CONTOUR BLASTING

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Abstract

Contour blasting is a technique employed in underground mining and tunnel to achieve a smooth contour of underground openings, minimizing rock mass damage and overbreak. Article studies the mechanics of stress redistribution around the future opening, emphasizing its role in blast-induced fracture development. We demonstrate that understanding stress redistribution can significantly impact the design of an effective blasting pattern. The article presents analytical and numerical models that clarify principles of contour blasting to achieve a smooth contour without necessary increase in drilling. Before the detonation of contour charges, the maximum principal stress aligns closely with the shape of the underground opening, significantly affecting the length and orientation of blast-induced fractures. In this context, the ratio between the maximum and minimum principal stresses plays a crucial role in designing an effective burden for the contour charges.

Keywords: contour blasting; explosives; mining; tunneling; fractures;

1 INTRODUCTION

Contour or smooth blasting involves drilling an increased number of boreholes that align with the contour of the future underground opening. These boreholes are drilled with reduced spacing and contain a lesser quantity of explosives, aiming to minimize both overbreak and damage to the surrounding rock mass.

Although contour blasting provides superior results compared to traditional blasting patterns, its application remains relatively uncommon. This is primarily due to the increased number of boreholes required and the increased drilling times.

However, understanding the stress redistribution during blasting, particularly before the initiation of the contour charges, may reduce the number of required boreholes. This is the primary focus of the paper.

2 THE DETONATION INDUCED A PRESSURE WAVE IN THE ROCK MASS

The detonation of an elongated cylindrical explosive charge inside the borehole influences a sudden pressure increase within a reaction zone. As a result, the borehole walls are subjected to an impact load, which in turn induces a pressure wave in the rock medium.

In case of an ideal detonation, its pressure is estimated using following expression:

$$P_{CJ} = \frac{\rho_e D^2}{\gamma_{CJ} + 1}$$

Where:

P_{CJ} *– ideal detonation pressure (GPa),*
ρ_e *– explosive density (g/cm^3)*
D *-velocity of detonation (km/s)*
γ_{CJ}*- isentrope slope parameter:*

for explosives with density above 1(g/cm^3) γ_{CJ}=3,
for explosive with density below 1(g/cm^3) γ_{CJ}=1.25-1.4

Detonation pressure within the borehole is estimated using expression:

$$P_b = \frac{P_{CJ}}{2}$$

Therefore, for explosive with density above 1 g/cm^3 expression takes form:

$$P_b = \frac{\rho_e D^2}{8}$$

On the other hand, for explosives with density below 1 g/cm^3 :

$$P_b = \frac{\rho_e D^2}{4.5}$$

Intensity of the pressure wave induced in the rock, when explosive density is above 1 g/cm^3, is expressed as:

$$P_s = \frac{\rho_s V_p^2}{8}$$

And for the se of explosive density below 1 g/cm^3:

$$P_s = \frac{\rho_s V_p^2}{4.5}$$

Where:

P_s – Pressure wave intensity in the rock at borehole wall (GPa),
ρ_s – Rock density (g/cm^3),
V_p – P-wave velocity of rock (km/s)

The P-wave velocity is a function of the compressive stress within the rock mass along the direction of wave propagation, which has been investigated by Long Zhang et al [1]. This relation is expressed as:

$$V_p = k \cdot ln(\sigma + 1) + V_{p0}$$

Where:

k- fitting parameter,
V_{p0}- P-wave velocity of monolith rock.

Rock mass where drilling and blasting take place is under certain stress state which, in plane perpendicular to the borehole axis, is described as illustrated in Figure 1.

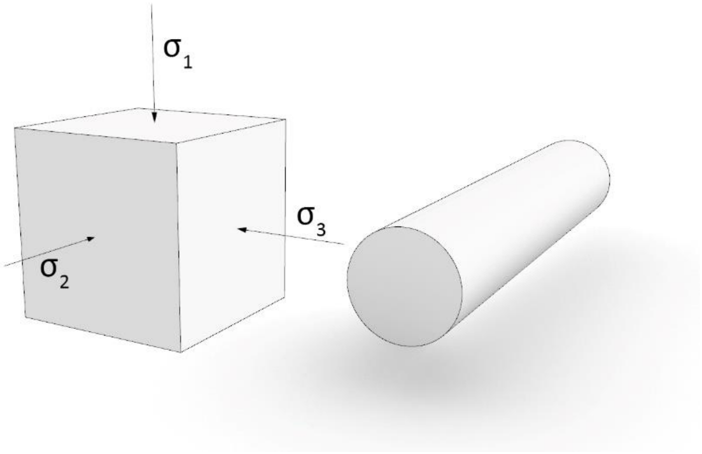

Figure 1 Stress state in the plane perpendicular to the borehole axis; σ_1- maximum principal stress, σ_2 – intermediate principal stress, σ_3 - minimum principal stress.

