

# Geomechanical analysis of mining system by cut and fill at deep levels of Internatsionalnaya pipe

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**Abstract.** The authors propose and comprehensively substantiate a mining system by cut and fill for Internatsionalnaya pipe. It is found that application of cut and fill at deep level is limited due to low strength of kimberlite and enclosing rock contact and low safety of mining owing to insufficient area of the pipe beneath the level of -950 m.

## 1. Introduction

Currently, in view of depletion of the exposed and prepared reserves, Internatsionalny Mine management is highly concerned with the safe and efficient mining at super deep levels -820 m/-1250 m (depth from the forum surface 1200–1650 m).

The feature of mining at Internatsionalnaya pipe, considering depth of occurrence and value of kimberlite ore, is the use of backfilling as the method to control stress state of rocks and extraction factor. Phasing of cutting and filling processes seems to be a sound approach to ground control [1–3].

The mine uses underhand cut and fill. Ore is recovered in slices with rooms and pillars in two or three stages. This combination mining system is the best from the viewpoint of safety and completeness of extraction. This system complies with the whole set of geological and geomechanical conditions of the deposit. On the other hand, low performance of stoping and considerable labor content of development and facer-entry drivage required new approaches to mineral mining. It was decided to analyze variants of cut and fill in combination with room-and-pillar stoping at deep levels of the mine.

This paper presents the data of 3D finite element modeling of state of rock mass, which illustrate the effect of geological, physical and geotechnical factors on the stability of structural elements in the system of mining with room-and-pillar and cemented backfill [4].

