Cut-and-fill stoping by vertical blocks in Internatsionalny mine

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Abstract. The paper describes design and geomechanical assessment of cut-and-fill system of stoping by vertical blocks under protection of artificial roof, with breakage and cemented backfill in the conditions of limited area of Internatsionalnaya kimberlite pipe. It has been found that safe stoping is ensured if the pillar between vertical blocks has the double width of a block.

1. Introduction
Deeper level mining features considerable natural, technological and economic complications. Modern mines use technologies based on the use of self-propelling machines and automated control over basic and auxiliary processes. In this connection, industrial highly mechanized geotechnologies enjoy increasingly extensive development and improvement.

For mining conditions of Internatsionalnaya kimberlite pipe currently developed at a depth below 1300 m, it is proposed to use the system of cut-and-fill stoping with drilling-and-blasting in high vertical blocks—CFVB (Figure 1). The application of this technology is conditioned by the extremely low rate of ore production and by the huge amount of development and face-entry drivage in the framework of the actually used top-down slicing with shearing and backfilling.

2. Features of the applied mining system
The feature of CFVB as against the conventional cut-and-fill stoping is considerable reduction of horizontal dimensions of stoping blocks (10×10, 12×12, 15×15 m) and, consequently, smaller exposed areas both in ore and backfill. The latter, particularly at great depths and under highly variable quality of rock mass, contributes to higher structural stability and safety of mining.

The system of mining with CFVB is as follows. Within the limits of a sublevel, vertical blocks VB are cut by drilling cross-cuts in the roof and haulage cuts (18–25 m) in the floor; the blocks have horizontal dimension 5×15 m and height of 20 m. Drilling cross-cuts and haulage cuts are made from the footwall drifts along the boundary of the ore body VBs are caved. In order to increase productivity and improve safety of mining, between vertical blocks under caving and backfill, ore pillars having sizes equal to one or two VB are left. Depending on efficiency of caving and backfilling, as well as on geomechanical behavior of rock mass, the sequence of stoping by VB may be such as illustrated in Figure 2. The stoping sequence can be varied with much experience gained in practicing this system of mining.
Figure 1. Cut-and-fill stoping by vertical blocks with cemented backfill (CFVB): 1—spiral decline; 2—access to haulage horizon; 3—access to drilling horizon; 4—haulage footwall drift (for haulage horizon); 5—drilling footwall drift (for drilling horizon); 6—haulage cross cut (cut 18–25 m); 7—drilling cross-cut; 8—extracted vertical blocks; 9—filled blocks (backfill); 10—initial cut layer; I, II, III etc.—sequence of stoping in vertical blocks.
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Figure 2. Sequence of stoping by vertical blocks in the system CFVB: (a) single pillar between VB in the same row; (b) double pillar between VB in the same row (in the next rows VB are arranged so that to have only corner-to-corner contact); (c) arrangement of VB to exclude formation of a through pillar (i.e. VB to be soon caved and backfilled): I, II, III, etc.—sequence of stoping by VB.

In this technology, an extraction panel 40 m high is separated from the above-adjacent rock mass by a split layer (SL) to serve as an artificial roof for lower lying stoping. The extraction panel 40 m high is divided into sublevels. The height of a sublevel is set subject to quality of rock mass and kimberlite. In accord with the geological information on the quality of ore and enclosing rocks, the height of sublevels is advises to be no more than 20 m.

Sublevels are prepared by driving spiral annular declines to the drilling and haulage horizons. Then, from the declines, along the boundary of the kimberlite pipe, haulage and drilling footwall drifts are made to ensure accesses to mining machines to the haulage and drilling horizons, respectively, as well as for ventilation of stopes. Drilling cross-cuts under protection of the split layer (the roof of a drilling cross-cut is the artificial fill mass) can be cut to the fill width (length) of the pipe, or as VB are being extracted. Before breakage, in each VB, sot raises are made and enlarged into a cutoff.

Stoping is carried out by layered (or bulk) breakage of ore in downward holes drilled from drilling cross-cuts. Broken ore is drawn from a haulage cut driven on the block floor. As breakage is completed, the floor is cleaned up using a remote-control load–haul–dumper. The machine operates immediately on the floor of the mined-out stope where people are prohibited to enter.

After cleaning-up of the floor, apron walls are constructed and the area between them is backfilled. Stoping in the next VB is only allowed when the backfill reaches the rated strength such that is exposure by a required size stope is safe. For sustainable high output of kimberlite, no less than two extraction panels should be operated.

Sequence of VB breakage is selected with regard to required strength of backfill for stoping in the neighbor blocks and with a view to eliminating equipment stoppage in wait for the backfill to reach the required strength.

