Validation of choice and determination of geotechnology parameters with regard to stress–strain state of rocks

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Abstract. The paper illustrates efficiency and reliability of types of rock mass stress state conditioned by geological and structural features of rocks in design, selection and validation of geotechnology parameters. The authors of the paper present calculation of stresses in rock mass under sublevel stoping depending on the type of the geosphere and on the depth of the ore body occurrence.

One of the possible ways to deal with the problems connected with great depth is the conceptualization of rock mass by the type of stress state versus the geological structure.

The identified types of geological–tectonic structures are related with the stress state of rock mass (see the table below). The joint analysis of these two factors makes it possible to substantiate boundary conditions to solve practical problems of geomechanics and to select mining technologies in this bases.

Aiming to test methodology of geomechanical modeling (with regard to stress state conditioned by geological–tectonic structure) [1, 2], mining systems are divided into classes subject to model representation of state of rocks at different depths (table).

The review of geotechnologies practiced in more than 90 mines of the world has allowed some conclusions to be drawn.

In relatively simple geological and geotechnical conditions, all known systems of mining are applicable [3].

The main outcome of the implemented generalization is the depth-related overlap of different mining system with the formation of cross-effect areas (table). This cross-effect areas point at the capability of safe operation of alternative geotechnologies and combination of different ground control method, which expands the range of application of inexpensive systems of mining at deep levels. In this case, the choice of a mining system is governed equally by the type of stress state of rock mass, and regional and local features of a deposit, for instance, geomorphology, seismic activity, deep faulting etc.

The proposed geomechanical model of geomedia improve estimation of geotechnical situation in mines and favor more correct mine design and planning.

Validation of key solutions on deeper level mineral mining, as well as their reliability and certainty reduces to finding rational geotechnologies in the sphere of influence of geomechanical models of geomedia represented by different tectonic types of rock mass and their comparison with the practical examples of deep ore body mining.
### Classes of mining system per stress state of rock mass and mining depth

| Stress state, correlation coefficient $C_c$ | Geological–tectonic structure | Stress state versus depth | Depth-related mining system |
|-------------------------------------------|--------------------------------|--------------------------|-----------------------------|
| 1. Geodynamic $300 \leq H \leq 1300$ | Stable basal complexes and shelves of platforms. Mobile and seismically active folded mountainous systems. | $\sigma_{H_{\text{max}}} = \alpha \lambda^* \ln(H) - \delta \approx \sigma_1$; $\sigma_{H_{\text{min}}} = \frac{(\sigma_{H_{\text{max}}} + \sigma_c)}{2} \approx \sigma_2$; $\sigma_c \approx H \approx \sigma_3$ | to 0.5 km—caving, sublevel drifting below 0.5 km—backfilling |
| $1.6 \leq \lambda \leq 4.0$ | | | to 0.5 km—with natural support from 0.5 to 1.0 km—ore caving, sublevel drifts below 1.0 km—cut-and-fill and combined methods |
| $C_c > 0.87$ | | | to 0.8 km—with natural support from 0.81 to 1.5 km—ore caving, sublevel drifts below 1.2 km—cut-and-fill methods under 2 km—physico-technical and physicochemical methods to 0.8 km—with natural support and caving from 0.81 to 1.5 km—with caving below 1.2 km—with backfill and combined methods under 20 km—physicochemical methods |
| 2. Tectonic $300 \leq H \leq 2000$ | Young mobile platforms, fault troughs, island arcs, overthrust folding and faulting nontectonic faulting | $\sigma_{H_{\text{max}}} = 2.8 e^{2 \phi^*} H^{0.7} \approx \sigma_1$; $\sigma_{H_{\text{min}}} = (0.6 \pm 1.0) \sigma_{H_{\text{max}}} \approx \sigma_2$; $\sigma_c \approx \gamma H \approx \sigma_3$ | |
| $1.2 \leq \lambda \leq 2.1$ | | | |
| $C_c > 0.88$ | | | |
| 3. Geostatic $200 \leq H \leq 5000$ | Young mobile platforms, fault troughs, island arcs, overthrust folding and faulting nontectonic faulting | $\sigma_{H_{\text{max}}} = \lambda \gamma H \approx \sigma_1 \approx \sigma_3$; $\sigma_{H_{\text{min}}} = (0.8 \pm 1.0) \sigma_{H_{\text{max}}} \approx \sigma_4$; $\sigma_c \approx \gamma H \approx \sigma_5$ | |
| $0.8 \leq \lambda \leq 1.3$ | | | |
| $C_c > 0.90$ | | | |
| 4. Gravity $100 \leq H \leq 5000$ | Sedimentary covers, mobile shelves and platforms. Caledonian structures in the form of overlapped folds and faults | $\sigma_{H_{\text{max}}} = \lambda \gamma H \approx \sigma_2$; $\sigma_{H_{\text{min}}} = \lambda \gamma H \approx \sigma_3$; $\sigma_c \approx \gamma H \approx \sigma_5$ | |
| $\lambda = \frac{v}{1-v}$ | | | |
| $C_c > 0.92$ | | | |

* $\gamma$—bulk weight of overlying rocks, MN/m³; $H$—occurrence depth, m; $\lambda$—lateral earth pressure coefficient; $v$—Poisson’s ratio; $\kappa$—empirical coefficient: for very hard rocks $\kappa = 0.12–0.30$, for medium hard and fair rocks $\kappa = 0.08–0.12$; $\alpha$, $\delta$, $\psi$ and $\theta$—empirical coefficient of proportionality: $\alpha \approx 32–37$, $\delta \approx 65–80$, $\psi = 0.8–0.9$, $\theta \approx 5–10$. 