It is evident that the P-wave velocity is greater in the direction of the maximum principal stress compared to the direction of the minimum principal stress.

In a plane perpendicular to the borehole axis, the P-wave front takes on an elliptical shape. The major axis of this ellipse aligns with the direction of the maximum principal stress, while the minor axis corresponds to the orientation of the minimum principal stress. In scenarios where the maximum principal stress is equal to the minimum principal stress, the P-wave front has a circular shape.

3 RADIAL TENSION FRACTURES

As described in "Rock Fracturing Mechanism by Blasting" [2], the detonation products generated within the reaction zone create a cylindrical pressure wave that propagates through the rock medium. In the radial direction, the rock medium is subjected to a compressive load, while simultaneously, in the lateral direction, the rock is subjected to a tension load. As depicted in Figure 2, radial tension fractures form around the borehole in the rock due to the tension.

The area surrounding the borehole can be divided into various zones based on the density of fractures in each zone. The number of fractures decreases as the distance from the borehole increases, with the highest fracture density being closest to the borehole. When the tension load generated by the pressure wave falls below the rock's tensile strength, fracture development ends.

In Figure 2, the rock mass is shown as isotropic and without any stress before the explosive charge is activated. In some cases, the block set to be blasted is only affected by its own weight, making the influence of in-situ stress negligible.

Consequently, the radius of the fracturing zone, or the length of the radial tension fractures, is:

$$r_{cn} = \frac{P_s r_h}{k \sigma_t n}$$

Where:

P_s – intensity of the P-wave in the rock at the borehole wall,
σ_t - tensile strength,
r_h - borehole radius,
r_{cn} – fracturing zone radius
N - number of fractures.

$$k = \frac{(1-\nu)}{(1+\nu)(1-2\nu)}$$

ν - Poisson's ratio

In this specific case, radial tension fractures take an axis-symmetrical arrangement.

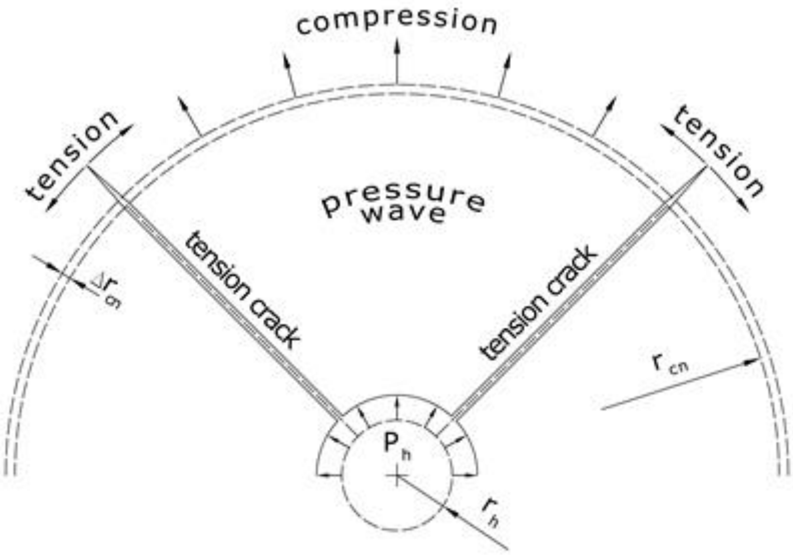

Figure 2 Radial tension fracture formation in isotropic and destressed material

When a rock mass is stressed, the minimum and maximum principal stresses determine the elliptical shape of the p-wave front. As a result, symmetry is observed in two distinct directions, aligning with the trajectories of the principal stresses. Therefore, the fracturing zone comprises two symmetrical tension fractures in two mutually perpendicular directions.

For a tension fracture to form along the major axis or the trajectory of the maximum principal stress, the blast-induced tension load perpendicular to the major axis must exceed the sum of the tensile strength and the minimum principal stress.

Therefore, length of the tension fracture aligned with the trajectory of the maximum principal stress is:

Consequently, the length of the tension fracture that aligns with the trajectory of the maximum principal stress is:

$$r_{\sigma 1} = \frac{P_s r_h}{2k(\sigma_t + \sigma_3)}$$

The length of the tension fracture that aligns with the trajectory of the minimum principal stress is:

$$r_{\sigma 3} = \frac{P_s r_h}{2k(\sigma_t + \sigma_1)}$$

where:

P_s – *intensity of the P-wave in the rock at the borehole wall (MPa),*
σ_t - *tensile strength (MPa),*
σ_1 – *maximum principal stress (MPa)*
σ_3 – *minimum principal stress (MPa)*
r_h - *borehole radius (m),*
$k = \dfrac{(1-\nu)}{(1+\nu)(1-2\nu)}$

