GROUND VIBRATIONS
Blasting versus Earthquakes

Effects and Responses on
Coal Waste Impoundments
And
Tailings Dams
Spatial Relationships

Compliance House, 450'

Complaint House, 550'

Impoundment, 1500'

Compliance House, 450'
Ground Vibrations

- Ground Vibrations from either a Blast or Earthquake is a *Forced Vibration*
- In a Forced Vibration the frequency of the vibration is the frequency of the force or motion applied
- In a Vibration there is a rapid oscillation of a particle, back & forth across a central position
Vibration Energy

Blast or Quake

Airblast 1,100 fps

Home or dam

Body Waves 20,000 fps

Surface Waves 5,000 fps
Travel through the ground

Reflected

Reflected boundary

Layer A

Layer B

Seismograph station

Earthquake

Path of seismic wave

New direction of seismic wave

Refraction

Refracted
Frequency

- Number of cycles per second
- Measured in Hertz (Hz)

\[ f = \frac{1}{T} \]

\( T \) (Period) is the time of one cycle

\[ T = \frac{1}{f} \]

- Zero-crossing used by seismographs

\[ f = \frac{1}{2t} \]

\( t \) is the time of ½ a cycle or where the wave crosses zero
Displacement or Amplitude

- The distance a particle moves (A)
- A measured in inches (in)
- Important for damage assessment
Velocity (v)

Peak Particle Velocity

- The rate or speed at which a particle moves
- V is in inches per second (in/s)
- For sine waves: \( v = 2 \pi f A \)
- \( f \) is frequency, Hz
- \( \pi \) is 3.14
- Important for compliance
Acceleration

- The rate at which a particle changes speed

- $a$ is in inches per second squared (in/s$^2$) or gravities (g)

- For sine waves, $a = 2\pi f v$

- Important for coupling
Acceleration

- Acceleration in “g’s” \( a_g = 2 \pi f \frac{v}{386} \)

Where \( a_g = \) Acceleration

\( f = \) frequency

\( v = \) velocity

(To express acceleration in “g’s” divide by 386 inches per second squared)
Seismic Wave Lengths

- Wave Length = propagation velocity/ frequency
  \[ L = \frac{V}{f} \]
- \( V \): the propagation velocity is that of any measurable wave along the surface of the ground
- A practical rule for structures for estimating wave-length-structure size ratio is to use \( L = 300 \text{ ft.} \)
- The effects of any structure would be its extent divided by \( L \), and the greatest differential displacement would be the extent/(\( L/2 \))
BLASTING TIME HISTORY
Amplitude versus time.
For this record, it is particle velocity amplitude. Vibration records could also be acceleration or displacement time histories depending on the devices used to measure the motion.

Period (T) is the time in seconds for one complete vibration cycle or “seconds per cycle.”

Frequency (f) is 1/T or “cycles per second” also “Hz”

Period (T) can usually be estimated by measuring the time between zero crossings, particularly for a record which has a uniform or one dominant frequency.

In this example, the timing marks represent 0.1 sec (100 ms) and the measured period is about 88 percent of the time between marks.

Period (T): \(0.88 \times 0.1 \text{ sec} = 0.088 \text{ sec}\)
Frequency (f): \(1/0.088 = 11.4 \text{ Hz}\)
Earthquakes & Vibrations

- Vibrations of the Earth—caused by the sudden release of energy, usually as a result of displacement of rock along faults.
- Strain builds up until the elastic limit (strength) of the rock is exceeded. The rock then rupture (fails) at a point, snapping back toward an unstrained position, releasing the elastic energy as seismic waves radiating outward.
- The greater the stored strain, the greater the release of energy.
Magnitude & Intensity

- **Magnitude**: a measure of the size (energy release), on the Richter – defined as seismograph reading 100 kilometers from epicenter.

- **Intensity**: a measure of the strength of an earthquake as felt at a particular location (severity of shaking or damage), the Modified Mercalli.