With a view to validating reliable determination of geotechnology design based on stress state conditioned by a type of geological–tectonic structure of rock mass, case studies have been carried out to find application area and limit depth for combination of room-and-pillar and caving method in two variants (Figures 1 and 2) and sublevel caving technologies (Figure 3). For the corrected comparison of the calculated results and actual performance of real mine, the international experience of gently dipping ore body mining using room-and-pillar method has been generalized as this method is close to the discussed geotechnologies [4] and sublevel caving systems.
At the present time, mining depth has reached 1000 m below the ground surface and deeper, and the methods of room-and-pillar and caving technologies yet remain to be studied more comprehensively.

The international mining practice has many examples of room-and-pillar operation in unfavorable mine-technical conditions as well as geotechnologies with caving at the depths below 700–100 m. Mines Konrad (Germany), Denison and New-Quirk (Canada) first extracted gently dipping ore bodies to 12 m thick using the room-and-pillar method [4].

Reliability of parameters and application fields of the mining systems with regard to stress state of rock mass was verified by comparing the research findings with the actual data of mines operating under different geomechanical conditions and at various depths.

The check calculations have been performed to assess stability of structural elements in room-and-pillar method in terms of Konrad mine (Germany) for the depth of 1000 m and in sublevel caving under different geological conditions of an iron ore body.

Figures 1 and 2 show areas of probable damage of rocks in the structural elements of a combined mining system at the structural weakening coefficient $C_c$ 0.5 and 0.8, while Figure 3 depicts tension zones in the structural elements of sublevel caving technology.

**Figure 1.** Prediction of rock damage zones in combination of room-and-pillar and sublevel caving technologies: (a) $C_c = 0.5$; (b) $C_c = 0.8$; ●—probable damage zones.

**Figure 2.** Prediction of post-limit deformation zones in room-and-pillar mining with periodic extraction of ore reserves from pillar and roof caving: (a) $C_c = 0.5$; (b) $C_c = 0.8$. 
Figure 3. Distribution of minor principal stresses (tensile stress zones).

The outcome of the studies [5] is given in brief below.

The discussed combination geotechnologies with room-and-pillar and caving in the conditions of the gravity model of a geomedium have the limit application depth not deeper than 1000 m in good and fair quality rock mass. Below the depth of 1000 m, these mining systems are only applicable after obligatory relaxation of rock mass from high stresses.

The comparative estimation undertaken shows good consistency between the calculated and actual data (in terms of Konrad mine in Germany). According to the available information, the mine transited from the classical room-and-pillar to the combination of this method with caving and performed safely at the depth of 1000 m.

The prediction estimate of application depths for the sublevel caving method satisfactorily agrees with the actual data from operating mine, namely:
— mines Artem and Irtysh, Easter Kazakhstan—geostatic stress state, $H = 800$ m (no observable changes in rocks);
— mines Creighton, Sudbury, Canada—tectonic and geostatic stress states, $H = 1300–1800$ m (mining in stable and undamaged areas);
— mine Lucky Friday, USA—gravity stress state, $H = 1710$ m (local application);
— mine Kiruna, Sweden—tectonic stress state, $H = 1300$ m (applied without limitation and observable changes in rock mass);
— Mine Nikolaevsky, Vostok-2 deposit, Russian Far East—tectonic stress state, $H = 900$ m (local application);
— Lenin mine, Krivbass, Russia—gravity stress state, $H$ below 1000 m (satisfactory correlation with the undertaken research findings in terms of combination of systems with caving and backfilling).
Conclusion
Selection and validation of mining systems for deep ore bodies should be based on the prediction of type and value of rock mass stresses at the stage of mine design and planning. The analysis of geological conditions performed by the authors on the database on 90 ore deposits in Russia and in the world has shown that the existing geological structure of ore deposits correlates with the definite type of stress state of enclosing rock mass with regard to the ore occurrence depth.

References
[1] Neverov SA 2012 Types of orebodies on the basis of the occurrence depth and stress state. Part I: Modern concept of the stress state versus depth J. Min. Sci. Vol 48 No 2 pp 249–259
[2] Neverov SA 2012 Types of orebodies on the basis of the occurrence depth and stress state. Part II: Orebody tectonotypes and geomedium models J. Min. Sci. Vol 48 No 3 pp 421–428
[3] Tapsiev AP, Freidin AM, Uskov VA, Filippov PA, Neverov AA and Neverov SA 2014 Resource-saving geotechnolgies for thick gently dipping complex ore deposits in the Norilsk Region J. Min. Sci. Vol 50 No 5 pp 904–913
[4] Freidin AM, Neverov SA et al 2016 Geomechanical assessment of geotechnology at a project stage of underground ore mining Gorny Zh. DOI: 10.17580/gzh.2016.02.08
[5] Neverov AA, Vasichev SYu and Neverov SA 2013 Experience of gently dipping orebody mining and basic trends in development of the promising mining systems Proc. All-Russian Conf. Miners’ Offspring–2013 Novosibirsk: IGD SO RAN (in Russian)