Technological schemes of blasting operations for ensuring stability of Amantaytau quarry slopes

Abdunor Jiyanov*, *Shukurulla* Buriyev, and *Shokirjon* Sunnatulloev

Navoi State University of Mining and Technologies, Navoi, 210100, Uzbekistan

Abstract. This article presents a comprehensive study conducted at the Amantaytau Quarry, focusing on enhancing slope stability through advanced blasting techniques. The research includes theoretical analyses, laboratory experiments, and geomechanical assessments to optimize quarry face parameters and ensure long-term stability. Key findings involve developing specialized blasting technologies for extracting pre-contour zones to reduce dynamic loads on quarry faces. The study also zones the quarry based on stable slope angles, providing crucial insights for the project contour. Achieving recommended slope angles requires specific drilling and blasting methodologies to configure benches into their ultimate positions. Quantitative and qualitative patterns of rock fragmentation have been analyzed to determine the width of the pre-contour zone, charge quantity, specific explosive consumption, and parameters for explosive borehole placement. These methodologies are crucial for ensuring safety and long-term stability. The article concludes with recommendations for practical applications, emphasizing the need to reevaluate zoning boundaries and parameters when modifying the project contour. This research contributes valuable insights to quarry engineering, providing a basis for implementing efficient and safe blasting practices for improved slope stability.

1 Introduction

The conducted research focusing on the physico-mechanical properties and deformations along the perimeter of quarry slopes during the zoning of the quarry field based on slope stability approaching the ultimate contour highlights the imperative need for a paradigm shift in the technology employed for drilling and blasting operations.

Despite the escalating scale of explosions and their consequential impact on slope stability, effective measures to mitigate the seismic effects near the ultimate contour have been largely undeveloped and consequently remain underutilized in the majority of quarries.

One crucial criterion for determining the quantity of simultaneously detonated explosives is the seismic hazard level, at which residual deformations of the rock formations comprising benches and the quarry perimeter are practically eliminated [1-3].

*Corresponding author: 89258957224@mail.ru

Well-known studies have established that the use of inclined wells makes it possible to produce high-quality ledges placed in a limiting position, as well as in cases where, during the development of ledges, the width of the contour protective zone, for one reason or another, excludes the use of other methods of angling. The method is recommended for use in areas with different strength and structure of the mountain range [4].

2 Materials and methods

The extraction of the final pre-contour protective zone is recommended through the drilling and detonation of three rows of vertical and one row of inclined boreholes when the indicator $p \geq 1$. For an indicator of $p=0.9$, it is advised to employ drilling and detonation involving two rows of vertical, one row of shortened vertical, and one row of inclined boreholes. When the indicator is $p=0.8$, the optimal approach involves drilling and detonating two rows of vertical and two rows of inclined boreholes. To position the bench in the ultimate configuration, inclined boreholes with a diameter of 243 mm are utilized, strategically placed along the project contour at a calculated angle, maintaining a distance of 3–3.5 m between each borehole. An auxiliary row of inclined boreholes is positioned 5 m from the projected upper edge of the bench [5].

The established sequence of detonation ensures a reduction in the seismic impact of mass explosions on the rock mass. The layout of blast holes is configured as a grid, measuring 6x6 m for hard-to-blast rocks and 7x7 m for moderately blast able rocks, effectively minimizing overbreaks beyond the designed contour of the bench [6].

3 Results and discussion

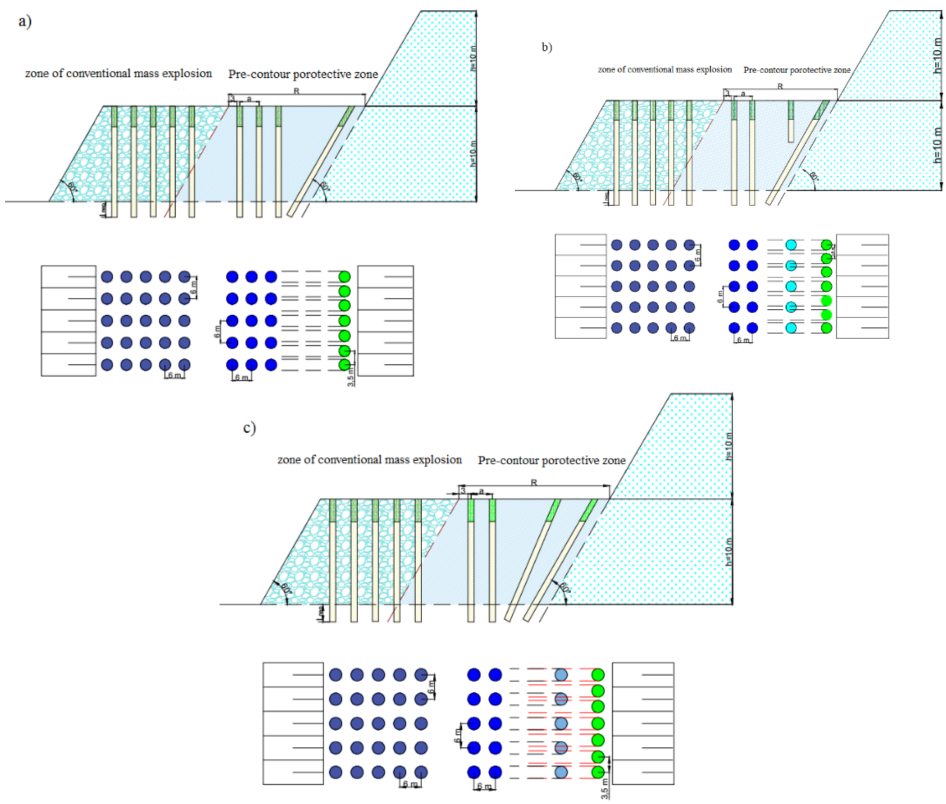
The effectiveness of bench stabilization operations is notably influenced by blasting schemes and delay timing. Within the context of the Amantaytau Quarry, three bench stabilization schemes were rigorously examined:

