Fragmentation Management for the Downstream Value Chain

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QUARRY ACADEMY

Improving Processes. Instilling Expertise.
Topics to Be Covered

• The purpose of drilling & blasting in producing crushed stone
• Relative cost of drilling & blasting vs other quarrying activities
• Cost/production opportunities offered with optimized fragmentation
• Factors affecting fragmentation
• Self-evaluation of fragmentation
Why Drill and Blast?

Drill and Blast is the first step in the breakage and separation process. Therefore, it impacts all the subsequent downstream process efficiencies.

Drill and Blast is still the most cost effective method to break and move the large volumes of rock – when done correctly!
Rock Breakage Phases

Cum % passing

Size mm

0% 20% 40% 60% 80% 100%

0.1 1 10 100 1000 10000

ROM

In-situ

Crusher Product

Energy $
## Relative Energy and Costs

<table>
<thead>
<tr>
<th></th>
<th>Specific energy kwh/t</th>
<th>Energy factor</th>
<th>Cost factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill and Blast</td>
<td>0.1 – 0.25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Load and haul</td>
<td>0.2 – 0.5</td>
<td>1 - 5</td>
<td>2 - 10</td>
</tr>
<tr>
<td>Crushing</td>
<td>1 – 2</td>
<td>4 - 20</td>
<td>2 - 10</td>
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Generally the harder the rock, the higher the factor.
Drilling & Blasting Cost - Leverage

- Drilling: 33%
- Blasting: 11%
- Secondary Breakage: 1%
- Loading: 15%
- Hauling: 30%
- Crushing: 10%
Drilling & Blasting Cost - Leverage

• Drilling and blasting is the first step in the comminution processes

• A 10% increase in drilling and blasting cost can be compensated by
  ✓ 4.6% reduction in excavation and hauling costs
  ✓ 6.4% reduction in crushing

or

1% decrease in excavation/hauling = 2.1% increase in D&B
or
1% decrease in crushing/benefaction = 1.6% increase in D&B
Fragmentation Management

Profit = Revenue - Cost

- Rip-rap (+$)
- Best Saleable Product(s) (+$)
- Fines (-$)

Blasting effort $/t

Optimum

Percent Passing

Rock Size (in)
Fragmentation Management

Profit = Revenue - Cost

Profit = Revenue - Cost

Blasting effort $/t

Optimum Cost

Revenue
Common Fragmentation Issues

- Oversize breakage costs
- Excavator costs (diggability)
- Crusher costs (throughput)
- Recovery (fines)
Fragmentation Optimization Opportunities

- Better digging and bucket fill factors
- Consistent crusher throughput and power draw
- Reduction in blast induced damage
- Reduction in material losses (*more saleable product*)
- Potential to produce better priced end product
Factors Affecting Fragmentation

- Geology
  - Joint Spacing
  - Joint Condition
  - Joint Strike & Dip
  - Bedding Planes Strike & Dip
  - Bedding Plane Condition
  - Bedding Plane Spacing
  - Rock Strength
  - Rock Elasticity
  - Hard/Soft Seams
  - Grain Size
  - Sonic Velocity

- Design
  - Burden
  - Spacing
  - Hole Diameter
  - Stemming
  - Subdrilling
  - Delay Timing & Accuracy
  - Bench Ht
  - Staggered/Square Pattern

- Explosives
  - Energy
  - Energy Partitioning
  - Density
  - Velocity of Detonation
  - Coupling
Balancing for Fragmentation
Geology Factors

Structure describes the features which primarily determine the fragmentation performance of the rock mass.

- Jointing/Bedding
  - Defines maximum fragment size
  - Influences transmission of stress wave
  - Influences gas penetration

- Rock Strength & Elasticity
  - Determines how the rock mass responds to the explosive energy applied
  - Influences confinement on explosive
Rock Structure

Block size < 0.7 ft (0.2 m)

Friable and Powdery

Block size > 6.5 ft (2 m)

Massive
Rock Structure

Block size 0.6 – 3 ft
(0.2 – 1 m)

Fractured

Block size 0.3 – 0.8 ft
(0.1 – 0.25 m)

