Common Blasting Issues

• Productivity
  – Minimizing drill/blast cost
  – Maximizing production
  – Reducing oversize/fines
  – Adjusting drill/blast program to optimize total productivity

• Community Impact
  – Reduce complaints
  – Minimize barriers to expansion/permit renewal
  – Reduce/eliminate litigation costs

• Community Impact may represent most serious challenge to an operations long term viability
Minimizing Community Footprint

• Reduce community perception of blasting
  – Reduced overpressure
  – Reduced ground vibration amplitude
  – Improved frequency spectra
• Technology available to meet needs
• Can be impacted by regulatory barriers
• Can be negated by lack of understanding of process
Improved Blasting Designs

- Electronic Initiation Systems
  - Precision
  - Programmability
  - Flexibility

- Vibration prediction processes
  - Active vibration cancellation
  - Real time analysis
  - Alternative timing sequences

- Impact can be negated or blocked by regulatory limits based on older technology
Where It All Began
VIBRATIONS FROM INSTANTANEOUS
AND MILLISECOND-DELAYED
QUARRY BLASTS

By Wilbur L. Duvall, Charles F. Johnson, Alfred V. C. Meyer,
and James F. Devine

* * * * * * * * * * report of investigations 6151

US Department of Interior
Office of Surface Mining
Reclamation and Enforcement

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UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director
• Published in 1963
• Measured vibration from single row shots at a single location in Iowa
  – 3 hole shots
  – 7 hole shots
  – 15 hole shots
• Holes detonated with Det Cord (no down hole dets)
• Holes delayed using 9ms and 17ms surface delays
• Delayed shots shows significant vibration reduction
• Scatter for electric seismic caps used was +/- 1 ms
• 8ms was listed as minimum delay
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<th>Number of holes</th>
<th>Delay interval, milliseconds</th>
<th>Charge/delay, pounds</th>
<th>Radial intercepts</th>
<th>Vertical intercepts</th>
<th>Transverse intercepts</th>
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So what did this tell us???

- 0 delay does not work !!!!
- 9ms was never the lowest ppv
- 17ms was not lowest ppv in all cases
- 34ms was not lowest ppv in all cases
- 0 delay ppv did not increase proportionally to charge weight increases.
BLASTING VIBRATIONS
AND THEIR EFFECTS ON STRUCTURES

By Harry R. Nicholls, Charles F. Johnson, and Wilbur L. Duval

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UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
USBM Bulletin 656

• Published in 1971
• Not so much a research report but a summary of previous work
• Single row shots and simple multi row shots
• 0ms, 9ms, 17ms and 34ms delays
• Set vibration limit of 2.00 ips
• Used Scaled Distance to maintain safe blasting limits
• 8 ms criterion again implied based on previous research
Scaled Distance

\[ SD = \frac{d}{(wt)^{1/2}} \]

Where:
\( d \) = distance to dwelling
\( wt \) = max charge per 8ms delay
What else does it say ????

- Electric Caps reduce vibration more compared to cord (accuracy)
- Geology, rock type and orientation effects vibration within Scaled Distance limits
- Seismographs, not scaled distance is recommended to insure safe blasting limits are maintained
Summary of Early Research

• Mostly simple, single row shots
• Simple delay timing achieved with surface delays
• 8 ms criterion simply because 9ms caps available
• No consideration of frequencies
• Based on two assumptions
  – As distance increases, vibration decreases
  – As charge weight decreases, vibration decreases
• Neither assumption is always true
  – Undershooting
  – waveguides
Scaled Distance

\[ SD = \frac{D}{W^{1/2}} \]

Where

SD = Scaled Distance
D = Distance from the blast to structure (ft.)
W = Maximum pounds per delay of detonated explosives

SMCRA 38CSR2-6.5.i. and West Virginia 199CSR1-3.6.h. stipulate minimum scaled distance factors or maximum allowable PPV to be used for the protection of structures. These requirements are:

<table>
<thead>
<tr>
<th>Distance from blast to structure (ft.)</th>
<th>Scaled Distance factor</th>
<th>Maximum PPV allowed (ips)</th>
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</thead>
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<tr>
<td>0 - 300</td>
<td>50</td>
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<td>301 – 5,000</td>
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<tr>
<td>5,000+</td>
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Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting

By D. E. Siskind, M. S. Stagg, J. W. Kopp, and C. H. Dowding
RI - 8507

- Documented importance of frequency in structure response to blasting
- Created frequency based safe blasting limits
- Used regression to develop vibration prediction formulas
- Still promoted scaled distance concept
APPENDIX B—ALTERNATIVE BLASTING LEVEL CRITERIA

Safe blasting vibration criteria were developed for residential structures, having two frequency ranges and a sharp discontinuity at 40 Hz (table 13). There are blasts that represent an intermediate frequency case, being higher than the structure resonance (4 to 12 Hz) and lower than 40 Hz. The criteria of table 13 apply equally to a 35-Hz and a 10-Hz ground vibration, although the responses and damage potentials are very much different. Using both the measured structure amplifications (fig. 30) and damage summaries (figs. 52 and 54), a smoother set of criteria was developed. These criteria have more severe measuring requirements, involving both displacement and velocity (fig. B-1).

Figure B-1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.
Figure 10.—Summary of ground vibrations from all surface coal mines. The component H-1 approximates “radial” and H-2 “transverse”.

SD approx = 18
PPVmin = 0.10 ips
PPVmax = 2.90 ips
So where do we stand now ???

- RI 8507 provides documented, safe blasting criteria
- Still pays homage to scaled distance concept
- Predicted PPV using SD varies widely, not a good predictor at all
So where do we stand now ???

• How can we change SD to impact vibration?
  – Smaller hole size
  – Reduced pattern
  – 1 hole per “delay”
  – Decking
• Most have impact on cost
• Not very effective tool for reducing vibration
• Other options available
Vibration Control
Vibration Control

• Passive
  – Reduced charge weights per hole
  – Decking
  – Smaller patterns
  – Smaller hole diameter
Vibration Control

• Active
  – Linear Superpositioning
    • Established concept
    • Enhanced by accuracy of electronic detonators
    • Advanced by new concepts in software design
Linear Superpositioning

• Seismic Wave Interaction
  – Acts as sound waves in the ground
    • Compression waves
    • Lower frequency with distance
    • Waves can be influenced by other waves
  – To understand seismic wave interaction, we can look at simple sound wave interaction
Sound can be represented by waves

Simple sine wave for single sound frequency
When two similar sounds are combined that are only slightly out of phase...

One pure sound a fraction of a second after the next
We get a single sound almost twice as loud

Sum of two waves slightly out of phase
If the two sounds are perfectly out of phase....

Sum of waves equals zero sound
If the two sounds are perfectly out of phase....there would be no sound.

Sum of waves equals zero sound.
Critical Factors

- Determine phase delay to perfectly cancel waves
- The shape of the wave (wave period) determines delay that provides optimum cancellation
This concept has led to the development of active noise cancellation applications

- Headphones
- Automobiles
- Aircraft
- Heavy equipment
QuietComfort® 15 Acoustic Noise Cancelling® headphones

Our best headphones reduce more noise across a wider range of frequencies. Enjoy your music and movies even more, with clear and lifelike sound. Comfortable, around-the-ear fit. AAA battery: 35 hours average life. Ideal for frequent flyers.

The headphones that pioneered an industry are now even better.

QuietComfort 15 headphones feature exclusive Bose® advancements in noise reduction technology. You hear less noise than ever before, and even more of your music and movies. With the quality sound you expect from Bose. And a lightweight fit that stays comfortable for hours. It's a combination of benefits unmatched in the industry.
Toyota develops noise-cancelling system for cars

Expanding on the same concept used in noise-cancelling headphones, Toyota has developed a noise cancelling system for its Japanese-market Crown Hybrid that nearly eliminates engine sound within the passenger compartment. The system uses a complex system of microphones,
The same technology has been transferred to ground vibration control

- Record “background” vibration
- Impact target with similar amplitude vibration out of phase
- Up to ten times more effective than traditional isolation systems
Semiconductor Manufacture

