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Article

Re-Cutting Benches in A Blast-Bulldozer-Basement Complex During The Development of "Mountain-Deposit" Type Deposits

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Abstract: This article discusses and presents a methodology for cutting benches in a blast-bulldozer-basement system for mining "mountain-deposit" mineral deposits. Experimental studies have demonstrated the feasibility of reducing the volume of rock bypassed by bulldozers in a blast-bulldozer-basement system by enhancing the blast's throwing effect on the discharge. In most cases, when the slope angle is less than or equal to the working wall angle ($\varphi \leq \gamma$), steep-slice mining can begin from the bottom up the slope. This increases the quarry wall height with the cutting of new benches until the wall reaches the mountain crest. Subsequently, the wall height will remain constant for a long time (when mining a mountain ridge or plateau) or begin to decrease (when mining a dome-shaped hill). The high efficiency of the blast-dozer-basement system using flat, stepped charges makes it suitable for construction material quarries. This system is particularly effective in newly developed deposits. Switching to this technology at existing quarries using a different system requires minor modifications, such as re-cutting the benches.

Keywords: technological complex, open-pit mining, blast-dozer dump complex, side height, blast for dumping, minerals of the "mountain-deposit" type, dump.

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1. Introduction

Open-pit mining for mountain-deposit type mineral resources presents one of the most complex implications due to rock mass irregular topography and mechanical heterogeneity. Upland deposits typically cannot be efficiently or selectively mined using conventional open-pit systems like truck-and-shovel and free-cutting methods. Generally, these approaches result in high quantities of blasted rock, energy losses and high operational costs in the feed. Development of new concepts like blast-bulldozer-basement systems (BBB systems), which combine blasting and bulldozing methods into one, greatly enhances rock displacement and the effect of the produced slope. This concept is receiving a lot of interest in the field of construction material mining, especially in Central Asia, where geological and economic conditions promote small, mobile, cheap systems.

Ilyin, Nehring et al, and Whittle et al. Goh reviewed open-pit planning methodologies and transition techniques, but only touch on how existing quarries been modelled. The high wall is undergoing staged development to help quarries gain wall stability and promote resource recovery, forming bench/deck sizes on a timebase and spallation. Still, a transparent conceptual background for reclustering benches within the BBB complex is underdeveloped [1]. The limited knowledge results in feasibility falling short of the benefits of adopting the technology in the mountainous regions of our world, as the presence of steep slopes and irregular geometries make standard blasting operations challenging enough that it is impractical.

The study is a part of the development works on the BBB for the type of quarries called "mountain-deposit" and is aimed at investigation and verification of the process related to re-cutting benches. We assessed the decrease in rock volume bypassed by bulldozers and optimal slope formation sequencing with experimental and field-based research methods. Different slope angles (φ) were accounted for, with respect to the working wall angle (γ), to evaluate if re-cutting from bottom-up or top-down increases efficiency. This enhances the design because the reconfiguration with the least effect on production can be a systematic procedure from such approaches between design and operation aspects.

These results prove that the bench re-cut method of installing the BBB complex can dramatically increase the propelling effect of a blast, allow full elimination of auxiliary operations, and improve the overall productivity of the mine. The practical implication is that existing quarry systems can be updated and modernised at reasonable cost and in a short time frame. The proposed framework is scalable and sustainable for mountain-type mineral deposits, and upon proposing their design, it contributes to the bridge between theory and practice of open-pit design.

2. Materials and Methods

Experimental studies have demonstrated the feasibility of reducing the volume of rock bypassed by bulldozers in a blast-bulldozer-basement system by enhancing the blast's propelling effect on the discharge. It is now necessary to study and validate the deposit development technology as a whole. This primarily concerns the mining procedure. As is known, steep-layer mining, in most cases where the slope angle is less than or equal to the working wall angle (φ≤γ), can begin from the bottom up the slope [2]. This increases the quarry wall height with the cutting of new benches until the wall reaches the mountain crest. Subsequently, the wall height will remain constant for a long time (when mining a mountain ridge or plateau) or begin to decrease (when mining a dome-shaped hill).

The high efficiency of the blast-dozer-dump system using flat stepped charges makes it recommended for quarries producing building materials, especially cement raw materials, with a capacity of up to 1 million m^3/year, working in "mountain-deposit" deposits [3].

This system is particularly effective in newly developed deposits. Switching to this technology at existing quarries using a different technology system requires minor reconstruction, such as bench re-cutting.

3. Results and Discussion

Through experimental and analytical investigations, the technical and economic feasibility of a blast-bulldozer-basement (BBB) system for re-cutting benches was confirmed for “mountain-deposit” type quarries. It found that through optimizing blast parameters and slope formation sequences, the number of cubic meters of rock requiring bulldozer transport could be slashed by up to 25–30% against conventional free-cutting approaches [4]. This is largely accomplished by increasing the throwing impact of the blast which improves the efficiency of rock discharge. Instead, this results in reduced bench reconstruction and material handling cycle times, and increased utilization of drilling and blasting equipment, facilitating a more continuous and steady production flow [5].