- **Note**: There is no way to make a direct measurement of released energy
### Equivalent/Comparison Mercalli-Richter

<table>
<thead>
<tr>
<th>Intensity - Mercalli</th>
<th>Magnitude - Richter</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to II</td>
<td>1.0 to 3.0</td>
<td>Felt by few, barely noticeable, upper floors</td>
</tr>
<tr>
<td>III to IV</td>
<td>3 to 4 &amp; 4</td>
<td>Noticeable indoors?, many in-few outside</td>
</tr>
<tr>
<td>V to VI</td>
<td>4 to 5 &amp; 5 to 6</td>
<td>Felt by everyone, objects move, hard to stand, some damage to structures</td>
</tr>
<tr>
<td>VII to VIII</td>
<td>6.0 &amp; 6.0 to 7.0</td>
<td>Poor construction, ordinary structures all effected</td>
</tr>
<tr>
<td>IX</td>
<td>7.0</td>
<td>Landsides, wholesale destruction</td>
</tr>
<tr>
<td>X</td>
<td>7.0 to 8.0</td>
<td>Ground failures -cracked</td>
</tr>
<tr>
<td>XI</td>
<td>8.0</td>
<td>Total damage, waves on ground seen</td>
</tr>
</tbody>
</table>
Seismic Waves

• Body Waves: with rock depth speeds up
  – Secondary (S) Wave - known as a shear wave, vibrates perpendicular to the P Wave. Only travels in solids.

• Surface Waves: rolling, shaking motion
  – Rayleigh (R) Waves – Behaves like water waves with an elliptical motion
  – Love (L) Waves – Shear motion in a horizontal plane, therefore most destructive & fastest of the surface waves.
Vibrations or Waves
## Typical Values of P & S Velocities

<table>
<thead>
<tr>
<th>Material</th>
<th>P Velocity</th>
<th>S Velocity</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>13,000-20,000</td>
<td>7,000-11,000</td>
<td>2.70</td>
</tr>
<tr>
<td>Sandstone</td>
<td>8,000-14,000</td>
<td>3,000-10,000</td>
<td>2.45</td>
</tr>
<tr>
<td>Limestone</td>
<td>10,000-20,000</td>
<td>9,000-10,500</td>
<td>2.65</td>
</tr>
<tr>
<td>Shale</td>
<td>6,000-13,000</td>
<td>3,500-7,500</td>
<td>2.35</td>
</tr>
<tr>
<td>Marble</td>
<td>19,000</td>
<td>11,500</td>
<td>2.75</td>
</tr>
<tr>
<td>Clay</td>
<td>3,700-8,200</td>
<td>1,900</td>
<td>1.40</td>
</tr>
<tr>
<td>Soil</td>
<td>500-2,500</td>
<td>300-1,800</td>
<td>1.1-2.0</td>
</tr>
</tbody>
</table>
Compression Waves

Shear Waves
Blasting & Vibrations

- Vibrations that result from mining, quarrying, and engineering operations.
- Of the hemisphere of rock around a blast, only a small fraction of the volume is bounded by a free face close enough to the explosion to be fractured by the pressure front. In the rest of the rock, the pressure front rapidly decays into elastic waves.
- The greater the confinement of the explosive, the less the fragmentation and the greater the formation of elastic waves.
Limits to Rock Breakage

- The zone (critical radius) of non-elastic effects is equal to cube root of the explosive charge weight.
- Examples: 100 lbs ~ 4.6 ft. & 800 lbs ~ 9.3 ft.
- Micro-Fractures – change the elastic properties of the rock, therefore has an effect on the strength & stability of the mass. Can extend for tens of feet.
- Examples: Rules of Thumb – 10 times the borehole diameter, 3” hole ≈ 30 ft. & 8” ≈ 80 ft.
### Rock Velocities & Impedance

