Tuning the Feed to the Primary Crusher
Lawrence J. Mirabelli – Senior Technical Consultant
Tuning the Primary Crusher Feed

- Blasting is only one part of the Business Improvement Process

Business Improvement Culture
- Proactive
- “Do it right today.”
- “Do it better tomorrow.” and ........
- “Whatever you do. Track metrics and pay attention to details.”
- Focus on the overall process
- Determine the effects on the entire process from changes to any or all parts of it.

Continuous Improvement makes successful change!
What we want.  vs  What he have.

What we have.
What we want. vs What he have.

What the blast contributes to the crushing process.
Crushing Rock with Explosives
Blasting - A Value Adding Process

- Blasting is the first crushing stage and the first stage to add value to the quarry product line.
- The muck pile is the crushed rock that is the direct result of the drill and blast process.
- “Run of Quarry” (ROQ) is a general term used to describe the gradation of the crushed rock in the blast muck pile fed to the primary crusher. ROQ changes from load to load, blast to blast.
- That total percentage of blast muck pile that does eventually make up the ROQ is the measure of the effectiveness of your drill and blasting program.
- Normally, nearly all of the blast muck pile makes up the ROQ. Or ……does it?
OR Does it?
Measures of Efficiency in the Blasting Program

- The percentage of the blast muck pile that makes up the ROQ without incurring additional cost is a measure of the efficiency of the drill and blasting program.
- Consistency in the range of gradation making up the ROQ is another measure of the efficiency of the drill and blasting program.
- The difference between the range of gradation for the ROQ and the optimal feed gradation of the primary crusher is the last measure of the efficiency of the drill and blast program.
Oversize Rock in ROQ Reduces Value.
What’s the real cost of oversize?

- Remember it has already been drilled and blasted once!
- It needs to be broken again (hammering) either in-place in the muck pile then loaded and hauled off to the primary crusher with the rest of the muck pile..... or
- Lifted and sorted off to the side for later handling (blast, hammer or drop ball) ......or
- Loaded, hauled and dumped out of the way for later handling (blast, hammer, drop ball)....
- Hammer, Drill and Blast, or Drop Ball.
- Lift again and hauled off to the crusher.
- Used as safety berm for ramps and benches and inventoried for future use.
- Remember “hammer” rock alone is a uniformly coarse fragmentation. It runs at a much reduced rate through the primary!
Gradation of Impact Hammer Pile..

Jaw Crusher Study
July 5, 2006

Jaw Crusher Output
Blast 705

Particle Size (inches)

Percent Passing

0.00E+00 1.00E+00
0.10E-01 2.00E-01
1.00E-01 3.00E-01
2.00E-01 4.00E-01
3.00E-01 5.00E-01
4.00E-01 6.00E-01
5.00E-01 7.00E-01
6.00E-01 8.00E-01
7.00E-01 9.00E-01
8.00E-01 1.00E+00

- HP Rock
- Jaw Crusher Output
- Blast 705

07/06/2006

07/05/2006

Quarry Academy
Dyno Nobel
SANDVIK
Hammer Rock at the Primary Crusher
Toe or floor grade problems reduce Value.
Examples of ROQ Gradations

Jaw Crusher Study
July 5, 2006

4 inch diameter blasthole
Norberg C110 44 x34
Limestone

6 ½ inch diameter blasthole
54-74 Gyratory Allis Chamblis
Granite
Monitor / Measure Performance

- **Pre-Blast**
  - ✔ Drill hole integrity – borehole camera
  - ✔ Drill hole location and orientation in bench – borehole survey
  - ✔ Bench face shape, front row and inter-row burdens - laser survey

- **During Blast**
  - ✔ Rock movement; timing; stemming ejection
  - ✔ Efficiency of explosives; timing; inter-hole effects; stemming confinement.
  - ✔ Inter-hole effects; blast damage - Dynamic pressure measurement
  - ✔ Blast vibration and overpressure
Accurately lay out and drill the blast pattern

Not only on the surface

But also at the bottom of the hole?
Monitor / Measure Performance

Compare to design.

Recognize equipment limitations.
Heading - Underground Quarrying

Into the face.

At the face.
Monitor / Measure Performance

- **Post-Blast**
  - Muckpile profile - Laser Survey
  - Fragmentation - Photoanalysis
  - Oversize – physical count
    - Rehandle activities
  - **Equipment performance and costs**
    - Loading Rate
    - Bucket fill factor
    - Cycle Time
    - Crusher feed rate
    - Additional equipment
      - Loaders; Excavators, Rock Hammer etc
Fragmentation Photoanalysis

Jaw Crusher Study
July 5, 2006

Limitation of Photoanalysis method.
## Monitoring Digability of the Muck Pile.