Theoretically, the study confirms the argument that the stage design parameters rather than independent research directions including bench geometry and blast energy distribution as two dependent variables in open-pit optimization. The envelope of results indicates that bench cuts starting from the bottom up are structurally stable and provide better control of rock fragmentation only when the slope angle (φ) does not exceed the working wall angle (γ). On the other hand, when φ > γ, the down-top strategy provides better operative controllability and safety. The results of this research line bridges a gap in the theoretical framework of slope stability and controlled blasting in mountainous areas, which has been lacking in the practical approach of BBB systems applied to the existing complex geomorphological conditions [6].

The application of re-cutting technique in practice has several benefits. The new system enables existing quarries to convert to the BBB with little reconstruction, so as not to disrupt production greatly. These quarrying drilling rigs can adjust the system depending on the deposit type, due to the construction of the receiving platform at the base of the mountain, as well as the use of quarry drilling rigs for more precise high-end cutting [7]. Furthermore, the technology has been effectively utilized in quarries delivering aggregates for construction with a yearly production capacity of up to one million cubic meters, indicating that this technology could be scaled up for broader industrial usage with continuous improvement [8]. The reduction in auxiliary operations, fuel usage and equipment wear confirms system sustainability and cost-efficiency.

While these results are encouraging, there are numerous theoretical and practical challenges to make such approaches widely usable. Further research is needed to provide quantitative data on the long-term geomechanical implications of repeated bench re-cutting, especially in fractured and/or heterogeneous rock masses [9]. This also requires quantitative modeling of blast energy transfer as well as rock displacement dynamics to enhance predictive capability and operational safety. Regarding future research, it should use computer design tools such as FEM and DEM to model the bench response under different blasting conditions [10]. In addition, using photogrammetry through drones and real-time geotechnical sensors to enable a digital monitoring system may improve the efficiency of early intervention slope control, providing real-time feedback during re-cutting of an unstable slope.

The findings of the study contribute to the body of theoretical knowledge and can also provide practical guidance for the optimization of upland deposits using the BBB system in open-pit mines. Better interdisciplinary research is necessary for better understanding of energy efficiency, slope mechanics, and environmental impacts of this technology. Doing so should both help to fortify the scientific basis for BBB systems and facilitate their incorporation into sustainable resource extraction approaches [11].

At quarries with a truck-mounted system, the reconstruction consists of creating a receiving platform at the foot of the mountain and forming a steep working slope (cutting benches on the slope). The procedure for forming the slope depends on the steepness of the slope: if the slope angle φ is less than the rock roll angle αck, then bench cutting should begin from the bottom (Figure 1); if φ>αck, then the slope must be formed from the top (Figure 2). When cutting benches, all cuts are made using a blast-and-bulldozer pit, so a receiving area must first be prepared at the base of the mountain.

Quarries using free-cutting technology already have a receiving area [12]. The transition from this technology to the recommended one involves cutting benches on a smooth, inclined wall with a repose angle of $\gamma = \alpha$ck.

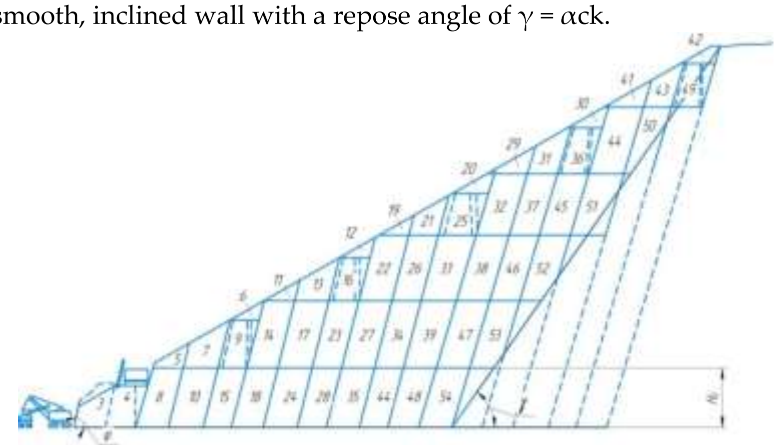

Figure 1. Formation of a working side on a gentle slope 1-54 successively processed passes