Blocky
Rock Properties

Density

Compressive Strength

Tensile Strength

Young's Modulus
Effect of Rock Stiffness

High rock stiffness

Low rock stiffness
Effect of Rock Stiffness

High rock stiffness

Low rock stiffness
Blast Design Factors

• Hole Diameter
  • Influences energy distribution and burden stiffness

• Burden/Spacing
  • Influences energy distribution and burden stiffness
  • Relationship with joint spacing affects oversize

• Bench Height
  • Influences burden stiffness

• Delay Time & Accuracy
  • Influences interaction between detonating holes

• Staggered/Square pattern
  • Determines distribution of energy in rock mass
Hole Diameter & Burden/Spacing

Free Face

Small dia holes

Free Face

Large dia holes

Poor fragmentation zones
Blast Design Factors

- Hole Diameter
  - Influences energy distribution and burden stiffness
- Burden/Spacing
  - Influences energy distribution and burden stiffness
  - Relationship with joint spacing affects oversize
- Bench Height
  - Influences burden stiffness
- Delay Time & Accuracy
  - Influences interaction between detonating holes
- Staggered/Square pattern
  - Determines distribution of energy in rock mass
Burden Stiffness

Stiffness = Height/Burden
Blast Design Factors

- Hole Diameter
  - Influences energy distribution and burden stiffness
- Burden/Spacing
  - Influences energy distribution and burden stiffness
  - Relationship with joint spacing affects oversize
- Bench Height
  - Influences burden stiffness
- Delay Time & Accuracy
  - Influences interaction between detonating holes
- Staggered/Square pattern
  - Determines distribution of energy in rock mass
Interhole Delay Time & Fragmentation

(after Cunningham, 2005)
Blast Design Factors

• Hole Diameter
  • Influences energy distribution and burden stiffness

• Burden/Spacing
  • Influences energy distribution and burden stiffness
  • Relationship with joint spacing affects oversize

• Bench Height
  • Influences burden stiffness

• Delay Time & Accuracy
  • Influences interaction between detonating holes

• Staggered/Square pattern
  • Determines distribution of energy in rock mass
Explosive Energy Distribution

Square Pattern

Staggered Pattern
Explosives Factors

- Velocity of Detonation
  - Indication of energy available
  - Indicator of energy partitioning (shock vs gas)
  - Determines how explosive energy is applied to rock mass
- Density
  - Influences total explosive energy available in a hole
- Coupling
  - Influences transfer of explosive energy to rock mass
Explosive Selection

Hard and Brittle Rock

- High VOD
  - Pressure vs. Volume graph with points A, B, C, D, E
  - Rock stiffness indicated

- Low VOD
  - Pressure vs. Volume graph with points A, B, C, D, E
  - Rock stiffness indicated

Soft and Plastic Rock

- High VOD
  - Pressure vs. Volume graph with points A, B, C, D, E
  - Rock stiffness indicated

- Low VOD
  - Pressure vs. Volume graph with points A, B, C, D, E
  - Rock stiffness indicated

Legend:
- Hard and Brittle Rock
- Soft and Plastic Rock
- High VOD
- Low VOD

VOD:
- High VOD
- Low VOD

Rock Types:
- Hard and Brittle Rock
- Soft and Plastic Rock

Stiffness Levels:
- Hard and Brittle Rock: High (D), Low (O)
- Soft and Plastic Rock: High (D), Low (O)
Explosive Selection to Meet Rock Structure and Strength Properties

Strength

Structures

High VOD
High density

Medium VOD
High density

High VOD
Low density

Low VOD
Low density
Explosive Selection to Meet Blast Objectives

- **Low VOD**
  - Med-High density

- **High VOD**
  - High density

- **Low VOD**
  - Low density

- **High VOD**
  - Med density
In Summary Fragmentation Results. . .

Have a significant impact on quarry economics

Therefore, Fragmentation Optimization …

• Should consider all the downstream processes rather than just drill and blast costs
• Should consider quality as well as quantity
• Should be site specific
• Should be flexible to cope with site specific changes and market conditions
‘Take Home’ Questions on Fragmentation

- Does the shovel/loader bucket fill with a single smooth pass?
- Does the shovel/loader remain stable during digging (no rocking or violent movements)?
- Does the muckpile flow during digging?
- Do the haul trucks dump at the crusher without delay?
- Is the throughput and power draw of the crusher consistent?
- Is secondary breakage required on a regular basis?
- Are the desired product sizes produced without waste (fines or other unsaleable/low profit products)?