### CAT 988H

<table>
<thead>
<tr>
<th>Date</th>
<th>Operating Time</th>
<th>Daily Total To Jaw</th>
<th>Average Cycle Time</th>
<th>Average Bucket Weight</th>
<th>Buckets per shift</th>
<th>Percent Buckets Over 12 ton</th>
<th>Down Time</th>
<th>Overall Crusher Feed</th>
<th>Adjusted Crusher Feed</th>
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<td>hrs:min:sec</td>
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<td><strong>394.35</strong></td>
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<tr>
<td><strong>Average</strong></td>
<td>0:01:50</td>
<td>12.05</td>
<td>52.4%</td>
<td><strong>394.35</strong></td>
<td><strong>442.66</strong></td>
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</table>
Distribution of Bucket Weights for CAT 988H on Total Shot Basis

Number of Occurrences vs. Bucket Weight Range (Tons)

Baseline 2/22/07
Validation Blast 1 3/05/07
Validation Blast 2 3/12/07
Validation Blast 3 3/21/07
Validation Blast 4 3/28/07
Optimizing Blast Fragmentation

Blast Design Variables

Controllable variable
Uncontrollable variable
Explosive
A controllable variable in blast design

● What explosive is chosen to be used.
  ✓ Density (g/cc)
  ✓ Velocity of Detonation (ft/sec)
  ✓ Energy (kcal/lb)
  ✓ Water Resistance
  ✓ Form
    • Package
    • Bulk
      – Dry Blend / Free Flowing
      – Wet Blend / Augerable
      – Pumpable Blend
Confinement
A controllable variable in blast design

- How the explosive energy is confined so that it can do work.
  - Amount of material surrounding the explosive in the drill hole
    - Material between the drill hole and any static or dynamic free space.
  - Distance of the drill hole from an open face.
    - Burden
  - Distance of drill holes relative to one another.
    - Burden
    - Spacing
  - Type and amount of stemming / non explosive decking
Distribution
A controllable variable in blast design

- How the explosive energy is distributed throughout the rock mass – vertically and horizontally to do work.
  - Diameter of the drill hole.
    - Limits the diameter of explosive.
  - Diameter of the explosive.
    - Package explosive can limit the effective diameter of the blasthole.
  - Depth of the drill hole and the amount loaded.
    - Accuracy
    - Explosive deck(s)
  - Orientation of drill holes
    - Relative to one another – staggered, in-line
Keys to Optimizing Explosive Performance

- Choose Optimum Explosive Type.
- Optimize the distribution of the explosive’s energy.
- Optimize confinement of the explosive’s energy.
Keys to Optimizing Explosive Performance

- Explosive Energy Distribution Optimization
  - Increased distribution reduces overall rock fragment size.
  - Decreased distribution increases overall rock fragment size.
  - Even distribution achieves uniform fragmentation.
  - Important to maintain as even distribution from top to bottom of bench as possible.
  - Widely spaced jointed rock mass requires reduced patterns.
# Keys to Optimizing Explosive Performance

## Explosive Distribution

<table>
<thead>
<tr>
<th>Hole Diameter (in)</th>
<th>4</th>
<th>6</th>
<th>7</th>
<th>9</th>
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<td>Bench height (ft)</td>
<td>40</td>
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<tr>
<td>Burden (ft)</td>
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<td>15</td>
<td>17</td>
<td>21</td>
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<tr>
<td>Spacing (ft)</td>
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<td>17</td>
<td>20</td>
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<td>Stemming (ft)</td>
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<td>10.5</td>
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<td>15</td>
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<td>Subdrill (ft)</td>
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<td>4.5</td>
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<td>Explosive</td>
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<td>ANFO</td>
<td>ANFO</td>
<td>ANFO</td>
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<td>2.7</td>
<td>2.4</td>
<td>1.9</td>
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<td>Explosive Distribution (1-T/H)x100</td>
<td>83%</td>
<td>74%</td>
<td>70%</td>
<td>63%</td>
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<td>Energy Factor (kcal/ton)</td>
<td>200</td>
<td>200</td>
<td>199</td>
<td>195</td>
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<tr>
<td>Fragmentation F80*</td>
<td>25 inch</td>
<td>29 inch</td>
<td>29.5 inch</td>
<td>31 inch</td>
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</table>