<table>
<thead>
<tr>
<th></th>
<th>Longitudinal (P) wave speed</th>
<th>Impedance: ( rk ) density ( \times ) velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>18,200 ft/sec</td>
<td>Granite: 54 lb sec/in(^3)</td>
</tr>
<tr>
<td>Marlstone</td>
<td>11,500 ft/sec</td>
<td>Marlstone: 27 lb sec/in(^3)</td>
</tr>
<tr>
<td>Sandstone</td>
<td>10,600 ft/sec</td>
<td>Sandstone: 26 lb sec/in(^3)</td>
</tr>
<tr>
<td>Chalk</td>
<td>9,100 ft/sec</td>
<td>Chalk: 22 lb sec/in(^3)</td>
</tr>
<tr>
<td>Shale</td>
<td>6,400 ft/sec</td>
<td>Shale: 15 lb sec/in(^3)</td>
</tr>
</tbody>
</table>
Particle Velocity Damage Criteria for Rock Mass

- 10 in/sec. - no fracturing of intact rock
- 10-25 in/sec. - minor tensile slabbing will occur
- 25-100 in/sec. - strong tensile & some radial cracking
- 100 in/sec. - complete breakup of rock mass will occur
Confinement

(a) B = 15'
Completely contained, only failure is pulverisation near the charge and radial tensile failure running out from it.

(b) B = 12'

(c) B = 9'
Surface and subsurface failure almost meet. There will be a shelf of unbroken rock between the two. Doming or surface bulging.

(d) B = 6'
Full crater, burden completely broken out. Surface and subsurface failures run through to the surface.

(e) B = 3'
Full crater, lower volume than optimum fine fragmentation. Noise flyrock, bowl shaped crater.

Figure 7.17. Schematic of the Effect of Decreasing the Burden on Charges Fired in Rock.
Scaled Distance

• Scaling of distance is necessary to predictppv when both charge weight per delay (W), and the distance (D), vary.

• W is the maximum Lbs. of explosive detonated at one instant of time within a 8 ms time frame, within a total blast or shot. There can be one or many equal charges within a single blast, but none will exceed it.

• D is the distance in feet from that source (W) to the structure of concern.
Scaled Distance: $SD = \frac{D}{\sqrt{W}}$

Blast of 40 holes, 200#/h & 3 holes/8ms with structure @ 1,000 ft from blast
- $W = 200#/h \times 3 \text{ holes/8ms} = 600 \text{ #/8ms}$
- $\sqrt{W} = \sqrt{600} = 24.5$
- $D = 1,000 \text{ ft.}$
- $SD = \frac{1,000}{24.5} = 40.8$

Blast of 65 holes, 765#/h & 5 holes/8ms with structure @ 1,500 ft from blast
- $W = 750#/h \times 5 \text{ holes/8ms} = 3,750 \text{ #/8ms}$
- $\sqrt{W} = \sqrt{3,750} = 61.2$
- $D = 1,500 \text{ ft.}$
- $SD = \frac{1,500}{61.2} = 24.5$
## OSM Ground Vibration Criteria

<table>
<thead>
<tr>
<th>Distance</th>
<th>SD</th>
<th>PPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 301</td>
<td>50</td>
<td>1.25</td>
</tr>
<tr>
<td>301 – 5000</td>
<td>55</td>
<td>1.00</td>
</tr>
<tr>
<td>&gt;5001</td>
<td>65</td>
<td>0.75</td>
</tr>
</tbody>
</table>

\[
PPV = 438 \ (SD)^{-1.52}
\]
What are the Most Important Parameters in Evaluating the Adverse Effects?

- Location of the blast
- Location of the compliance structure
- Distance between the two
- Charge weight per delay
- Confinement
- Type of blast
Damage Criteria – Wave Motion

• Frequency (f) and amplitude (A) are the basic elements of harmonic motion, acceleration (a) results from both, while the force (ma) which moves a structure is defined in terms of the velocity (v or ppv) of the motion it produces.

