OPTIMIZATION OF TECHNOLOGICAL PARAMETERS OF CONTOUR DRILLING AND BLASTING OPERATIONS IN UNDERGROUND EXCAVATION OF COMPLEX STRUCTURAL DEPOSITS

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Abstract. This paper investigates the optimization of technological parameters of contour drilling and blasting operations during underground excavation in complex structural deposits. The relevance of the study is driven by increasingly complicated geological conditions, heterogeneous rock mass structures, high jointing intensity, and the presence of tectonic disturbances, all of which significantly affect excavation contour stability. The influence of borehole diameter, hole spacing, charge concentration, explosive distribution, and blasting sequence on the development of the near-contour damage zone is analyzed. Based on geotechnical and geomechanical considerations, scientifically grounded recommendations for selecting contour blasting parameters are proposed. The results demonstrate that optimized contour blasting significantly reduces overbreak, improves excavation profile accuracy, and enhances the stability of the surrounding rock mass, thereby increasing safety and efficiency in underground tunneling operations.

Keywords: Contour drilling and blasting; underground excavations; complex structural deposits; blasting parameter optimization; rock mass behavior; geotechnical basis; contour stability; overbreak control; drilling pattern; geomechanical conditions.

Аннотация. В статье рассматриваются вопросы оптимизации технологических параметров контурных буровзрывных работ при проведении подземных выработок в сложноструктурированных месторождениях. Актуальность исследования обусловлена усложнением горно-геологических условий, высокой трещиноватостью пород и наличием тектонических нарушений, которые существенно влияют на устойчивость

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контуров подземных выработок. В работе выполнен анализ влияния диаметра буровых скважин, шага шпуров, удельного заряда взрывчатых веществ, схемы их размещения и последовательности взрывания на формирование зоны разрушения в приконтурной области. С учётом геотехнических и геомеханических факторов разработаны научно обоснованные рекомендации по выбору параметров контурного взрывания. Полученные результаты позволяют снизить избыточные разрушения массива, повысить точность формирования профиля выработки и обеспечить её долговременную устойчивость.

Ключевые слова: Контурные буровзрывные работы; подземные горные выработки; сложноструктурированные месторождения; оптимизация параметров взрывания; массив горных пород; геотехнические основы; устойчивость контура; избыточное разрушение массива; схема бурения; геомеханические условия.

Annotatsiya. Mazkur maqolada murakkab strukturali konlarda yer osti lahimlarini o‘tishda konturli burg‘ilab-portlatish ishlarining texnologik parametrlarini optimallashtirish masalalari kompleks ilmiy yondashuv asosida tadqiq etilgan. Tadqiqotning dolzarbligi kon-geologik sharoitlarning murakkablashuvi, tog‘ jinslarining notekis tuzilishi, yoriqlanish darajasi va tektonik buzilishlar ta’siri ostida yer osti lahimlarining kontur aniqligi hamda turg‘unligini ta’minlash zarurati bilan belgilanadi. Ishda burg‘ilash diametri, shpurlar oralig‘i, zaryad zichligi, portlovchi moddaning joylashuvi va portlatish ketma-ketligining lahim konturida hosil bo‘ladigan buzilish zonasiga ta’siri tahlil qilingan. Geotexnik va geomekanik omillarni hisobga olgan holda konturli portlatish parametrlarini tanlash bo‘yicha ilmiy asoslangan tavsiyalar ishlab chiqilgan. Olingan natijalar kontur ortiqcha buzilishlarini kamaytirish, lahim kesimining aniqligini oshirish hamda tog‘ jinslari massivining turg‘unligini saqlash imkonini beradi.

Kalit so‘zlar: Konturli burg‘ilab-portlatish; yer osti lahimlari; murakkab strukturali konlar; portlatish parametrlarini optimallashtirish; tog‘ jinslari massivi; geotexnik asoslar; kontur barqarorligi; ortiqcha buzilish (overbreak); burg‘ilash sxemasi; geomekanik sharoitlar.

INTRODUCTION

The continuous increase in the depth of underground mining and tunneling has led to significantly more complex geological and geotechnical conditions. Underground excavations in complex structural deposits are often characterized by heterogeneous lithology, intensive jointing, fault systems, and variable in situ stress fields. These factors substantially complicate the construction of underground

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openings and increase the risk of excessive overbreak, instability of excavation contours, and degradation of the surrounding rock mass.

