Soil improvement and mixture preparation in construction of protective cushion

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Abstract. The authors discuss soil improvement and mixture preparation for the construction of a protective cushion on the bottom of a mined-out kimberlite surface mine of ALROSA in order to extract ore reserves under the pit bottom using the mining systems with caving. The paper briefly describes overburden dumps at kimberlite surface mines, lists the main requirements for the protective cushion material, and presents the process flow chart and the machine chain for the production of the wanted mixture. The proposed technology makes it possible to prepare the mixture with the required composition and to construct the protective cushion up to enhanced safety of underground mineral mining.

1. Introduction
Having reached the critical depth in mining at the top of the kimberlite pipes in Yakutia, ALROSA mines are forced to change to the underground method of block caving or sublevel caving by analogy with advanced foreign mines. The latter transit from open pit to underground mining with construction of a protective cushion as a thick layer of barren rocks under an open pit bottom, in order to eliminate the adverse effect on underground ore drainage and haulage horizons. Construction of such protective cushion needs great volumes of dumped overburden of various material constitution and grain size composition, which predetermines obligatory soil improvement activities. Selection produces a uniform rock composition, which ensures the multifunction operation of the protective cushion for a long time (to 30 years), i.e. for the whole service life of a mine [1, 2].

A protective cushion as the method of ground control in disturbed rock mass and in the stoping void filled with caved rocks should protect the underground mine from shock loading due to air blasts and uncontrollable caving (both enclosing rocks and sidewalls) over vast areas, and should isolate the underground space from cold outdoor air in winter to prevent from destabilization of ventilation and temperature regimes, as well from inflow of any water to the mined-out pit. Moreover, the protective cushion should be in the condition of continuous year-round mobility to ensure uniform subsidence as mining operations are advanced to the deeper levels, without formation of bridges and domes.

2. Soil improvement and protective cushion preparation
The protective cushion can be constructed by three methods: by caving of pit walls by large-scale blasting; placement of overburden from the lower benches on the pit bottom; placement of overburden from surface dump on the pit bottom. The latter approach is assumed as the most acceptable method as
the first two approaches eliminate soil improvement and disable production of a protective cushion of the wanted grain size composition.

As a rule, kimberlite overburden rocks are extremely nonuniform in terms of any characteristic and, for this reason, are inapplicable in construction of a long-term service structure as a protective cushion, due to many weathered pieces, from boulds to chips. According to [1], the highest strength rocks are dolomite, as well as dolomitic and cavernous limestone. It is necessary to be guided by this information when choosing dumps for soil improvement tests in the infrastructure area of a mining and processing plant. It is highly important that the chosen dumps contain the minimum content of marl, clay and silt.

Fine grains, oftentimes with jellous nests promote consolidation of rocks inside a protective cushion, which reduces its mobility and permeability and, finally, can induce accidents [2]. Furthermore, the high-quality mixture production requires a certain grain composition of geomaterials, at least of three sizes (-150; -50; -16 mm). These values are preliminary and need additional field testing [3].

The protective cushion geomaterial should meet some standards: soaking not allowed; freeze resistance $F \geq 50$; density $\approx 2.5$ t/m$^3$; porosity $\leq 6\%$; degree of salinity $\approx 0.15–0.2\%$; compression strength $\geq 10$ MPa.

The grain size composition of the protective cushion rock mixture (stones, break stone and landwaste) to include these sizes: maximum stones are 150 mm; average break stone is 50 mm; average landwaste size is 16 mm.

The wanted physicochemical characteristics of the protective cushion rock mixture are: porosity $\geq 20\%$; permeability $\geq 0.5$ m/day; degree of salinity $\approx 0.15–0.2\%$; content of chips (clay and silt) $\leq 5\%$.

Soil improvement in terms of dump rocks is aimed at production of grainular and deslimed geomaterial of three sizes (150, 60 and 16 mm), of low content of cubic shapes, disintegration, fine washing-off of clay and silt particles and dewatering of the product, as well as mixing and blending toward preparation of a uniform mixture of the required composition.

Within a mine lease, it is necessary to undertake special-purpose engineering survey to upgrade such parameters the characteristics of the degraded landscape, location of process water bodies and pits, review of earlier surveyes, R&D paperwork and geological reports. A special emphasis is laid on identification of the preferable dumps, their position, grain size composition and mineralogy, structure, rate of decay, temperature conditions and seasonal freezing and thawing depth. Moreover, it is necessary to select a site for the soil improvement equipment, water supply, settling ponds, temporal dumps (open heaps), etc.