ν - *Poisson's ratio*

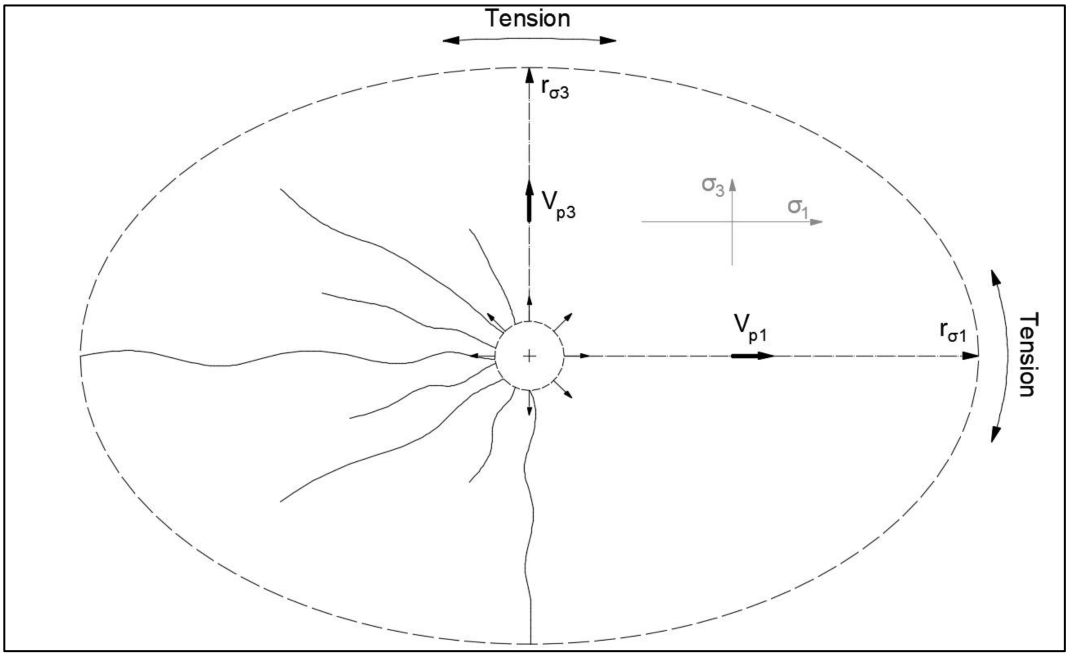

Figure 3 Radial tension fracture formation in rock with $\sigma_1 \neq \sigma_3$

When the principal stresses are equal in intensity and significant enough to be considered, the shape of the p-wave front becomes circular, and fractures form in an axis-symmetric layout. In this scenario, the fracture length is determined by considering both the value of the principal stress and the tensile strength.

A fundamental aspect of this research is the understanding that in hydrofracturing, for fractures to form along the trajectory of the maximum principal stress, the pressure inside the borehole must exceed the sum of the tensile strength and the minimum principal stress [3]. This was also confirmed in cases where an explosive charge was used inside the borehole [4].

4 STRESS EVOLUTION AND ITS IMPACT IN CONTOUR BLASTING

For underground mine development or tunneling, blasting assumes that a void space starts from the central boreholes (or cut) and progressively expands until intended shape of the opening is achieved. During this process, the stress around the void space evolves, meaning that the principal stress components to alter both their intensity and orientation. The ratio between the maximum and minimum principal stresses also changes. This leads to a reduced burden for the final explosive charges at the opening's contour, as the σ_3 stresses tend to decrease. This provides favorable conditions for fractures to form along the intended shape of the opening or in alignment with the maximum principal stresses. Figure 4a depicts a blasting scenario in that we use to illustrate this principle, while Figure 4b shows the stress state around the underground opening before the contour charges are blasted. Stress state is analyzed using FEM and RS2 software [5].