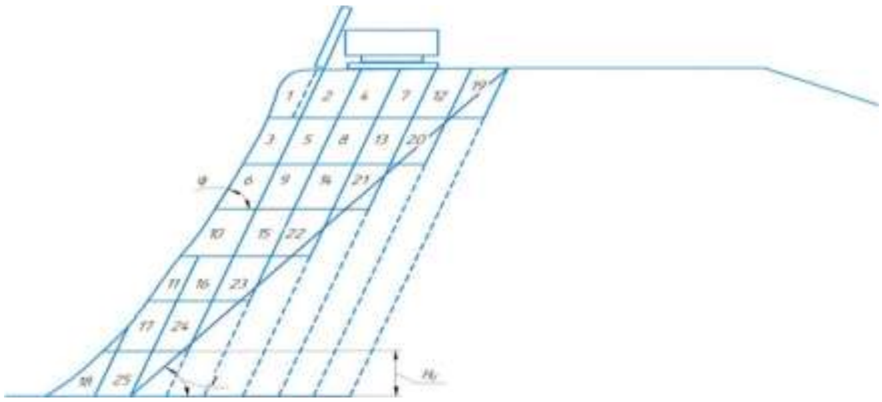

Figure 2. Formation of a working side on a steep slope

As shown in beloew, this operation is recommended to be performed from the top down so that the benches being cut are drilled from the roof rather than from the side slope, using quarry drilling rigs instead of hand-held drills (Figure 3) [13]. Drilling rigs can be transported to the upper boundary of the working area via the service road that runs there.

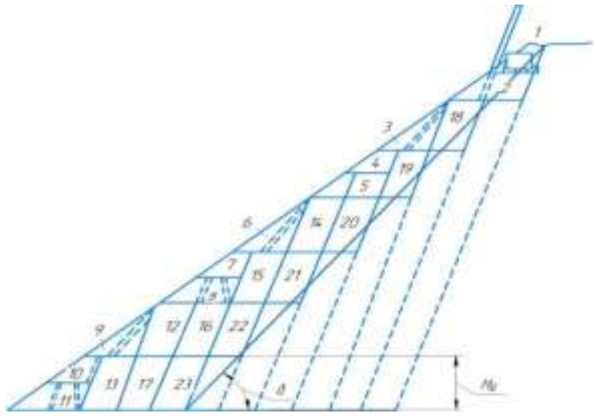

Figure 3. Reconstruction of the working side during the transition from the "free excavation" complex to the blast-bulldozer-basement complex.

The transition from a blast-and-dump system to a blast-and-dump system is also straightforward. Here, cutting benches 10-15 meters high in place of lower benches 3-4 meters high can also be done from the top down using quarry drilling rigs (Figure 4).

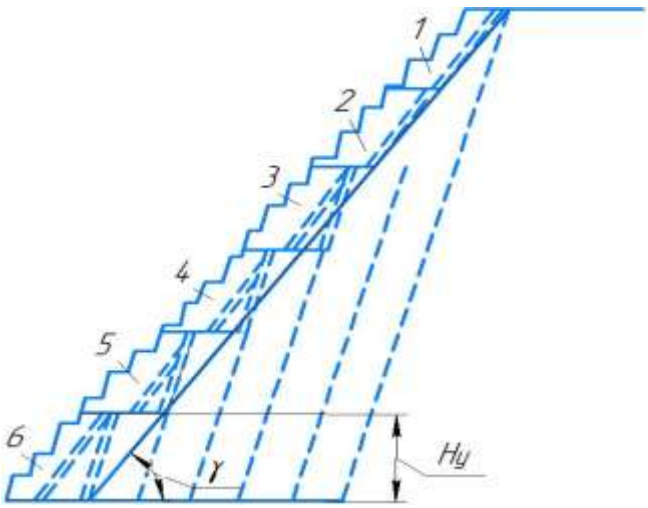

Figure 4. Reconstruction of the working side during the transition from the blasting and dumping complex to the blasting, bulldozer and dumping complex

As follows from the above, replacing previous technologies with the new one requires virtually no additional costs, can be implemented in the shortest possible time (up to one year), and can be done without interruption to mineral production, continuing during the bench cutting process [14].

The blast-and-bulldozer basement technology is emerging as a promising option for construction material quarries in Tajikistan. The transition to this technology has already been discussed for several quarters in Central Asia.

This technology is also expected to find widespread application in upland quarries worldwide, leading to increased efficiency in open-pit mining [15].

4. Conclusion

The proportion of rock (in the volume of one steep layer) subject to removal by bulldozers from the side can be estimated using the dumping coefficient K_(subj.). This proportion (and, accordingly, the coefficient K_(subj.)) decreases according to a power law as the bench height increases from 10 to 20 m.

The possibility of mining a steep layer using several benches and several blocks along the front is limited by the length of the latter and is impractical for organizational reasons. Effective operation of a blast-dozer-dumping system is ensured by mining the steep layer using one bench with one drilling block, which determines the quarry productivity achieved in this system. It is advisable to place and alternately use dumping and reloading zones on different sides of the mountain.

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