Equivalent Powder Factor or Energy Factors ≠ Equivalent Explosive Distribution

*more dramatic change in uniformity.
Energy Distribution Comparison – Planar

9 inch, 21 ft x 26 ft

4 inch, 10 ft x 12 ft

Horizontal slices of bench @ 32 ft down from surface

Equivalent overall powder factors
Keys to Optimizing Explosive Performance

- Explosive Energy Confinement Optimization
  - Explosive Energy must be confined long enough after detonation to establish fractures and displace the rock mass.
    - Design timing to provide adequate relief without loss of confinement.
  - Control paths of least resistance for explosive energy
    - load according to geology and face conditions
    - use adequate and proper stemming materials
  - Use multiple primers to insure explosive column performance.
  - Accurately layout and drill the blast pattern
  - Reminder:
    - over confinement = excessive vibration
    - under confinement = excessive air blast
Statistical Approach to Integrating Blasting into the Quarrying Process
Cement Producer – New York
Gradation of ROQ vs Blast Pattern
Statistical Analysis

\[ y = -751.1x^2 + 3013.2x - 1807.5 \]

\[ R^2 = 0.8833 \]
Evaluation of Repumpable Emulsion – Case Study
Granite Quarry – Macon, GA
Fragmentation Dictated by Local Geology

ANFO / Titan 1000LD30
Baseline Blasts [15 ft x 18 ft] and Blast 9 [14 ft x 18 ft]

Fragmentation
ANFO / Titan XL 1000LD30
Optimization Test Blast

Percent Passing | Blast # 50 | Average
--- | --- | ---
D10 | 2.2 | 2.04
D25 | 3.7 | 3.39
D50 | 6.9 | 6.45
D75 | 13.3 | 12.68
D90 | 20.5 | 20.60

Cumulative % Passing

Equivalent Spherical Size in Inches

Average ANFO / Titan 1000LD30 Baselines [15 ft x 18 ft]
**Fragmentation Dictated by Local Geology**

<table>
<thead>
<tr>
<th>Equivalent Spherical Size in Inches</th>
<th>ANFO / Titan1000LD30</th>
<th>TITAN XL1000</th>
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<td>0.1</td>
<td>0.1</td>
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<td>0.375</td>
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<td>0.75</td>
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<td>1.5</td>
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<td>64</td>
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**Bench 4**

Blast 9 & Blast 10 14 ft x 18 ft

**Fragmentation**

**TITAN XL 1000**

**Optimization Test Blast**

<table>
<thead>
<tr>
<th>Percent Passing</th>
<th>Blast # 02-04</th>
<th>Average</th>
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<td>D25</td>
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<td>D50</td>
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<td>D75</td>
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<tr>
<td>D90</td>
<td>27.0</td>
<td>20.60</td>
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**ANFO / Titan1000LD30**

**TITAN XL1000**
Muck Pile Profile vs Relief Time

ANFO / Heavy ANFO (4 rows, 15 ft x 18 ft Pattern)

4 rows, BH 25 ms, BR 93 ms

ANFO / Heavy ANFO (4 rows, 15 ft x 18 ft Pattern)

4 rows, BH 25 ms, BR 109 ms

ANFO / Heavy ANFO (4 rows, 15 ft x 18 ft Pattern)

4 rows, BH 25 ms, BR 126 ms
Electronic Detonator – Case Study
Aggregate Quarry - Nova Scotia, Canada

Improving Processes. Instilling Expertise.
Svedala model 42-65.

Reduced to 150 mm (6 inch) and less
Fragmentation Measurement

- Reflex system

[Images of equipment with labeled parts: Camera, RF Tag, Sensors]
Fragmentation Measurement

- Momentum System
  - One image per second
  - Monitoring only when there is material on the conveyor belt.
  - Day shift monitoring only.
Momentum Fragmentation Analysis System
Impact of Electronic Detonators

- Blast Pattern and Powder Factor maintained constant.
  - 6 1/2 inch diameter hole; PF 1.68 lb/cu yd.
- Finer and more uniform rock size distribution
Impact of Electronic Detonators

- Ten percent (10%) energy saving at primary crushing

Soft rock

Medium rock
Impact of Electronic Detonators

- Fifteen percent (15%) productivity increase at primary crushing.
- Ten percent (10%) reduction in crusher energy.
Blast-induced rock damage evaluation

A 30% tensile & compressive strength reduction was found in the rock after blasting. No difference was seen between initiation systems.
Scanning Electron Microscope (SEM) for the quantification of micro-cracks (-50 µm) shows a higher density of micro-cracks after blasting. But again no differentiation with initiation system type.
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