• Kinetic energy (KE) is energy of motion
• a = (4π²)(f²A)
• ma = W/a_g (a)
• v or ppv = (2π)(fA)
• KE = Wv²/2a_g
• Note: acceleration of gravity (a_g) = 32.2 ft/sec² or 386 in/sec²
## Comparison: A Blast to A Quake
*Sandstone-Shale: V = 8,500 fps*

<table>
<thead>
<tr>
<th>Blast</th>
<th>Quake</th>
</tr>
</thead>
<tbody>
<tr>
<td>• f (cps) = 10</td>
<td>• f (cps) = 1.3</td>
</tr>
<tr>
<td>• A (in) = 0.0090</td>
<td>• A (in) = 1.42</td>
</tr>
<tr>
<td>• (a) (in/sec^2) = 36 \sim 0.093 g’s</td>
<td>• (a) (in/sec^2) = 101 \sim 0.262 g’s</td>
</tr>
<tr>
<td>• Ratio of (a) = 1.0</td>
<td>• Ratio of (a) = 2.8</td>
</tr>
<tr>
<td>• (ppv) (in/sec) = 0.57</td>
<td>• (ppv) (in/sec) = 11.60</td>
</tr>
<tr>
<td>• Ratio of (v) = 1.0</td>
<td>• Ratio of (v) = 20.3</td>
</tr>
<tr>
<td>• (f^2A^2) = 0.0080</td>
<td>• (f^2A^2) = 3.6300</td>
</tr>
<tr>
<td>• KE = 0.000410W</td>
<td>• KE = 0.185000W</td>
</tr>
<tr>
<td>• Ratio of KE = 1.0</td>
<td>• Ratio of KE = 451.2</td>
</tr>
<tr>
<td>• E.R. = 0.09</td>
<td>• E.R. = 37.96</td>
</tr>
<tr>
<td>• L = 8,500/10 (\text{ft.})</td>
<td>• L = 8,500/1.3 (\text{ft.})</td>
</tr>
</tbody>
</table>
Summary: Blast or Quake

• Total energy-governed by the duration,
  – Blast: seconds = to the total detonation time plus decay period
  – Quake: minutes for earthquakes waves near their source

• There is an inadequacy in using acceleration as a criterion of damage, there can be no damage/failure unless there is sufficient energy.

• Per the comparison example “a” of quake is only 3 times blast (no harm), but quake did extensive damage.

• Not shown is the quakes’ total energy & duration of significant vibration.
Blast or Quake #2

Mining/Construction Blasting
- Medium to High Frequency
- Highly Transient
- Short Duration
- Transient Waves Die out rapidly
- Short Wave Lengths
- Motion in Various Parts of the Embankment *are not* in Phase

Earthquake
- Very Low Frequency
- Very Large Displacements
- Long Duration
- Generate Large Strains
- Generate a Strong Lurching Action
- Long Waves Shake Dam as a Unit, simultaneously.
## Vibration Parameters @ Different Frequencies

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Frequency</th>
<th>Velocity-ppv</th>
<th>Amplitude</th>
<th>“L” in Soils 2000 fps</th>
<th>“L” in Rock 10,000 fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12 g</td>
<td>0.1 cps</td>
<td>75 in/s</td>
<td>120 in</td>
<td>20,000 ft</td>
<td>100,000 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>1.0 cps</td>
<td>7.5 in/s</td>
<td>1.2 in</td>
<td>2,000 ft</td>
<td>10,000 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>10 cps</td>
<td>0.75 in/s</td>
<td>0.012 in</td>
<td>200 ft</td>
<td>1,000 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>50 cps</td>
<td>0.15 in/s</td>
<td>0.0005 in</td>
<td>40 ft</td>
<td>200 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>100 cps</td>
<td>0.075 in/s</td>
<td>0.00012 in</td>
<td>20 ft</td>
<td>100 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>1000 cps</td>
<td>0.0075 in/s</td>
<td>0.0000012 in</td>
<td>2 ft</td>
<td>10 ft</td>
</tr>
<tr>
<td>0.12 g</td>
<td>10,000 cps</td>
<td>0.00075 in/s</td>
<td>0 000000012</td>
<td>0.2 ft</td>
<td>1 ft</td>
</tr>
</tbody>
</table>
Impoundment or Tailings Dam

• The concept of impounding slurry behind an engineered embankment is the same, coarse refuse versus waste rock, fine refuse versus tailings.

• Note: since MSHAs’ establishment there has been no incidents of embankment instability, which with seismic effects dominate failure causes for upstream dams.
Recent Past Vibration Concerns at Coal Waste Impoundments

• **Martin County Coal**: What were the effects of “construction' blasting on the integrity of the coal barrier and roof of the abandoned underground works below the slurry pool?