Electro-Damp® Active Vibration Isolation Systems

Electro-Damp® II Active Pneumatic Vibration Damping System
PEPS® II Digital Precision Electronic Positioning System
AccuDock™ Precision Kinematic Docking System
Quiet Island®
Sub-Floor Platforms and Supports
Tables for electron microscopes
Active Vibration Cancellation

- In manufacturing, vibration is cancelled by using actuators to provide the out-of-phase signal
Active Vibration Cancellation

- In blasting we use explosive column detonations to cancel out vibrations from previous hole detonations
Signature Analysis Basics

• Similarities
  – All require seismogram from a single hole
  – Waveform is digitized
  – Wave is used over and over to simulate multiple hole shots
  – Delays simulated by time lagging waves on x axis
  – Waves are summed to represent delayed multiple hole shots

• ALL require use of electronic detonators to be effective
Linear Superpositioning

Individual Waves

Combined Waves
Linear Superpositioning

Individual Waves

Combined Waves

No delay
Linear Superpositioning

8 ms delay
Linear Superpositioning

67 ms delay
Linear Superpositioning

42 ms delay
Linear Superpositioning

92 ms delay
Linear Superpositioning

115 ms delay
Differences Between Programs

- Number of seismograms used
- Generic signature wave from production blast
- Shot design metrics
  - Simple shots (holes and rows)
  - More complex designs rows, number of holes per row
  - Added complexity
    - Import precise hole locations (GPS)
    - Import seismograph locations (GPS)
    - Import hole loading metrics
    - Import rock properties
    - Import p-wave velocity
    - Utilize multiple signature holes
    - Utilize existing production shot data
Simple Linear Superpositioning
Simple Linear Superpositioning

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<th>Row</th>
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<tr>
<td>2</td>
<td>21</td>
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<tr>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td><strong>4</strong></td>
</tr>
</tbody>
</table>

**Delay Between Holes**
- Starting Delay (ms): 10
- Ending Delay (ms): 25
- Resolution (ns): 1

**Delay Between Rows**
- Starting Delay (ms): 50
- Ending Delay (ms): 125
- Resolution (ns): 10

**Delay Between Decks**
- Number: 0

**Alpha-Blast - Evaluate Delays**

[Diagram of the software interface showing the delays and options]
## Simple Linear Superpositioning

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<th>Hole</th>
<th>Row</th>
<th>Deck</th>
<th>Charges</th>
<th>Peak</th>
<th>Radial</th>
<th>Vertical</th>
<th>Transverse</th>
<th>Graphs</th>
<th>RHz</th>
<th>VHz</th>
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More Complex
### More Complex

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*Note: The table contains data for different blast numbers and dates, along with various measurements such as distance, De, Radial, Vertical, Traverse, Acoustic, Radial Hz, Vertical Hz, and Traverse Hz.*
More Complex
### More Complex

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Advanced Techniques

- Have not hit mainstream industry
- Testing new concepts
- ALL require use of electronic initiators
Multiple Seed Waveform

- Multiple Seed Wave (MSW)
  - Extension of Standard Method
- Can’t Measure Everywhere
  - Establish Local Variability
  - Interpolate Between Measured Sites
- Some Locations Are Shielded
  - By Broken Rock
  - By Open Face
  - Develop Local Shielding Parameters
Multiple Seed Waveform

• Waveforms for Measured Sites
  – Existing Single-hole Data

• New Location Becomes Critical
  – Complaints
  – New Construction

• Technique Resolves Problem
  – Use Existing Data
  – “Average” the Waveforms
  – No Need for Additional Holes
Silva – Lusk Method

- Variation Between Signatures
- “Monte Carlo” Technique
  - Random Signatures
  - Fit to Existing Signatures
Silva – Lusk Method
Silva – Lusk Method

- Use an Array of Randomized Signatures
- Find out the Bounds of Vibration
  - What is the “Worst” you might get?
Wavelet Transform

- Analyzing Blast Performance from Seismograph Data
- Use Existing Compliance Records
- Perform “Wavelet Transform”
- Shows Details of Shot Performance
  - “Buried” in Complex Waveform
Wavelet Transform

- Wavelet Transform
- High Peaks in Background Due to Geology
- Low Peaks in Foreground Due to Detonations
  - Hole Firings Marked by Arrows!
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Improving Processes. Instilling Expertise.