Substantiation of artificial composite-structure roof construction in top-down cut-and-fill stoping

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Abstract. It has been found efficient and safe to use top-down cut-and-fill stoping with saving of the artificial backfill cost and material through the use of a solid nonuniform material composed of two components (layers). It is shown that the artificial roof can be advanced after a stope without essential change in the stope condition as compared with the classical top-down slice method, which provides higher safety of mining.

Majority of mines in Norilsk ore province use different versions of top-down cut-and-fill method. Such geotechnologies are generally applied in the conditions of difficult ground, complicated geomechanics and great depths. Alongside key advantages in terms of enhanced safety and minimized ore loss and dilution as well as fully mechanized preparation and stoping, these technologies have some shortcomings such as high material and labor cost of backfilling.

A trend in expanding the application field of the top-down cut-and-fill methods in medium quality ore is an attempt to reduce material and labor inputs in stoping and backfilling operations.

This research is focused on the efficiency of top-down cut-and-fill with the formation of an artificial reinforced layer of increased strength in the bottom of backfill.

The proposed engineering solution consists in caving of high-strong backfill at the above-lying level subsequent to the transition to the lower-lying level and formation of a new artificial composite-structure roof for the lower-lying level by means of mixing the caved backfill and concrete mix with the improved characteristics. This approach ensures reduction in inputs of basic materials used to prepare backfill (by 34%) and, accordingly, saves backfilling expenditures.

The idea of the proposed engineering solution lies in the safe horizontal cutting of ore under the protection of artificial composite roof made by blasting and caving of the above-lying backfilled layer and further impregnation of the caved heap with cement binder. The diagrams of the variants of top-down cut-and-fill are shown in Figure 1.

The geomechanical evaluation of the proposed method involved modeling and computation of stress state in ore body and backfill with the assessment of their stability in the finite element-based solution of 3D problem of elasticity 1–3].

According to the lithology of Talnakh–Oktyabrsky deposit, ore bodies and enclosing rock mass were simulated by hard high-modulus geological materials; the table 1 below describes the physical properties of the simulation materials. The problems assumed that backfill bears a certain load and has cohesion with ore and rocks. Based on that, backfill was modeled by a low-modulus elastic material (table 1) which ensured continuous fill of mined-out void. The mechanical behavior of the reinforced highly strong cemented backfill was determined in terms of the reduced modulus of elasticity.
Figure 1. Top-down cut-and-fill (a) with the artificial composite roof and (b) with the formation of artificial backfill roof of different strength: 1—layers; 2—artificial roof under protective cover; 3—backfill; 4—mined-out void; 5—load-bearing composite structure layer; 6—above-lying layer caving for impregnation with the cemented binding mix; 7—current high-strength reinforced backfill layer.

Numerical estimation was carried out for standard conditions of a persistent ore body with a thickness of 36 m at a depth \( H \) of 1000 and 1600 m.

Regarding grades of strength, cemented backfill is presented by mix M30 intended for backfilling in the main layers and mix M100 for making the load-bearing reinforced and composite backfills.

Table 1. Physical properties of ore, host rocks and backfill

| Description                      | Young’s modulus, MPa | Poisson’s ratio | Density, kg/m\(^3\) | Cohesion \(C\), MPa | Internal friction angle \(\varphi\), deg |
|----------------------------------|----------------------|-----------------|----------------------|---------------------|--------------------------------------|
| Host rock mass                   | 60000                | 0.25            | 4000                 | 15                  | 35                                   |
| Ore body                         | 50000                | 0.22            | 2700                 | 18                  | 35                                   |
| Main layer backfill              | 1500                 | 0.3             | 1800                 | 1.2                 | 25                                   |
| Composite structure backfill     | 2800                 | 0.3             | 2000                 | 1.7                 | 25                                   |
| Load-bearing reinforced backfill | 3500                 | 0.3             | 2200                 | 2.0                 | 25                                   |

Figures 2–4 allow comparing the numerical modeling results on stress state of ore, enclosing rock mass and backfill and stability of structural elements of the top-down cut-and-fill variants.
Figure 2. Distribution of minor principal stresses in the top-down cut-and-fill with the artificial composite roof and under different-strength reinforced backfill at the depths of (a) 1000 m and (b) 1600 m.

