MINING ENGINEERING

Technical Optimization of Drilling and Blasting Parameters: A Comprehensive Guide for Quarry Operations

Published: June 23, 2025 | Index ID: #657

In the global mining and construction industry, drilling and blasting (D&B) represent the primary stages of the comminution process. The efficiency of these operations dictates the downstream economic performance of a quarry, influencing everything from loading and hauling costs to the energy consumption of secondary crushing and grinding units. Precision in the **calculation of drilling and blasting parameters** is not merely a technical requirement but a strategic necessity for achieving optimal rock fragmentation while minimizing environmental impacts such as ground vibration, flyrock, and air blast.

Theoretical Framework of Rock Fragmentation by Blasting

The science of rock fragmentation involves the rapid release of chemical energy from explosives, which is converted into mechanical energy. This process occurs in three distinct phases. First, the **shock wave phase** involves high-pressure waves radiating from the borehole, causing radial cracks. Second, the **gas expansion phase** occurs as high-pressure gases enter the cracks, wedging them open and displacing the rock mass. Finally, the **reflection phase** occurs when shock waves hit a free face and reflect as tensile waves, causing further breakage because rock is significantly weaker in tension than in compression.

Understanding the **zones of destruction** is critical for calculating parameters. Based on the energy density of the explosive, three zones are generally identified around a blast hole: the crushing zone (nearest to the hole), the fracture zone (where radial cracking occurs), and the elastic zone (where energy dissipates into seismic waves). Optimization aims to maximize the fracture zone while minimizing the crushing and elastic zones.

The Role of Rock Mass Characterization

Before any mathematical models are applied, the geological and engineering properties of the rock must be quantified. Parameters such as **Unconfined Compressive Strength (UCS)**, Young's Modulus, rock density, and the presence of joints or bedding planes significantly influence how energy propagates. For instance, in the Dobrnja quarry near Banja Luka, detailed geological assessments are required to determine the resistance of the limestone to explosive forces, ensuring that the selected explosive energy matches the rock's structural integrity.

Core Geometric Parameters in Drilling

The geometric design of a blast pattern is the foundation of a successful shot. Several interdependent variables must be calculated using empirical formulas, such as those developed by Ash, Konya, and Rustan.

1. Borehole Diameter (D)

The choice of bit diameter affects all other parameters. As highlighted in technical studies of quarry operations, utilizing a **105 mm minehole diameter** is often identified as an optimal balance for medium-scale quarries. Smaller diameters increase the cost per cubic meter due to higher drilling density, while excessively large diameters can lead to poor fragmentation and excessive vibration in sensitive areas.

2. Burden (B)

The burden is the shortest distance from the borehole to the nearest free face. If the burden is too small, energy is wasted as flyrock and excessive noise; if too large, it results in poor fragmentation and the formation of "toes" at the quarry floor. A common empirical formula for burden is:

B = (3.15 * d * (< R ò Ár)^(1/3)) 12 (where d is hole diameter, < R —2 Pxplosive density, and < " —2 &ö0k density).

3. Spacing (S)

Spacing is the distance between boreholes in the same row. It is typically calculated as a function of the burden, often ranging from 1.1 to 1.4 times the burden value. For a staggered pattern, spacing is often increased to improve the distribution of energy throughout the rock mass.

4. Hole Depth and Sub-drilling (J)

Hole depth (H) depends on the bench height. To ensure the quarry floor is broken cleanly at the desired level, **sub-drilling** is required. Sub-drilling usually equals approximately 0.3 times the burden. Insufficient sub-drilling leaves high spots on the floor, which significantly increases wear and tear on loading equipment.

Explosive Selection and Powder Factor Calculations

The selection of explosives is a trade-off between energy requirements, water resistance, and cost. Modern mining frequently utilizes a combination of **ANFO (Ammonium Nitrate/Fuel Oil)** and **emulsion explosives**.

Comparison of Common Explosives

Explosive Type	Density (g/cm³)	VOD (m/s)	Water Resistance	Primary Use Case
ANFO	0.80 - 0.85	2,500 - 3,500	Poor	Dry holes, soft-to-medium rock
Emulsion	1.15 - 1.25	4,500 - 5,500	Excellent	Wet holes, hard rock, high energy
Heavy ANFO	1.05 - 1.15	3,500 - 4,500	Fair/Good	Variable conditions, increased energy

The **Specific Charge (Powder Factor)**, denoted as 'q', is the amount of explosive used per unit of rock (kg/m³). In quarrying, this typically ranges from 0.25 to 0.50 kg/m³. A precise powder factor ensures that the rock is fragmented to the size required for the primary crusher without producing excessive fines.

Energy Distribution and Hole Loading

The loading of the borehole is divided into two parts: the **bottom charge** and the **column charge**. The bottom charge usually consists of a high-density, high-VOD explosive (like emulsion) to break the toughest part of the rock at the toe. The column charge, often ANFO, fills the remainder of the hole up to the stemming zone. **Stemming (T)** is the inert material (usually crushed stone) placed at the top of the hole to confine the gases and prevent "stemming ejection," ensuring the gas energy remains within the rock mass as long as possible.