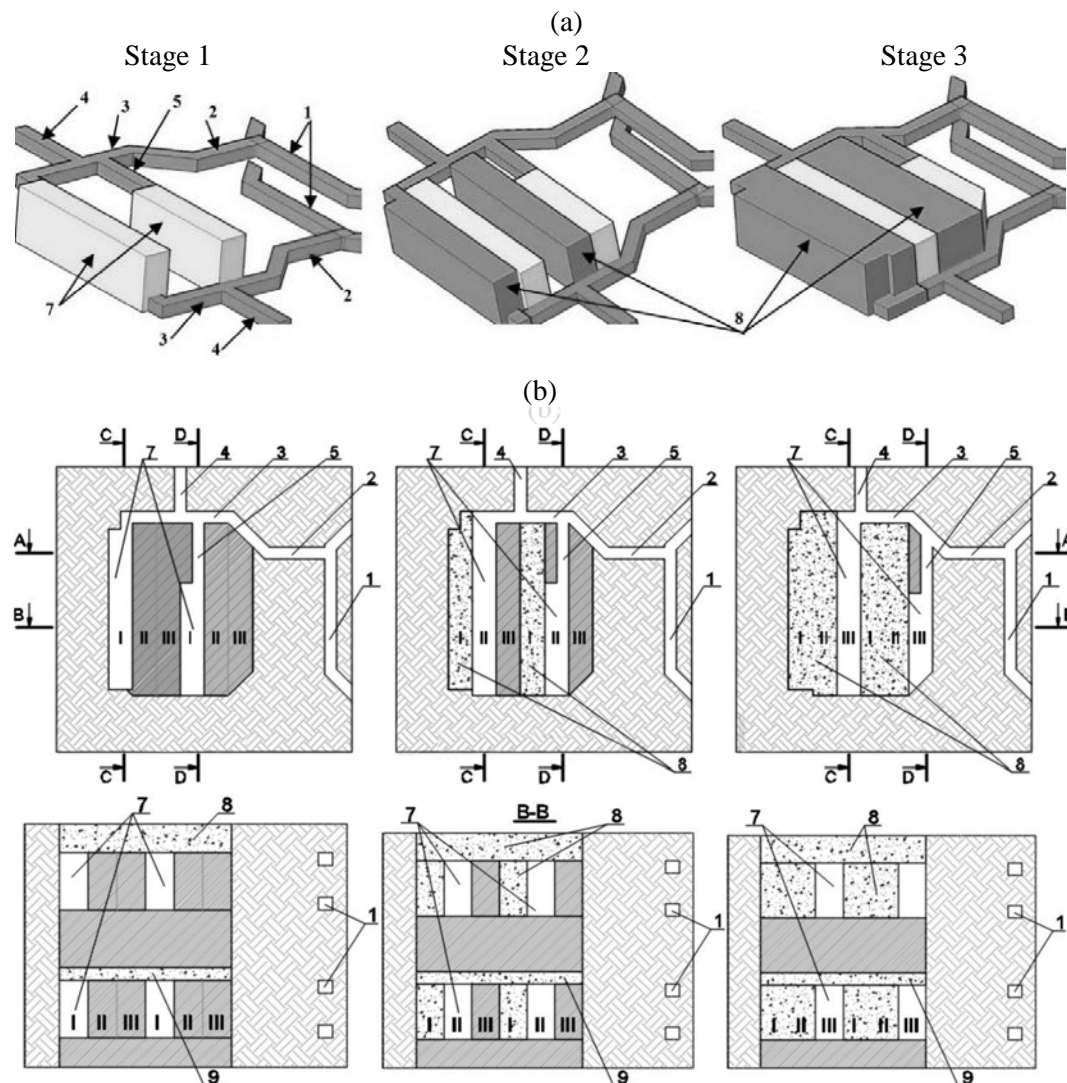
## 2. Mining system

Figure 1 shows the currently applied system of room-and-pillar mining with backfill (RPB).

An extraction block is divided into sublevels by mine roadways of drilling and haulage horizons. The sublevels are mined using room-and-pillar in three stage mining sequence. Stoping includes ore breakage by top-down holes drilled from the drilling crosscut, transport of broken ore from the haulage crosscut and cemented backfill of mined-out area. Adjacent rooms are permitted for extraction when backfill reaches the standard strength.



Considering the depth of mining at the levels -820 m/-1250 m and the presence of backfilled roof, the basic and most important criterion of influence on structural parameters of a RPB variant is the stability and safety of exposed walls in rooms for the preset period.

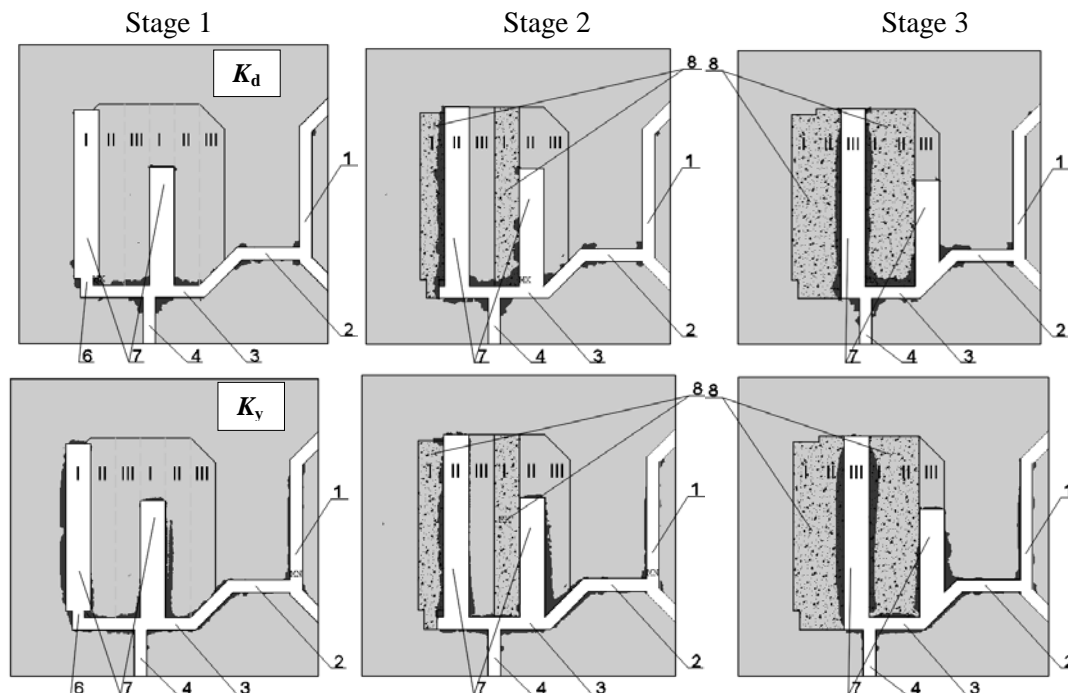


**Figure 1.** RPB mining system: (a) volume representation of a sublevel; (b) lateral and vertical sections; 1—spiral ramp; 2—roadways to drilling and haulage horizons; 3—rock gangway (for drilling horizon)/haulage drift (for haulage horizon); 4—air crosscut; 5—drilling crosscut; 6—haulage crosscut (cross-bearing 3–4 m); 7—mined-out rooms; 8—backfilled rooms; 9—underhand cutting layer; I—III—sequence of room mining.