Figure 3. Distribution of major principal stresses in the top-down cut-and-fill with the artificial composite roof and under different-strength reinforced backfill at the depths of (a) 1000 m and (b) 1600 m.
Figure 4. Prediction of probable collapse zones in the structural elements of the top-down cut-and-fill with the artificial composite roof and under different-strength reinforced backfill at the depths of (a) 1000 m and (b) 1600 m.

The results of the calculated stress state for the elements of the variant with the artificial composite structure roof in Figure 2 are indicative of tensile stresses in sidewalls and in roof irrespective of the depth of mining. In the top-down cut-and-fill with the formation of a different-strength backfill, no zones of tensile stresses are observed.

The change in the major compressive stresses in the discussed variants of the cut-and-fill method is reflective of the influence exerted by the backfill structure and the depth of mining on the stress state of the backfill, ore and rock mass (Figure 3).

At the depth of 1000 m, no hazardous concentration of the compressive stress is observed in ore body and enclosing rock mass. In the backfill, at the edges of cutting zone, maximum compressive stresses reach 14–16 MPa, which is much higher than the compression strength of backfill. On the other hand, the backfill will experience triaxial compression, which will favorably contribute to its strength.

The increased in the mining depth from 1000 to 1600 m entails higher major compression in ore body and rock mass by 1.5–1.7 times. The most adverse conditions are in the backfill at the edges of cutting zone, where the concentration zones of compression up to 20–25 MPa arise. In the backfill compressive stresses vary from 6.0–9.0 MPa in the center to 12–14 MPa at the edges of cutting zones. At the edges of the roof made of an artificial composite-structure layer as well as in the reinforced backfill, concentration of maximum compressive stresses higher than 25 MPa is observed.

The increased concentration of major tensile stresses $\tau_{\text{max}}$ in the ore body, rock mass and backfill is traced in the same zones as the major compression. Thus, stability of ore, rocks and backfill in the discussed process charts of the top-down cut-and-fill method will be governed by the increased compressive and tensile stresses.

Based on the estimates of the stress state in the structural elements of the top-down cut-and-fill system, their stability was assessed using the Mohr–Coulomb criterion [4–5]. The results are depicted as the critical zones of probable failure.
Figure 4 shows the pictures of instability zones (black-colored) in ore body, rock mass and backfill for the variants of the composite roof and the load-bearing reinforced backfill at the depths of 1000 and 1600 m. It has been found that given the assumed physical properties of the model media, the areas most susceptible to probable failure in the structural elements of the top-down cut-and-fill method are the walls of the cutting layer from the side of the backfill and the corner zones of the composite-structure roof and the load-bearing reinforced backfill from the side of the ore body. The roof in the cutting layer remains stable owing to the higher rigidity and strength of the composite structure and reinforce backfill. As mining transfers to deeper level of 1600 m, the zones of instability and probable failure expand.

Thus, by the condition of safety, the process chart of the top-down cut-and-fill variant with the artificial roof of composite structure backfill is equal to the classical scenario of different-strength backfilling and can efficiently be used in deep-level mining of gently dipping ore strata. As against the classical variant of artificial roof formation, the proposed engineering solution is advantageous for the ability to ensure the desired integrity and continuity of the load-bearing backfill layer owing to elimination of multi-stage operation.

The scaled-up feasibility study of the top-down cut-and-fill variant with the artificial composite-structure roof as against the classical scenario has shown:

—reduction in material and labor cost of making load-bearing highly strong backfill layer more than by 2 times;
—essential shortage of time of backfilling;
—increased productivity by 15–20%;
—possible saving of backfilling cost by 20–25%.

**Conclusion**

The authors have evaluated and compared the variant of the top-down cut-and-fill method with the formation of an artificial composite-structure roof and the classical variant with the formation of backfill made of different strength mixes. At the level of project solutions, the efficiency of the proposed approach has been proved in terms of copper ore mining at Oktyabrsky deposit.

**References**

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