An important stage of the survey is laboratory-scale and filed testing of physicotechnical properties of geomaterials using certified procedures and standards [1].

From the survey results, a preliminary grain size composition of the protective cushion rock mixture is determined and its conformity with the requirements is proved through pilot testing. The facilities designed and patented by the Institute of Mining of the North, SB RAS [4, 5] provide high-quality conformity testing of the protective cushion mixture in accordance with the procedure described in [3].

Equipment and machines recommended for the soil improvement operations are commonly employed and approved in diamond-bearing ore processing (Almazy Anabara) [6]. Equipment is arranged on the special process site, as a cascade on different elevations, to ensure maximum possible gravity flow of the process material and to reduce rehandling. Auxiliary and haulage machines are wheel loaders, conveyors, dump trucks, breaker-bos and electromagnets to catch metallic particles. The process flow chart of soil improvement and the machine flow sheet are demonstrated in Figure 1 and 2, respectively.

The proposed engineering solutions assume successive execution of operations, in summer, under positive temperature of outdoor air and with sufficient water available.

The soil improvement technology in production of a protective cushion mixture is described below.
Geomaterial is transported from dumps to the process site by dump trucks and is placed to a temporal dump, then wheel loaders carry it to a bin and loaded on a bar screen. The bar screen with a cell 400×400 mm is tilted time to time in order to throw oversizes to a dump for further crushing by breaker-boys and utilization.

![Process flow chart of soil improvement and protective cushion mixture preparation.](image)

The material 400 mm in size is hammer crushed to the size of 150 mm and is sent to a scrubbing and washing drum for disintegration and removal of size 140 mm to a temporal dump (open heap) for natural natural-way dewatering. Then, the material 50 mm in size is deslimed in a classifier and screened into two sizes of 50 (break stone) and 16 mm (landwaste) which are then dewatered in temporal dumps (open heaps).

Waste of each stage is sent to a slime pit. The dewatered material (stones, break stone and landwaste) is placed by loaders at a required ratio (determined in field tests), layer by layer to bins (not less than two) for blending and mixing. One bin is always under loading, the other bin is under
unloading. The angles of the bin bottoms are maintained at 2° more than the friction slope of rock flow on the bin bottom. The size of the outlet windows of the bins should be not less than 3–4 largest sizes of particles (≈ 600 mm).

It is an obligatory requirement that the bins are unloaded to dump trucks after full loading and are only filled after complete unloading. Efficient blending and mixing directly depends on the size of the bins where blending and mixing are achieved during layer-by-layer filling and unloading.

![Diagram](image.png)

**Figure 2.** Machine flow sheet for soil improvement and protective cushion mixture preparation: 1—grizzly screen; 2—feeding bin BPK-1000; 3—hammer crusher SM-170V; 4—scrubbing and washing drums SBR-159; 5—transfer unit; 6—classifier IKSN-24; 7—screen GLI-72VCH; 8—blending bin during unloading; 9—blending bin during filling; 10—open heap of coarse geomaterial; 11—open heap of break stone; 12—open heap of landwaste; 13—water line; 14—slime pit; 15—wheel loaders; 16—dump truck; 17—water pump.

The prepared mixture of three sizes of geomaterials is dump-trucked to the mined-out pit and layer-by-layer placed on the pit bottom using earth-moving machines in order to create the protective cushion of the required thickness and minimized compaction.

Correct execution of all operation in accordance with the developed process flow charts results in preparation of the wanted composition and in construction of the protective cushion meeting all requirements, which can ensure safe and well-balance underground mining of ore reserves deeply buried under the pit bottom for many a year.
Finally, implementation of the recommended soil improvement and protective cushion mixture preparation procedures ensures:
—construction of a protective cushion with the required grin size composition on the mined-out pit bottom, as well as the uniform progressive subsidence of the cushion with deeper level mining, without of bridging and doming;
—free flow of any water and melt snow through the protective cushion without generation a manmade pond on the cushion surface;
—all-year-round positive temperature in the protective cushion due to uniform distribution of warm upward mine air flow (heated by air heaters in winter), which prevents adfreezing of conglomerates which can arrest mobility of the cushion in coal seasons.

3. Conclusions
Thus a protective cushion made of a mixture with preliminarily improved properties reliably shelters an operating mine from various dynamic events (rock burst) and from water inrushes, which guarantees safe and well-balanced operation of the mine for many years ahead.

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