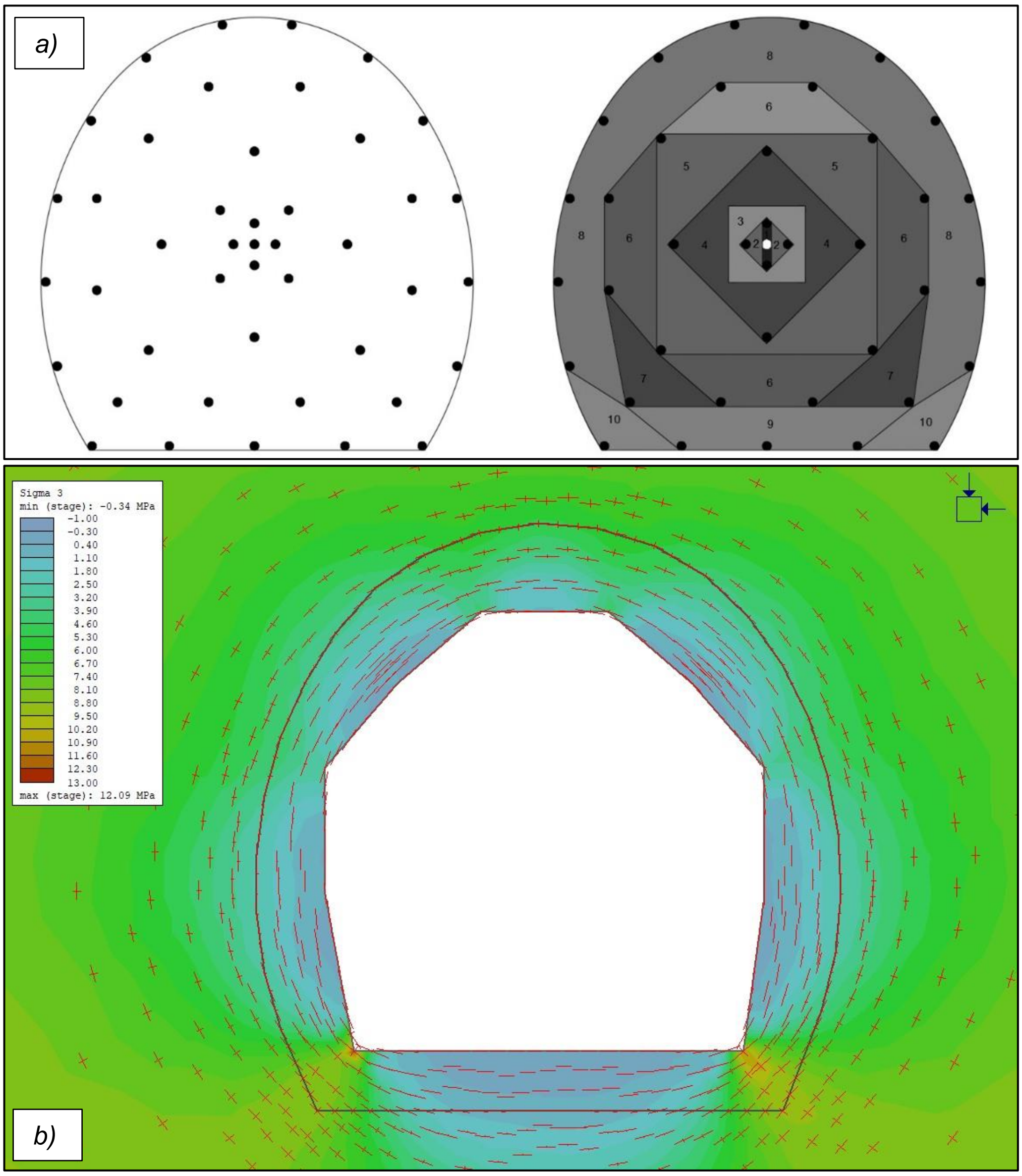

Figure 4 a) Blasting pattern with charge initiation sequence b) stress state prior the contour charge initiation

As observed in Figure 4b, the stress ratio between the maximum and minimum principal stresses significantly favors the maximum stress along the future contour of the underground opening. As detailed in Section 3, this will affect the development of longer radial tension fractures caused by the explosive detonation. It's evident that the longest blast-induced fractures will form along the path of the σ_1 stresses. This is a crucial aspect in the design of the blasting pattern that must be taken into account, as the intensity of the σ_3 stress will also influence the conditions for fracture development by influencing the burden for the contour charges.

5 CONCLUSION

Underground mine development relies on drill and blast operations as a dominant way of rock excavation. During the blasting process, rock is disintegrated, while the surrounding rock mass may experience varying degrees of blast-induced damage, depending on the quality of the blast design. Contour blasting is employed to achieve a smooth shape and minimize damage to the rock surrounding the underground opening.

This paper discusses the stress-dependent formation of blast-induced fractures. The paper explains how the length of the fractures is influenced by both the orientation and the ratio between the maximum and minimum principal stresses. The longest fractures align with the path of σ_1, while the intensity of σ_3 determines the burden for a specific explosive charge, in conjunction with the rock's tensile strength.

During the blasting sequence in typical blasting patterns, the path of σ_1 naturally aligns with the shape of the future underground opening. When designing a pattern, this principle should be adopted. The objective is to align σ_1 as closely as possible with the alignment of the contour charges.

Conversely, the intensity of σ_3 is affected by the shape of the void space before the initiation of the contour charges. This, combined with the rock's tensile strength, can significantly impact the blasting outcome. Thus, designing a blasting pattern without accounting for the stress evolution during the initiation sequence can result in significant misinterpretations of blasting conditions, leading to undesirable outcomes.

6 REFERENCES

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