### 3. Rock mass stability

Stability of structural elements in the room-and-pillar mine using backfill was estimated based on the data of stress state obtained in 3D numerical modeling [5–8].

The calculation results are depicted as the zones of probable failure of rock mass surrounding structural elements of the geotechnology (Figures 2–4) by the strength criteria by Mohr–Coulomb and Drucker–Prager [9, 10].



**Figure 2.** Anticipated zones of rock mass instability by Drucker–Prager and Mohr–Coulomb criteria  $K_d$  and  $K_y$ , respectively, in the structural elements of RPB mine of the haulage horizon in the upper extraction block (plan view, legend is in Figure 1).

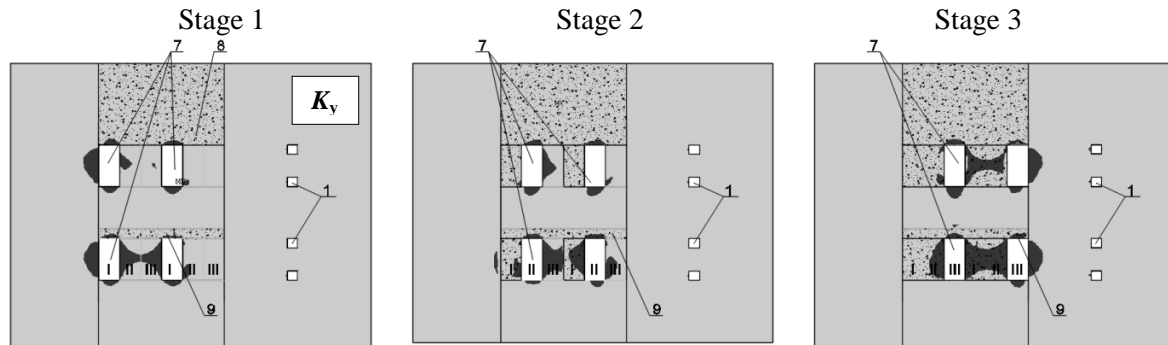
An extraction section is divided into upper and lower extraction blocks by an underhand cutting layer. Each block is divided into sublevels that are developed by rooms of Stages 1, 2 and 3. Between rooms of Stage 1, a temporary ore pillar 20 m long is left (at Stage 1), and hybrid ore-and-backfill pillar (at Stage 2) and backfill pillar (at Stage 3) composed of 2 rooms is established. The height of a sublevel (room) is 20 m, the rooms are 10 m wide and 65–72 m long. The standard strength of the backfill is assumed 3 MPa for the basic layer and 4–4.5 MPa for the load-bearing layer. At a distance of 10 m from the ore and enclosing rock mass contact, a zone of increased damage is detected. The damage ratio for the ore and enclosing rock mass, is assumed as high— $K_c = 0.25$ .

According to the calculation results, the structural elements of the RPB mine, which are the most prone to suffer from instability of enclosing rock mass, ore and backfill include (Figures 2 and 3):

- walls of roadways to the drilling and haulage horizons. In the roof of the roadways, a local damage zone is only observed in the ore and enclosing rock mass contact zone of 10 m;
- walls, roof and floor of rock gangways at the ore and enclosing rock mass contact. The size of the probable failure zones change from 2–2.5 m on the ore contact to 1.8 m on the enclosing rock mass side. The roof of the rock gangways of the haulage horizon and the floor of the rock gangways of the drilling horizon within the limits of a mined-out room (10 m) is inside the zone of anticipated avalanche failure due to room mining (end of the room);
- junctures of mine workings: failure zones are 2–3 m in the walls and 1.5–2 m in the roof;
- walls of the spiral ramp, as well as the walls and floor of the drilling crosscuts. In the backfilled roof of the drilling crosscut, the size of the failure zones varies from 0.2–0.5 m by the Mohr–Coulomb criterion to 1.5 m by the Drucker–Prager criterion;
- walls, roof and floor of the mined-out rooms. At Stage 1, in the lower block, in the 20-m temporary pillar, a wide zone of instability is observed. This situation is caused by the insufficient relief of the ore body by the underhand cutting layer 4.5 m high. At Stage 2, in the hybrid ore-and-backfill pillar, zones of instability are local and adjoin the ore side of the pillar in the upper block and are very wide

in the lower block. At the final Stage 3, the anticipated failure zones of considerable size appear around the rooms.

– in the roof and floor of the rooms, the instability zones in the backfill and in the ore are local.