Drilling and blasting remains the most widely applied excavation method for underground openings in hard rock conditions due to its flexibility, cost-effectiveness, and adaptability to diverse geological environments. However, conventional blasting practices frequently result in uncontrolled rock damage beyond the designed excavation profile, especially in the near-contour zone. Such blast-induced damage negatively affects the stability of underground openings, increases the demand for ground support, and leads to higher operational and maintenance costs.

Contour drilling and blasting techniques have been developed to address these challenges by minimizing damage to the surrounding rock mass while maintaining acceptable excavation rates. The effectiveness of contour blasting largely depends on the proper selection of technological parameters, including borehole diameter, spacing, burden, charge concentration, decoupling ratio, and initiation sequence. In complex structural deposits, inappropriate parameter selection may amplify tensile stress development, promote secondary cracking, and increase overbreak.

Despite extensive research on drilling and blasting optimization, many existing approaches do not sufficiently account for site-specific geotechnical and geomechanical conditions, particularly the influence of tectonic disturbances and rock mass anisotropy. Therefore, a comprehensive geotechnical basis for optimizing contour blasting parameters is required to ensure excavation stability, reduce blast-induced damage, and improve the overall efficiency and safety of underground construction.

This study aims to develop a scientifically grounded approach to optimizing contour drilling and blasting parameters for underground excavations in complex structural deposits, considering rock mass structure, stress redistribution, and near-contour damage mechanisms.

Theoretical Background of Contour Drilling and Blasting. Contour drilling and blasting is a controlled excavation technique aimed at forming a smooth and stable excavation boundary while minimizing blast-induced damage to the surrounding rock mass. Unlike conventional production blasting, contour blasting focuses on preserving the integrity of the near-contour zone by reducing tensile stress concentrations and limiting crack propagation beyond the designed excavation profile.

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Table-1

Influence of Blasting Parameters on Near-Contour Damage

Parameter	Increase in Value	Effect on Contour Quality	Effect on Damage Zone
Borehole diameter	Increase	Reduced contour accuracy	Enlarged damage zone
Hole spacing	Increase	Poor crack coalescence	Irregular overbreak
Charge concentration	Increase	Loss of smooth contour	Increased tensile cracking
Decoupling ratio	Increase	Improved contour control	Reduced damage extent
Initiation delay	Improper	Stress superposition	Local instability

When an explosive charge detonates in a borehole, stress waves propagate radially through the surrounding rock mass. These waves consist of compressive stress followed by reflected tensile stress waves, which play a dominant role in crack initiation. In the near-contour zone, excessive tensile stresses may lead to overbreak, spalling, and the development of a blast-damaged zone (BDZ).

In contour blasting, reduced explosive energy and controlled spacing of boreholes are applied to ensure that induced stresses remain below the tensile strength of the intact rock and the rock mass discontinuities. Theoretical analysis shows that the radius of the damaged zone is proportional to charge concentration and inversely related to the dynamic tensile strength of the rock mass.

The main objective of contour blasting is to create a preferential fracture plane along the excavation boundary. This is achieved by:

- Reducing the charge concentration in contour holes,
- Applying decoupled charging,
- Using small-diameter boreholes,
- Ensuring accurate drilling alignment and spacing.

Crack initiation occurs when the tensile stress exceeds the tensile strength of the rock, while crack propagation depends on stress wave interaction with pre-existing joints and bedding planes. Properly designed contour blasting produces controlled radial cracks that coalesce between adjacent contour holes without propagating into the surrounding rock mass.

Decoupled charging is a fundamental theoretical principle in contour blasting. The decoupling ratio (D), defined as the ratio of borehole diameter to explosive charge diameter, directly influences peak pressure on borehole walls. Higher decoupling ratios significantly reduce borehole pressure, thereby limiting crack penetration depth.

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Mathematically, the peak borehole pressure P can be expressed as:

$$P \propto \left(\frac{d_e}{d_h}\right)^2 \cdot P_0$$

where:

d_e – explosive charge diameter,

d_h – borehole diameter,

P_0 – detonation pressure of the explosive.

Table-2

Recommended Decoupling Ratios for Contour Blasting

Rock Mass Quality	UCS (MPa)	Recommended Decoupling Ratio
Weak fractured rock	< 40	2.5 – 3.0
Moderately strong rock	40 – 80	2.0 – 2.5
Strong intact rock	> 80	1.5 – 2.0

Theoretical models suggest that optimal spacing between contour holes should ensure interaction of tensile stress zones without excessive overlap. Excessive spacing prevents crack coalescence, while insufficient spacing causes cumulative stress effects and contour degradation.

