the coal-and-rock mass, the teardown room is in the critical limiting state at the sage of disassembling and removal of the powered roof support.

Stability estimation in teardown room

The quantitative characteristic of rock mass surrounding the teardown room is based on the values of the vertical displacements (verified by in-situ measurements) and the linear parameters of the most probable instability zones from the numerical modeling of the roof, floor and sidewalls of the drives and intersections in the influence zones of the geotechnical structure. Considering the initial natural stress field conformable with the gravitational model of the geomedium, the vertical displacements Y have the maximal values. The representative calculation data are given in **Table 2**.

The analysis of the research results point at the required reinforcement of the roof and sidewalls of the drives. Based on the solutions obtained in the numerical modeling of the stress–strain behavior in the coal-and-rock mass within the boundaries of the teardown room, it is recommended to use the two-level bolting, including cable bolts, with monomeric steel mesh, at the density of the first and second (cable bolts) bolting levels not less than 7 and 3 bolts per 1 m, respectively.

Conclusions

Based on the generalized geological data and geomechanical research accomplished within the boundaries of the geotechnical structure of extraction panel No. 52-13 in seam 52 In the Yalevsky Mine, stability of the coal-and-rock mass is estimated around the teardown room and in drives in the influence zone of this room.

The predicted instability zones are found in the structural elements of the teardown room; their linear sizes are: to 6.8–8.1 m in the roof (maximal value in the middle of the teardown room); to 4.0–4.5 m in the sidewall (negative influence of rock pressure propagates inward of the coal seam to 16–22 m, into the pillar between longwalls 52–10 and 52–13; however, this influence is only destructive at the distance to 4.5 m and shows itself as sloughing of the sidewall of the teardown room).

It follows from the analysis of the results obtained in coal-and-rock mass of poor quality in the range of the structural weakening coefficient $Kc < 0.12$–0.2 that failure in the teardown room is probable in the roof (doming), sidewalls (sloughing) and in the floor (buckling) at various intensities. For this reason, the teardown room is subjected to obligatory support at all stages of construction. It is recommended to install the combination of rock bolting and steel mesh reinforcement, with rock bolts of different length (two-level bolting), including cable bolts.

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