- three-row placement of vertical boreholes along with a single-row arrangement of inclined boreholes along the project contour to establish the predetermined slope of the bench;
- two-row arrangement of vertical boreholes, one row of shortened vertical boreholes, and a single-row placement of inclined boreholes along the project contour, utilizing short auxiliary and vertical blast holes for enhanced fragmentation of the rock mass situated between the inclined and vertical blast holes;
- two-row arrangement of vertical boreholes and two rows of inclined boreholes, with one row drilled along the project contour line.

When implementing the proposed blasting schemes, short-delay detonation with a delay between rows ranging from 35-42 ms is applied. In the first scenario, all vertical boreholes are sequentially detonated from the exposed surface towards the project contour, followed by the inclined boreholes (Figure 1, a). In the second case, all vertical boreholes are detonated initially, followed by one shortened vertical borehole and then the inclined boreholes along the project contour sequentially (Figure 1, b). In the third scenario, two rows of vertical and two rows of inclined boreholes are detonated sequentially (Figure 1, c). The quality of slope configuration was evaluated based on instrumental observations of deformations [7-8].

In the second slope stabilization scheme, utilizing two rows of inclined boreholes, the charge calculations were performed using the methodology outlined earlier. The boreholes were detonated row by row sequentially from the exposed surface towards the contour with a delay of 35 ms (Figure 1, c). Analysis of the blast results for slope configuration using this method revealed overbreaks along the upper bench extending into the rock mass up to 1 m, easily rectified by subsequent trimming of the upper part of the bench. The absence of berms, the presence of traces from contour holes on the slope surfaces, and consistent granulometric composition compared to the first slope stabilization scheme indicate the acceptability of employing this method for bench development along the ultimate contour.

The third scheme proposes a method for bench extraction and configuration by drilling and detonating vertical boreholes, with the final row consisting of short boreholes drilled to a depth of 0.3-0.5 times the height of the bench.



a – utilizing three rows of vertical boreholes along with inclined boroles along the ultimate contour for slope configuration; b – employing two rows of vertical boreholes, one row of shortened vertical boreholes, and one row of inclined boreholes;c – implementing two rows of both vertical and inclined boreholes.

Fig. 1. Technological Schemes for Bench Extraction and Slope Stabilization at Amantaytau Quarry.

This method is recommended for use in areas with large block structures of rock formations (with an average block edge size of 1.55 m). The slope stabilization of the upper portion of 10-meter-high benches to a height of 3-5 m is achieved by detonating charges in short vertical boreholes along the slope.

Depending on the rock type, when establishing the upper bench in the ultimate contour, the final row of vertical boreholes is drilled at a distance of 3-4 m from the projected position of the lower edge of this bench.

The study examines and recommends three layouts for the explosive network during multi-row short-delay detonation along contour lines to ensure stability of quarry slope faces (Figures 2, 3 and 4).

The above-discussed findings indicate that dynamic loads on benches and quarry slopes can be significantly reduced through the application of a specialized drilling and blasting technology during contour protective zone extraction.

The extent of the pre-contour zone and the contour protective zone is determined based on established empirical patterns, considering the strength and fracturing characteristics of the rock formations.

The properties of rock formations constitute a decisive factor in determining the parameters of drilling and blasting operations in the pre-contour zone, selecting technological schemes for the extraction of the pre-contour protective zone, and configuring slopes in a stable stationary position.

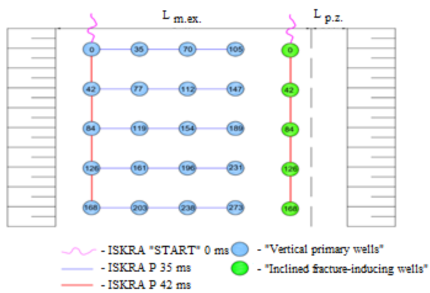


Fig. 2. Diagonal scheme for multi-row short-delay detonation.