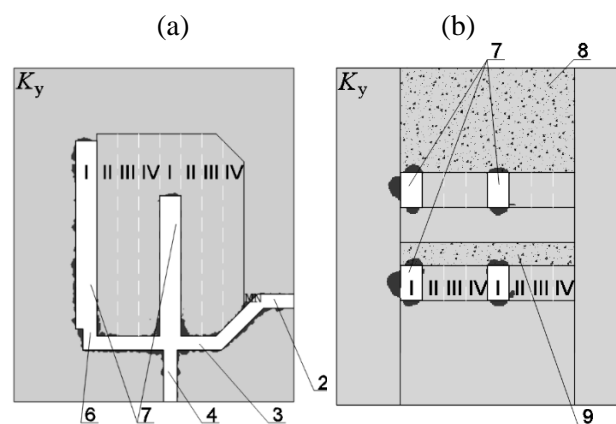
**Figure 3.** Anticipated instability zones by the Mohr–Coulomb criterion  $K_y$  in the structural elements of RPB mine in section B–B as per Figure 1.

Thus, in accordance with the outcome of the geomechanical evaluation of room-and-pillar mining using backfill (RPB) with the set room design as width×length×height as 10×70×20 m and the three-stage sequence of mining, it is in no way recommended to use this variant in extraction of kimberlite reserves from Internatsionalnaya pipe below the level of -820 m.

The main constraint of this RPB variant application is the considerable size of exposed surfaces in a very damaged rock mass. The main condition of RPB safety is the guaranteed stability of exposed surfaces in rooms; for this reason, this variant is only applicable in stable ore and rock mass after obligatory preliminary full-scale testing. Given the ground conditions of Internatsionalnaya pipe, another variant of RPB with the height of a sublevel (room) of 12 m, width of a room of 7.5 m and with the four-stage sequence was analyzed in terms of safety (Figure 4).

In the conditions of Internatsionalnaya pipe, mining in four stages is only possible when rooms are not wider than 6.0–7.5 m due to the limited size of the pipe. For this reason, the four-stage RPB variant is only applicable down to the depth of -950 m.

Figure 4 demonstrates probable areas of instability of rock mass for RPB variant of four-stage mining of rooms. The anticipated damage zones in the structural elements of RPB mine variants with 3 stage and 4 stage mining were subjected to the comparative analysis.



**Figure 4.** Potential damage zones by the Mohr–Coulomb criterion  $K_y$  in the structural elements of 4-stage RPB mine: (a) lateral section of the haulage horizon in the upper extraction block; (b) vertical section along the center of the pipe.

The decrease in the width and height of the room, 4-stage extraction and the thickness of the underhand cutting layer of 8 m between the upper and lower extraction blocks has allowed considerable enhancement of stability of kimberlite-composed walls in the rooms. At the same time, in the backfilled roof of the rooms and access workings, the situation is the same as in the variant discussed above in this paper. The reason is insufficient strength of the backfill for the application at the depth of 1250–1300 m.

As in the 3-stage RPB variant, the most unstable areas are the ore and enclosing rock mass contact and the junctions of drilling (haulage) crosscuts with rock gangways to be obligatory reinforced with the proper support.

On the whole, the geomechanical behavior of rock mass in the variant of 4-stage RPB mine is more favorable than in the variant of 3-stage RPB, and areas of potential damage and failure of rocks are considerably reduced. On the other and, in view of the smaller area of the pipe below the level -1000 m, the four-stage RPB mining will be complicated by longer downtime of mining machinery and will fail to offer required efficiency of stoping.

Accordingly, from evidence of the accomplished geomechanical analysis, 4-stage RPB variant with the discussed design parameters is applicable at the depth not more than 1300 m (mine levels -820 m/-950 m) after obligatory preliminary trial and with due regard to the exclusive standard imposed on backfill strength to be increased up to 5–6 MPa.

#### 4. Conclusions

1. It has been found that the application of combination of cut and fill with room-and-pillar mining at deep level of Internatsionalnaya pipe is limited by the damage ration of rock mass, geotechnology design parameters, consequence of room mining, insufficient standard strength of cemented backfill and small area of the pipe.

2. In view of instability of exposed room surfaces given the current damage ratio of rock mass and due insufficient standard strength of backfill, unsafe sequence of room mining (phasing), limited area of the pipe at the discussed depths and inefficiency of stoping due to long downtime of mining machines, the 3-stage variant of room-and-pillar mining using backfill is not recommended for application.

3. The variant of 4-stage room-and-pillar mining using backfill satisfies, on the whole, safety requirements at the depth not more than 1300 m subject to obligatory preliminary trial and given the increased standard strength of cemented backfill.

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