# The Dynamic Response Patterns of Goafs at Different Distances under Blasting Load

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**Abstract.** In the early stages of China's mining industry, due to underdeveloped legal regulations, small mining companies often neglected backfilling and support work after excavation, leading to the formation of numerous goafs (mined-out areas). These goafs are prone to instability under the influence of external factors. To prevent instability in the goafs of the Baiyin Nuoer lead-zinc mine and to study the effects of blasting at different distances, numerical simulations of the dynamic response of goafs under single-hole blasting were conducted using ANSYS/LS-DYNA software under consistent burial depth conditions. The analysis results showed that the vibration velocity of the roof was significantly higher than that of the middle and floor and decreased with increasing horizontal distance, although the rate of attenuation slowed. After slight upward displacement, the roof underwent downward displacement, forming residual displacement. It is recommended to assess the stability of the roof even when blasting outside the safety distance to prevent cumulative damage leading to collapse. The stress in the roof was much higher than in other parts, and effective stress gradually decreased with increasing horizontal distance. To ensure the stability of the roof, it is advised to calculate a safe blasting distance, ensuring that the maximum tensile stress in the roof is below the rock's ultimate tensile strength.

**Keywords:** goaf, blasting load, different distances, numerical simulation, dynamic response

## 1 Introduction

Blasting is a common method used in mining operations, and the dynamic loads generated can compromise the stability of the goaf, leading to the instability of the surrounding rock structure. Therefore, studying the impact of blasting loads on goafs is crucial for preventing safety accidents and ensuring the safety of mining operations.

Konicek[1] presents a pressure-relief blasting method that reduces rock burst risk by releasing stored energy in the rock, indicating that blasting alters stress in the goaf roof. Sandi [2] designed tunnel blasting and studied stress redistribution in and around the pillars within the goaf. Jia [3] used microseismic (MS) technology to evaluate rock failure and damage severity. Through 3D laser detection and high-precision MS


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monitoring, they analyzed the MS activity, stress, and displacement in a concealed goaf impacted by blasting in an open-pit mine. The results showed two arched fracture zones in the goaf roof, but the evolution of stress, volume, and displacement indicated the goaf remains stable. Wang [4] used FLAC3D to study the impact of bench blasting disturbance on the stability of shallow-buried goafs in open-pit mines. The results showed that after the blasting disturbance, the deformation of the goaf roof increased, and when the disturbance was applied 75 meters away from the goaf, there was a risk of instability and failure in the goaf roof. Jiang[5] introduced the damage factor($D_n$) caused by blasting stress waves to characterize the damage effects of blasting loads on rock masses. A structural model of bauxite goaf groups was constructed, which can represent the instability mechanisms of goaf groups after multiple blasting events.

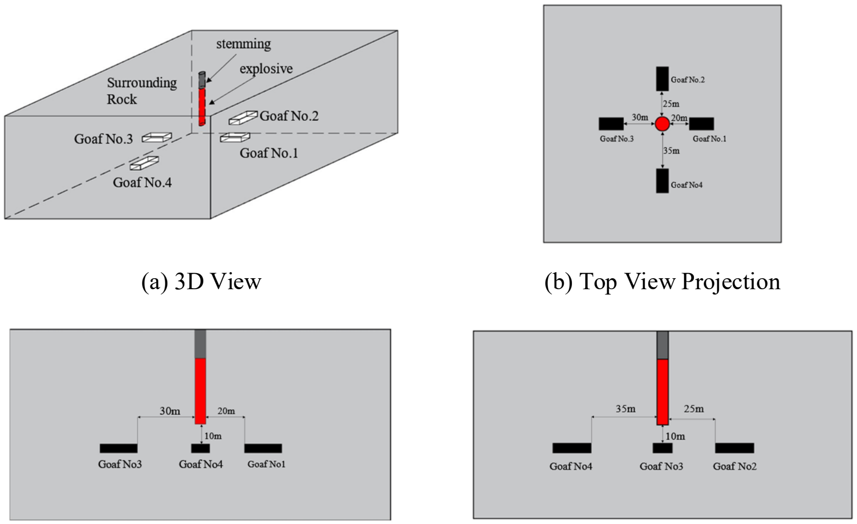
The aforementioned scholars have studied blasting methods that change stress distribution in the goaf, roof stability after blasting, and models describing group effects in the goaf. However, they have not examined how blast hole distance affects goaf stability. Assessing the impact of blasting loads at different distances can help optimize blasting parameters, reduce geological risks, and ensure the mine's long-term safety.