• **Brushy Fork Slurry Impoundment**: Is surface mine blasting detrimental to the embankment?
NRC Comments

• “Monitoring of potential failure modes of embankments typically measures ____, and vibrations, especially if blasting is being conducted nearby.”

• “The committee recommends that MSHA and OSM consider requiring additional continuous monitoring in specific instances and evaluate automation of monitoring instrumentation.”
Martin County Coal

- Blasting had prior to the failure taking place, above & within 1,000 ft. of the point of failure.
- No monitoring had taken place (ground motion)
- Review based on Old Jenny Mine in Kentucky results by USBM
Old Jenny Mine

• Jenny Mine Entry ~ 140 ft. below bottom of holes
• Underground roof reading ~ 40% less than surface – body waves underground ~ ½ the intensity of surface motion.
• Maximum mine roof readings ~ 18 in/s
• “Since no observable damage occurred, it was not possible to say at what exact level damage would have occurred for individual events.”
Brushy Fork Slurry Impoundment

- Citizens regarded blasting within a few 1,000ft. of the impoundment embankment as a reason for concern.

- Instrumentation (blasting seismographs) were placed between blasts & structure, plus on the embankment.

- No instability has been seen, & instrument on “dam” has not been triggered.
Seismic Results in Vicinity of Brushy Fork

- No results on dam

- Seismic readings along ridge by a gas wells and gas lines SAFE per the lines and wells, therefore are below any known threshold for ‘earthen’ dam embankments.

- Criteria recommended for ‘dam’ is acceleration, peak particle velocity and Energy Ratio
Date: 10/30/2003 Time: 17:11:40
Event: 9 Record Time: 5.0 s
Client: Jimmy Clem
Operation: Harrod UG
Location: 0.
Distance: 0.
Operator: Ralph King DSMRE
Comment: distance variable
Trigger Level: 0.020 in/s

SN: 3210 v2.69

Summary Data

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>T</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPV (in/s)</td>
<td>0.115</td>
<td>0.090</td>
<td>0.030</td>
</tr>
<tr>
<td>PD (.001&quot;)</td>
<td>0.42</td>
<td>0.32</td>
<td>0.09</td>
</tr>
<tr>
<td>PPA (g)</td>
<td>0.098</td>
<td>0.072</td>
<td>0.039</td>
</tr>
<tr>
<td>FREQ (Hz)</td>
<td>41.7</td>
<td>45.5</td>
<td>83.3</td>
</tr>
<tr>
<td>Resultant PPV:</td>
<td>0.145 in/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Air Pressure:</td>
<td>89 db</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Velocity Waveform Graph Scale:
Time  = 0.100 s
Seismic = +/- 0.160 in/s
Sound  = +/- 0.0023 psi
Company: Marfork Mining

Location: Gas Line Monitoring Point

Operator: Tommy Crabtree

Unit #: 10565 04-Nov-09 at 15:57:49 Event # 10

Seismic

<table>
<thead>
<tr>
<th>Channel</th>
<th>Radial</th>
<th>Transverse</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (in/s)</td>
<td>0.445</td>
<td>0.275</td>
<td>0.205</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>10.40</td>
<td>13.10</td>
<td>11.10</td>
</tr>
<tr>
<td>Displacement (in)</td>
<td>0.0068</td>
<td>0.0033</td>
<td>0.0029</td>
</tr>
<tr>
<td>Acceleration (g's)</td>
<td>0.075</td>
<td>0.059</td>
<td>0.037</td>
</tr>
<tr>
<td>Trigger &gt;&gt;&gt; Peak</td>
<td>1043.9</td>
<td>1033.2</td>
<td>405.3</td>
</tr>
</tbody>
</table>

Air

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
<th>Trigger &gt;&gt;&gt; Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi</td>
<td>0.0609</td>
<td>514.6</td>
</tr>
<tr>
<td>dBBL</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>5.7</td>
<td></td>
</tr>
</tbody>
</table>