Technical Workflow for Blasting Design

1. Field Data Collection: Measuring bench height, face angle, and rock density.
2. Borehole Selection: Determining the optimal diameter (e.g., 105 mm) based on production requirements and equipment capacity.
3. Geometric Calculation: Applying formulas to determine Burden, Spacing, and Stemming.
4. Explosive Selection: Choosing between ANFO and Emulsion based on groundwater levels and rock hardness.
5. Initiation Timing: Designing a delay sequence (using millisecond delays) to provide a second free face for subsequent holes, reducing vibration and improving fragmentation.
6. Verification: Using post-blast analysis (fragmentation software) to compare results against the calculated design.

Case Study Analysis: The Dobrnja Quarry Model

Studies conducted at the Dobrnja quarry near Banja Luka provide a clear example of the optimization process. By comparing different combinations of explosives and hole diameters, researchers determined that a **105 mm diameter minehole** combined with a specific powdered-AN-FO mixture provided the most rational organization for obtaining solid minerals. This combination optimized the **energy distribution**across the bench, resulting in a fragmentation profile that aligned perfectly with the primary crusher's intake capacity.

Fragmentation Distribution Matrix

Diameter (mm)	Explosive Type	Fragmentation (	Oversize (>800mm)	Total Cost Factor
89 mm	ANFO	82%	5%	High (Drilling Cost)
105 mm	ANFO/Emulsion	91%	2%	Optimum
125 mm	Heavy ANFO	78%	8%	Low (Drilling) / High (Crushing)

The matrix demonstrates that the 105 mm diameter offers the best "Fragment Consistency Score," reducing the need for secondary blasting and minimizing wear on the excavator bucket teeth.

Environmental and Safety Considerations

Calculations in drilling and blasting are not solely focused on fragmentation; they are also a tool for **risk mitigation**. The primary environmental hazards include ground vibration and flyrock.

Vibration Control (PPV)

The Peak Particle Velocity (PPV) is used to measure the intensity of ground vibrations. It is calculated using the Scaled Distance formula: **PPV = k * (D / " W)^-n**, where D is the distance from the blast, W is the maximum charge weight per delay, and k/n are site-specific constants. By reducing the charge weight per delay (using electronic detonators), quarries can operate safely near residential areas.

Flyrock Mitigation

Flyrock is the unexpected projection of rock fragments beyond the blast zone. It is caused by an insufficient burden or excessive explosive concentration. Proper **stemming height**(typically equal to the burden) is the most effective way to prevent flyrock. Using angular crushed stone instead of drill cuttings for stemming increases the "frictional lock" within the hole, significantly improving gas confinement.

Advanced Methodologies: Zones of Destruction

Recent research in 2024 has emphasized the calculation of drilling-and-blasting parameters based on the **zones of destruction of the rock mass**. This method moves away from purely empirical formulas toward a more mechanistic approach. By calculating the radius of the zone of intensive crushing and the zone of radial fracturing, engineers can space boreholes so that these zones overlap perfectly. This ensures there are no "dead zones" of unbroken rock between holes, which is a common cause of poor fragmentation in heterogeneous rock masses.

Emulsion Explosive Energy Regularities

Modern calculations now incorporate the **detonation pressure** and **explosion heat**of emulsion explosives more accurately. Emulsion explosives have a higher VOD, which creates a higher initial shock pressure. This is particularly useful in quarries with high UCS values where ANFO lacks the "brisance" (shattering power) required to initiate cracks in a dense rock matrix.

Practical Implementation Checklist

- Audit the Bench: Check for irregularities in the face before drilling. Adjust the front row burden accordingly.
- Drill Accuracy: Ensure the drill rig is aligned correctly. Deviation of even 2-3 degrees can lead to a significant change in burden at the bottom of a deep hole.

- Moisture Check: If the hole has standing water, use Emulsion or plastic-sleeved ANFO.
- Stemming Quality: Use clean, 10mm-20mm crushed stone. Avoid using fines or dirt.
- Delay Sequencing: Ensure a minimum of 25ms between holes and 42ms-65ms between rows to prevent vibration crossover.

Economic Implications of Precision Blasting

The cost of blasting is often less than 15% of the total operating cost of a quarry, yet it influences roughly 80% of the downstream costs. A well-calculated blast results in a "loose muckpile" that allows excavators to work at their maximum cycle speed. Furthermore, optimized fragmentation means the primary crusher operates at peak throughput with minimal downtime for unblocking "bridge" rocks.

As the industry moves toward **Mining 4.0**, the integration of digital blast design software and drone-based photogrammetry allows for real-time adjustments to parameters. By using 3D face profiles, engineers can calculate the exact burden for every single hole, accounting for any geological anomalies. This level of precision is the future of quarrying, turning the art of blasting into a data-driven engineering discipline.

Effective drilling and blasting management is a continuous cycle of design, execution, measurement, and refinement. By adhering to the principles of rock mechanics and utilizing the technical calculations for burden, spacing, and explosive energy, quarry managers can ensure a sustainable and profitable operation. The shift toward optimized hole diameters and the strategic use of emulsion explosives represents the pinnacle of modern quarry engineering, balancing production needs with environmental responsibility and cost efficiency.

Baca Juga (Artikel Terkait)

- **Advanced Geotechnical Engineering: A Comprehensive Guide to Rock Mechanics and Pillar Optimization in Mining Operations**

  URL: http://www.alliedcogroup.com/rock-mechanics-pillar-optimization-mining-engineering-guide.pdf

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