## 2 Calculation Model

Due to the high costs of testing the effects of blasting loads on goafs, this study uses numerical simulation. Rocks fail due to large strains generated instantaneously under high temperature and pressure. The RHT model effectively represents the stress state of this brittle material in those conditions.

### 2.1 Mine Overview

The Baiyin Nuole lead-zinc ore deposit contains numerous complexly shaped and clustered ore bodies, making it a rare large lead-zinc deposit in northern China. Over 160 lead-zinc ore bodies have been discovered throughout the mining area, which is divided into two mining belts distributed in the southern and northern directions. The southern mining belt is 1.1 km long and 0.2 to 0.4 km wide, while the northern mining belt is 1.3 km long and 0.6 km wide, with a distance of 0.4 km between the two. The area contains a large number of goafs, with the maximum exposed area of the goaf being 6,180 $m^2$ and the volume of the goaf measuring 223,202 $m^3$. When blasting operations are conducted in this mine, the dynamic response of goafs at different distances varies. To ensure safe mining operations, it is necessary to analyze this through numerical simulations. One such goaf is located 10 m from the bottom of the borehole, with a length of 20 m, height of 5 m, and width of 10 m. The distribution of the borehole and the goaf is shown in Figure 1, and the physical and mechanical pa-rameters of the rock are provided in Table 1.




(a) 3D View (b) Top View Projection

(c) Formal Projection View (d) Left View Projection

**Fig. 1.** Schematic Diagram of Borehole and Goaf Distribution

**Table 1.** Physical and Mechanical Parameters of the Baiyin Noer Lead-Zinc Ore Body

| Rock Types | $\rho$ /kgm$^{-3}$ | $E$/GPa | $v$ | $\sigma_{bc}$ /MPa | $\sigma_b$ /MPa | $\varphi$ /° | $c$/MPa |
|---|---|---|---|---|---|---|---|
| Surrounding Rock | 2720 | 60.56 | 0.31 | 60.56 | 9.02 | 31.25 | 35 |

## 2.2 Material Model Parameter Settings

Based on the presence of the goaf, a deep-hole blasting construction scheme is adopted. The MAT_RHT model is used for the rock, with the model dimensions of 200m × 200m × 100m. The borehole diameter is 160mm, the borehole depth is 50m, and the stemming length is 15m.

The explosive uses the HIGH_EXPLOSIVE_BURN model, defined by the JWL equation of state. The equation of state expression is as follows:

$$P = A(1-\frac{\omega}{R_1 V})e^{-R_1 V} + B(1-\frac{\omega}{R_2 V})e^{-R_2 V} + \frac{\omega E_0}{V}\sqrt{b^2-4ac} \tag{1}$$

In the equation: $P$ represents the detonation pressure, MPa; $V$ denotes the relative volume; $E_0$ is the internal energy per unit volume of the explosive; $A$, $B$, $R_1$, $R_2$, $\omega$ are parameters of the explosive, The parameters for this numerical simulation are shown in Table 2.

**Table 2.** Material Parameters of Explosive Models

| $\rho$/kgm$^{-3}$ | $D$/ms$^{-1}$ | $PCJ$/GPa | $A$/GPa | $B$/GPa | $R_1$ | $R_2$ | $\omega$ | $E_0$/J |
|---|---|---|---|---|---|---|---|---|
| 1000 | 3600 | 10.5 | 220 | 0.2 | 4.5 | 1.1 | 0.35 | 4.192 |

The MAT-NULL and the polynomial equation of state EOS-LINEAR-POLYNOMIAL are used to describe the goafs in the mine. The equation of state formula is as follows:

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E \tag{2}$$

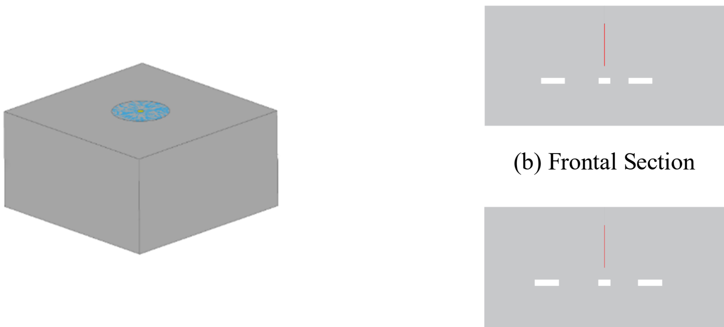
In the equation, the terms are defined as follows: $C_0$, $C_1$, $C_2$, $C_3$, $C_4$, $C_5$, $C_6$ all are constants, $\mu$ is the specific volume; $E$ is the ratio of internal energy to the initial volume, The parameters for this numerical simulation are shown in Table 3.

**Table 3.** Parameters of the Goaf Model

| $C_0$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $E$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0.4 | 0.4 | 0 | 2.5×10$^5$ |

### 2.3 Model Establishment

Using ANSYS/LS-DYNA, single-hole blasting models of goafs were created at a burial depth of 10 m below the borehole bottom, with horizontal distances of 20 m, 25 m, 30 m, and 35 m. The numerical simulation models are illustrated in Figure 2.



(b) Frontal Section

(a) Single-Hole Blasting Model in the Goaf

(c) Lateral Section

**Fig. 2.** Single-hole blasting model at different horizontal distances

The model is surrounded by non-reflective boundary conditions, with constraints applied to its degrees of freedom in the vertical direction. The upper part and the interior of the goaf are set to free boundary conditions. A coupled charge configuration is used, coupling the explosive with the air domain. The entire model is discretized using quadrilateral elements, with a total of 559,608 elements and 603,987 nodes. The mesh configuration is shown in Figure 3.

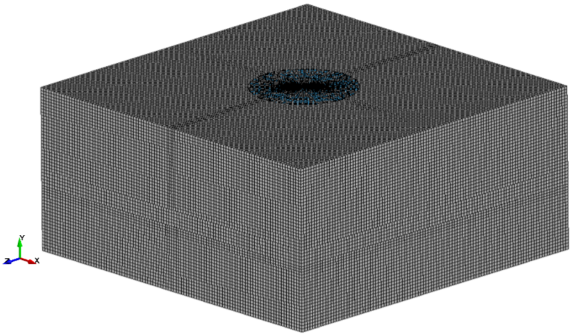


**Fig. 3.** Grid Division of the Goaf Blasting Model

## 3 Numerical Simulation Results and Analysis

Monitoring points A, B, C, and D are located at the roof, middle, and floor of the goaf, respectively. Their specific distribution is shown in Figure 4.

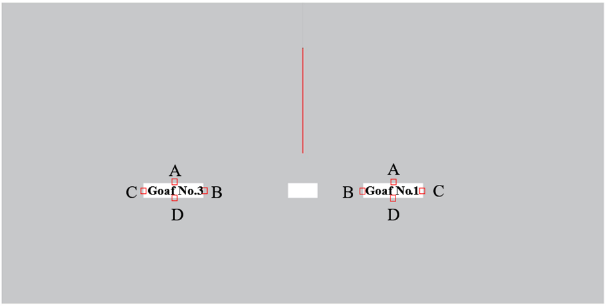



**Fig. 4.** Schematic Diagram of Displacement Monitoring Points in the Middle of the Goaf Roof

### 3.1 Velocity Analysis

The vibration velocities at points A, B, and D are shown in Table 4.