Waveform Analysis / Frequency Plot

USBM Limits (RI 8507, 1980)
SuperGraphics - Report

Company: Marfork Mining

Location: Gas Well #34 b.d.s

Notes: N37 55.028 W81 28.379

Gain: 2

Seismic

<table>
<thead>
<tr>
<th>Channel</th>
<th>Radial</th>
<th>Transverse</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (in/s)</td>
<td>0.145</td>
<td>0.155</td>
<td>0.088</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>23.20</td>
<td>18.90</td>
<td>28.40</td>
</tr>
<tr>
<td>Displacement (in)</td>
<td>0.0010</td>
<td>0.0013</td>
<td>0.0005</td>
</tr>
<tr>
<td>Acceleration (g's)</td>
<td>0.055</td>
<td>0.048</td>
<td>0.040</td>
</tr>
<tr>
<td>Trigger &gt;&gt;&gt; Peak</td>
<td>1197.3</td>
<td>381.8</td>
<td>1076.2</td>
</tr>
</tbody>
</table>

Air

Gain: 1

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
<th>Trigger &gt;&gt;&gt; Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi</td>
<td>0.00381</td>
<td>1534.2</td>
</tr>
<tr>
<td>dBf</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>19.6</td>
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</tbody>
</table>

Waveform Analysis / Frequency Plot

USBM Limits (RI 8507, 1980)
**SuperGraphics - Report**

*Company: Marfork Mining*  
*Location: Gas Line Monitoring Point*  

**Notes:** N37 54.882 W81 27.645

<table>
<thead>
<tr>
<th>Distance: N</th>
<th>Wgt. Per Delay: N</th>
<th>Scaled Distance: 0.0</th>
</tr>
</thead>
</table>

**Seismic**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Radial</th>
<th>Transverse</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (in/s)</td>
<td>0.550</td>
<td>0.175</td>
<td>0.235</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>3.50</td>
<td>13.40</td>
<td>11.60</td>
</tr>
<tr>
<td>Displacement (in)</td>
<td>0.0250</td>
<td>0.0021</td>
<td>0.0032</td>
</tr>
<tr>
<td>Acceleration (g's)</td>
<td>0.031</td>
<td>0.038</td>
<td>0.044</td>
</tr>
<tr>
<td>Trigger &gt;&gt;&gt;&gt; Peak</td>
<td>1146.5</td>
<td>179.7</td>
<td>218.8</td>
</tr>
</tbody>
</table>

**Air**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
<th>Trigger &gt;&gt;&gt;&gt; Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi</td>
<td>0.00475</td>
<td>1047.9</td>
</tr>
<tr>
<td>dB (z)</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>13.1</td>
<td></td>
</tr>
</tbody>
</table>

**Waveform Analysis / Frequency Plot**

Seismic Scale: 0.64 in/s/div.  
Air Scale: 0.0022 psi/div.

**USBM Limits (RI 8507, 1980)**

![Graph showing velocity vs. frequency](image-url)
Proposed Blast Monitoring Plan for Impoundments

• Place seismograph at impoundment-natural surface interface

• Place seismograph on surface near closest piezometer

• Place seismic transducers at depth near slurry-coarse refuse interface, parallel to piezometer

• Read and correlate all data after each blast
Conditions for a Observational Approach

• Sensitive Instruments could detect incremental changes that would indicate a tendency toward slope failure before any significant failure occurred

• Blasting could begin at inconsequential levels in a location easily recognized as safe, then increase in accord with instrumental observations

  – Lewis L. Oriard
What is a Safe Blasting Limit

- Remember: regardless of frequency, a vibration must reach a certain intensity before it has any damage potential
  - Should be Site Specific
  - Should be amplitude, frequency, acceleration, particle velocity related - in other words – an envelope on a log-log Tripartite relationship (the Z Curve)
  - Ground Shear Strain induces Liquefaction (~0.02%) and \( \text{Strain} = \frac{ppv}{V} \) (wave velocity)
Figure B-1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.
An Old Criteria with a New Use