The main advantages of this mining system are:
—extraction of diamond ore at permissible loss;
—minimum amount of development and face-entry drivage as against downward slicing;
—high productivity;
—lower labor content as compared with slicing;
—required safety of surface and underground structures as well as the nature from impact of underground mining operations;
—safe labor conditions.

Safe parameters of structural elements in the geotechnology CFVB are determined using 3D FEM-based modeling of stress state of rocks [1–4]. The estimation criterion is the Mohr–Coulomb strength [5–7].

Figure 3 depicts potential damage zones in ore body, rock mass and backfill (colored black) at various stages of stoping (Fig. 1) with single pillar between VB in the same row (Figure 2a). It follows
from the analysis of these results, subject to the points of the critical deformation zones in enclosing rocks, ore and backfill, the main loads casing rock failure are major compressive and shearing stresses [8, 9].

Figure 3. Probable damage zones by the Mohr–Coulomb criterion in the structural elements of CFVB technology with single pillars between VB: (a) section C–C in Figure 1; (b) in plan of the haulage horizon in the upper extraction panel (Figure 1). The legend is as in Figure 1.

The structural elements of the mining system, where instability of rocks, kimberlite and backfill is anticipated include [10–13]:

—VB–drive corner zones composed both ore and backfill;

—sidewalls, roof and floor of footwall drilling and haulage drifts. Probable failure zones are local and no more than 1.0 m in size. The situation is the same around the accesses to the haulage and drilling horizons I the area of 10-m damage zone of kimberlite and rocks contact. With distance from the accesses, conditions get much better (almost no damage zones are observed);

—sidewalls, roof and floor of the haulage cross-cut. Probable failure zones vary from 0.5 to 1.5 m in size. The same situation is observed in the sidewalls and floor of the drilling cross-cut. However, in the artificial fill roof of the latter, the probable failure zones have sizes from 0.5 to 2.0 m, which implies that the strength of the cemented backfill should be increased;

—intersections. Damage zones at intersections of various drives are: 2.0–3.0 m in the sidewalls and 1.5–2.0 m in the roof;

—sidewalls, roof and floor of mined-out VB. If the sidewalls are composed of kimberlite and adjacent rocks, at the top and bottom of VB, probable failure zones vary from 1 to 2 m in size, while in the center of VB they may range from 5 m up to a plastic hinge (damage zones of neighbor VB almost touch and even intercross). The situation is the same in VB with sidewalls composed of backfill. Sidewalls beyond mutual influence of VB are in more favorable conditions (VB sidewalls opposite to kimberlite pillars and fills), which is of the methods for safe arrangement of vertical blocks across the area of kimberlite pipe;
in the roof and floor of VB, zones of instability of backfill and kimberlite, respectively, are local and vary from 1.5 to 2.0 m in size.

An alternative of safe CFVB is the change of stoping sequence (safe arrangement of VB across the area of the pipe) so that the width of pillars between blocks equals two widths of a block (Figure 2b).

Figure 4 shows instability zones in structural elements of CFVB technology with double pillar between VB in the same row. From generalizations of these results in comparison with the single width pillar between blocks, some conclusions have been drawn.

On the whole, the locations and sizes of concentrations zones of major compressive and shear stress are the same. A slight difference is observed in the stress distribution between vertical blocks under backfill and under breakage. The situation is analogous when studying probable failure zones in rocks, kimberlite and backfill: the sizes and locations are identical. A significant difference of the variant with the double pillar between blocks is the absence of wide (intercross) zones of probable failure in kimberlite and backfill between inter-influencing VB at the stages of backfill and mining, which is an evidence of higher safety of this variant. The local areas of backfill damage in the roof of drives and VB is reflective of insufficient strength of backfill at the given depth (1300 m).

Figure 4. Probable zones of failure by the Mohr–Coulomb criterion in the structural elements of CFVB technology with the double width pillars between blocks (similarly to Stage 7 in Figure 3): (a) section C–C in Figure 1; (b) in plan of the haulage horizon of the upper extraction panel; (c) in plan of the center area of the upper extraction panel.

Thus, the main safety constraints of CFVB technology are: relative small horizontal dimension of the kimberlite pipe, which is the critical limitation for safer arrangement of VB in the ore body and, consequently, safer sequence of stoping; poor quality of kimberlite ore and insufficient strength of cemented backfill.

3. Conclusions

According to the performed calculations, the variant of CFVB with the double-width pillar between the vertical blocks in one row ensures the safest mining conditions are the given structural parameters and sequence of stoping. The large zones of instability in rocks and backfill in case of the single pillars impose constraint on the application of this technology at great depths. Therefore, safe application of cut-and-fill stoping by vertical blocks requires obligatory approval by full-scale trial and the increase in the strength of cemented backfill up to 5–6 MPa.

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