From the table, it can be seen that regardless of the distance from the drill hole, the horizontal and vertical vibration velocities at the goaf roof are significantly greater than those at the goaf middle and bottom. This analysis indicates that the goaf roof is the most susceptible position to instability under the influence of blasting loads compared to the middle and bottom sections. Additionally, vibration velocity decreases as the distance from the goaf increases. Therefore, when analyzing the stability of the goaf, special attention should be paid to the vibration velocity of the goaf roof, and controlling the safe horizontal distance from the goaf can effectively prevent instability.

**Table 4.** Vibration Velocity of Monitoring Points in the Goaf

| Distance from the Goaf | Direction of Vibration Velocity | Vibration Velocity /ms$^{-1}$ | | |
|---|---|---|---|---|
| | | A | B | D |
| 20 m | Horizontal | 8.69 | 0.19 | 0.22 |
| | Vertical | 8.97 | 0.50 | 0.81 |
| 25 m | Horizontal | 7.25 | 0.007 | 0.11 |
| | Vertical | 7.54 | 0.58 | 0.86 |
| 30 m | Horizontal | 5.87 | 0.23 | 0.12 |
| | Vertical | 5.89 | 0.52 | 0.82 |
| 35 m | Horizontal | 5.91 | 0.08 | 0.16 |
| | Vertical | 5.92 | 0.58 | 0.85 |

Since the horizontal distance from the goaf to the drill hole is greater than the vertical distance, the vertical vibration velocity of the goaf roof is consistently greater than the horizontal vibration velocity of the goaf. When the goaf is at the same burial depth, the vibration velocity decreases at a diminishing rate as the horizontal distance increases.

### 3.2 Roof Displacement Analysis

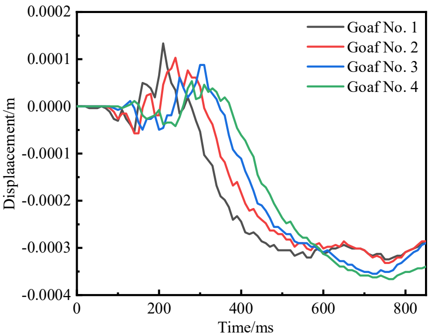



**Fig. 5.** Displacement Variation Diagram of the Goaf Roof

The figure 5 shows that the displacement at the center of the goaf roof first moves upward due to compressive forces from the blasting load, then transitions downward, leading to residual displacement. Thus, after blasting, the roof will have some downward vertical displacement. This highlights the need to assess the stability of the goaf roof after multiple blasting operations, even outside the safe distance, to prevent collapse from cumulative damage.

### 3.3 Stress Analysis

The stress peak values at monitoring points A, B, C and D are detailed in Table 5.

Under single-hole blasting, the stress on the goaf roof is much higher than at other locations, with the lowest stress at the goaf bottom. The roof initially undergoes compressive stress, followed by tensile stress. At 20 meters from the drill hole, the roof's maximum stress of 1.36 MPa is below the rock's tensile strength of 9.02 MPa, indicating stability.

**Table 5.** Effective Stress Results of Monitoring Units

| Distance from the Goaf | Effective Stress/MPa | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 20 m | 1.360 | 0.102 | 0.103 | 0.084 |
| 25 m | 1.310 | 0.104 | 0.099 | 0.076 |
| 30 m | 1.040 | 0.101 | 0.099 | 0.073 |
| 35 m | 0.723 | 0.103 | 0.103 | 0.064 |

## 4 Conclusion and Recommendations

Numerical simulation can only predict general trends. Future validation will involve drop weight model tests and field vibration measurements. The conclusions are:

(1) At the same burial depth, the peak velocity at the goaf roof is higher than at the middle and bottom locations. Additionally, the peak velocity at the roof decreases noticeably with increasing distance, though the rate of reduction slows down.

The goaf roof initially experiences slight upward displacement due to the compressive (2) impact of the blasting load, followed by downward displacement that results in irreversible residual displacement. Even when blasting outside the safe distance, assessing the roof's stability after multiple operations is advisable to prevent collapse from accumulated damage.

(3) The stress on the goaf roof from blasting vibration is significantly higher than in other areas and decreases with distance from the drill hole. It is recommended to calculate a safe distance during blasting to keep the maximum tensile stress on the goaf roof below the rock's tensile strength.

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