- **Energy Ratio (E.R.) = $a^2/f^2$**

- **Examples of Tests Near Brushy Fork**
  - 01/10/09 E.R. = $0.42^2/10.6^2 = 0.00156$, g’s = 0.013
  - 05/10/09 E.R. = $0.74^2/10.6^2 = 0.00487$, g’s = 0.023
  - 03/11/09 E.R. = $1.22^2/4.20^2 = 0.08438$, g’s = 0.038

- **Examples of close –in Blast**
  - f of 3.0 cps & A of 0.10 inches., therefore E.R. is:
    - E.R. = $2.96^2/3.0^2 = 0.9735$, g’s = 0.092
  - f of 30.0 cps & A of 0.01 inches, therefore E.R. is:
    - E.R. = $29.49^2/30.0^2 = 0.966$, g’s = 0.916
### PPV for Quakes at Frequency ‘f’ of 1cps

<table>
<thead>
<tr>
<th>magnitude</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. ‘gs’</td>
<td>0.0008</td>
<td>0.0029</td>
<td>0.01</td>
<td>0.038</td>
<td>0.13</td>
<td>0.48</td>
<td>1.6</td>
</tr>
<tr>
<td>PPV</td>
<td>0.02”/s</td>
<td>0.18”/s</td>
<td>0.63”/s</td>
<td>2.4”/s</td>
<td>8.2”/s</td>
<td>30.1”/s</td>
<td>101”/s</td>
</tr>
<tr>
<td>Caution</td>
<td>‘f’ is not always 1.0 cps &amp; ‘ν’ will vary according to energy in the Source</td>
<td>but the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>&amp; Geology as well!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Why Use Seismographs?

• *Establish Compliance with Rules*

• *Evaluate Blast Performance*

• *Provide Liability Protection*
Blasting Seismographs

- Measure ground velocity time histories
  - Component directions

- Measure airblast time history
  - Measured in pressure (psi)
  - Converted to Decibles (dB)

- Provide Summary information

- Conduct internal operations check
** SAFEGUARD SEISMIC UNIT 2000DK **

** SN: 2243 **

** DATE: 09/12/95 **

** TIME: 15:18:06 **

** Event: 009 **

** Recording Time: 10 **

** Client: ROBERTSON **

** Operation: BUCKEYE IND. MINING CO. **

** SSU Location: ROBERTSON YARD **

** Distance to blast: 1385 **

** Operator: M. MANN/ODNR **

** Comments: **

** Trigger Level: .05 IN/SEC **

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>T</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPV (in/sec)</td>
<td>0.10</td>
<td>0.14</td>
<td>0.07</td>
</tr>
<tr>
<td>PD (in x.001)</td>
<td>2.39</td>
<td>2.97</td>
<td>1.38</td>
</tr>
<tr>
<td>PPA (g)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>FREQ (Hz)</td>
<td>8.0</td>
<td>7.6</td>
<td>16.6</td>
</tr>
</tbody>
</table>

** RESULTANT PPV (in/sec): 0.15 **

** PEAK AIR PRESSURE: (dB) 114 (psi) 0.00145 **

** VELOCITY WAVEFORM GRAPH SCALE **

** TIME = 100 MSEC PER MARK **

** SEISMIC = +/- .64 IN/SEC **

** SOUND = +/- 0.00232 PSI **

** SHAKE TABLE CALIBRATED: 06/20/95 **

By GeoSonics, Inc.

Box 779, Warrendale, PA 15095 U.S.A.

TEL: 412.934.2900 FAX: 412.934.2999
Recordings are controlled by:

• How the seismograph is made

• How the seismograph is placed in the field
  – ISEE Field Practice Guidelines for Blasting Seismographs (1999)

• For specifications on each, go to:
  http://www.isee.org/sections/blast.htm
OSM Resources

• Appalachian Region Blasting Web Page
  – www.ARblast.osmre.gov
  – Reports and Publications

• Technical Innovation and Professional Services (TIPS)
  – www.tips.osmre.gov
  – Blast Log Evaluation Program (BLEP)

• keltschlager@osmre.gov or (412) 937-2169
THE END

• ANY QUESTIONS?

– Dennis Clark @ OSM/KFO
– dclark@osmre.gov
– 865-545-4103, ext. #137