Empirical and analytical studies indicate that contour hole spacing should be proportional to borehole diameter and rock tensile strength.

Table-3

Typical Contour Hole Spacing Parameters

Borehole Diameter (mm)	Recommended Spacing (m)	Typical Burden (m)
32 – 38	0.5 – 0.7	0.6 – 0.8
40 – 45	0.7 – 0.9	0.8 – 1.0
48 – 51	0.9 – 1.1	1.0 – 1.2

Theoretical Basis for Parameter Optimization. The optimization of contour blasting parameters is based on minimizing the energy input required to achieve controlled fracture along the contour while preventing excessive stress transmission into the rock mass. This requires integrating:

- Rock mass strength and discontinuity structure,
- In situ stress conditions,
- Dynamic rock behavior under blasting loads.

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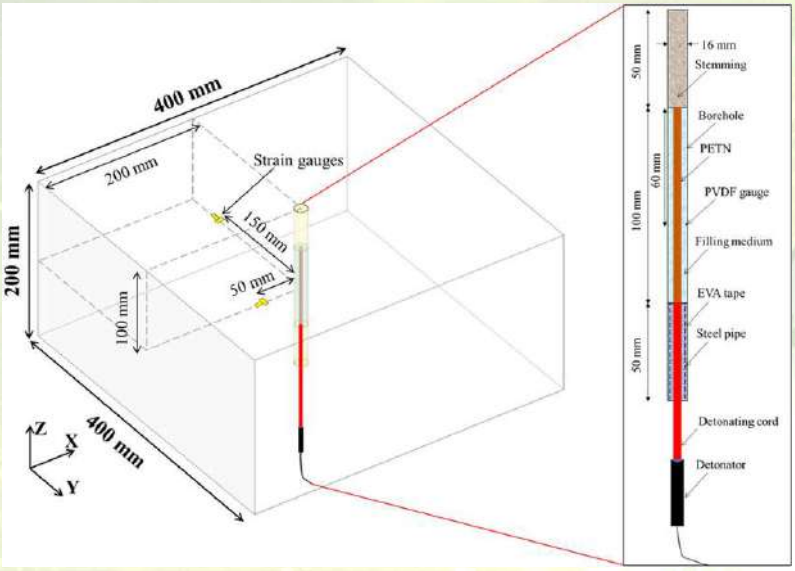


Fig-1. Experimental Setup for Measuring Strain Response around a Contour Blast Borehole

The optimization of technological parameters in contour drilling and blasting is a key factor in minimizing blast-induced damage and ensuring the stability of underground excavations in complex geological structures. Unlike production blasting, contour blasting aims not at maximum fragmentation but at controlled crack propagation along the designed excavation boundary. Therefore, parameter selection must be based on geotechnical and geomechanical considerations rather than empirical rules alone.

One of the most influential parameters is contour hole spacing. Excessive spacing leads to insufficient interaction of stress waves and incomplete crack coalescence, resulting in irregular excavation profiles. Conversely, overly small spacing causes excessive stress overlap, increasing tensile damage beyond the contour line. Optimal spacing is typically selected as a function of rock mass quality, joint spacing, and uniaxial compressive strength.

The decoupling ratio plays a critical role in reducing borehole pressure and limiting the radius of blast-induced damage. Decoupled charges reduce the peak detonation pressure acting on the borehole wall, thereby suppressing radial crack extension into the surrounding rock mass. Higher decoupling ratios are especially effective in highly jointed or tectonically disturbed rock masses.

Charge concentration must be carefully controlled to balance sufficient crack initiation with damage limitation. Lower linear charge density is preferred in contour holes to avoid excessive fracturing. Field observations and numerical simulations confirm that controlled energy release significantly improves contour smoothness and reduces overbreak.

The initiation delay sequence determines the interaction of stress waves between adjacent holes. Short, properly selected delays promote sequential fracture

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development and reduce simultaneous stress superposition. This controlled blasting sequence improves crack directionality toward the free surface and minimizes unwanted rock mass relaxation.

The optimization process involves iterative analysis using geological mapping, rock mass classification, analytical calculations, and numerical geomechanical modeling. By integrating these approaches, technological parameters can be adapted to site-specific conditions, resulting in improved excavation quality, reduced support requirements, and enhanced operational safety.

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