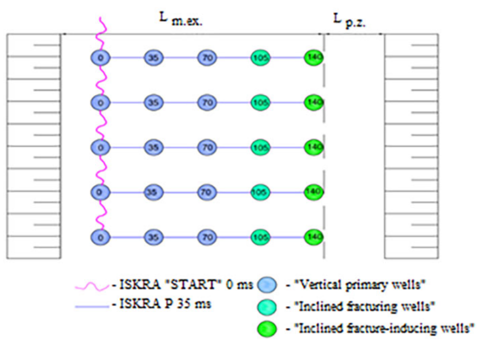


Fig. 3. Sequential layout for multi-row short-delay detonation.

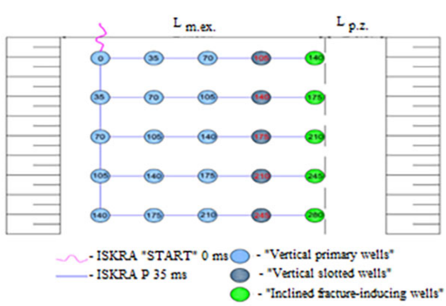


Fig. 4. Diagonal scheme for multi-row short-delay detonation.

Comparative data from experimental explosions are presented in Table 1. The quantitative assessment of the explosion effects indicates the expediency of implementing the proposed blasting schemes.

Table 1. Characterization of the Results of Experimental Explosions at the Amantaytau Quarry.

Indicators	Direct blasting sequence	Reverse blasting sequence
Width of the rock fracture zone, m	2.8	4
Extent of residual deformation zone, m	7	10
Maximum vertical displacement of the rock mass, mm	78	86
Qualitative description of the explosion	Visible traces of all boreholes, the slope surface is even	No traces of contour holes, uneven slope surface

Based on the analysis of global practices in the field and studies of the current state of geomechanical conditions in the rock mass, the criteria for zoning the peripheral areas of the quarry field regarding slope stability have been established. This is derived from research on the contemporary state of geomechanical conditions in the rock mass, assessments of the principal horizontal stresses using data from closely located analog deposits, and through geodynamic zoning of deposits [9-10].

Furthermore, laboratory research has been conducted to determine engineering-geological and physico-mechanical characteristics of rock formations. Theoretical justifications of the physico-mechanical parameters of the massif were carried out using advanced methods, such as the Hoek method, the VNIIMI finite element method, and the limit equilibrium method. Established limit parameters of the slope angle for quarry faces, along with the technology of blasting operations, lead to the following recommendations for ensuring the stability of the Northern and Central Amantaytau quarry faces [11].

1. It is recommended to zone the quarry based on the stable slope angles of benches and quarry faces. This zoning is applicable to the project contour of the quarry. Any modifications to the project contour should prompt a reevaluation of the boundaries and recommended parameters of the zones.
2. According to the conducted calculations to determine the ultimate quarry face angles, the width of the potential collapse prism on the eastern face reaches a maximum of 98 m, and on the western face, it reaches 65 m when adopting the recommended parameters for the quarry faces in the study. To ensure that spoil piles do not adversely impact the stability of the quarry faces, they should be located at a sufficient distance from the quarry faces, i.e., outside the potential collapse prism.
3. Recommendations for the parameters of stable quarry benches have been developed, calculated based on information about the fracturing using kinematic analysis and specialized calculations through the limit equilibrium method. It is important to note that the recommended slope angles for benches can only be achieved with the implementation of special drilling and blasting technology for configuring the benches into their ultimate positions.
4. Considering the geomechanical conditions of the Amantaytau deposit, specifically the fragmentation and relatively low strength of the rock formations, theoretical studies and experiments recommend the application of a specialized blasting technology for extracting the pre-contour zones. This is aimed at reducing dynamic loads on quarry faces, ensuring the reliable preservation of the contiguous mass.

5. Based on established quantitative and qualitative patterns of rock fragmentation from explosions, it is recommended to determine the width of the pre-contour protective zone, the charge amount in the borehole, specific explosive consumption, and the parameters of explosive borehole placement. This methodology ensures the safety and long-term stability of the quarry face.

4 Conclusion

Theoretical and experimental justification has been provided for the application of a specialized blasting technology for the extraction of pre-contour zones. This aims to reduce dynamic loads on quarry faces, ensuring the reliable preservation of the contiguous mass.

Methods for determining the width of the pre-contour zone, charge quantity in the borehole, specific explosive consumption, and parameters for the placement of explosive boreholes have been developed based on established quantitative and qualitative patterns of rock fragmentation from explosions. These methods ensure the reliable preservation of the quarry face.

The quarry has been zoned based on the stable slope angles of benches and quarry faces for the project contour of the quarry. Any modifications to the project contour should prompt a reevaluation of the boundaries and recommended parameters of the zones.

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