Source Scaling of Single-Fired and Delay-Fired Explosions

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Types of Explosions

**Contained, Single-Fired:** Cylindrical borehole with enough stemming to maintain containment of explosion. All explosives simultaneously detonated

**Delay-fired Explosions:** Cast shots with multiple boreholes detonated in time sequence to maximize the casting overburden. Coal shots with multiple boreholes detonated in time sequence to maximize the fragmentation of coal without casting.
PURPOSE

• Quantify Relationship Between Peak Seismic Amplitudes and Total Amount of Explosives for Contained, Single-Fired Explosions

• Quantify Relationship Between Peak Seismic Amplitudes and Total Amount of Explosives for Delay-Fired Explosions

• Compare Seismic Coupling In-Mine (kilometers) and at Regional Distances (100’s kilometers)
EXPERIMENT LOCATION
REGIONAL

• Sources in Powder River Basin in NE Wyoming

• Regional Stations at 100-360 km
EXPERIMENT LOCATION
IN-MINE

• Contained single-fired shots marked by stars

• Largest blasts were cast shots

• Also conducted coal shots for fragmentation
Contained Single-Fired Explosions

S7
10 boreholes
42.5 m depth
15.25 m stemming
10.4 m spacing

<table>
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<tr>
<th>Shot</th>
<th># boreholes</th>
<th>Weight</th>
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<tr>
<td>3</td>
<td>1</td>
<td>5500</td>
</tr>
<tr>
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<td>50000</td>
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Comparison of In-Mine Data

Single Shots, 5500 to 50000 lbs
LOCAL OBSERVATIONS

Time (s)

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Comparison of Regional Data

Single Shots, 5500 to 50000 lbs
Regional Seismogram

- $P_n$: Mantle P wave
- $P_g$: Crustal P wave
- $L_g$: Crustal S wave
Peak Amplitudes of Regional Data

Power Law Scaling: Amplitude = AW^b

PDAR Pn, Pg and Lg Peak Amplitudes

P_n  b = 0.83
P_g  b = 0.87
L_g  b = 1.03
Peak Regional Amplitude Scaling

\[ \text{Amplitude} = AW^b \]

All three of the high frequency regional phases (\(P_n\), \(P_g\), and \(L_g\)) have peak amplitudes that scale according to a Power Law:

\[ b_{P_n} = 0.83, \quad b_{P_g} = 0.87, \quad b_{L_g} = 1.03 \]

Scaling using in-mine data produced similar results

\[ b_{\text{in-mine}} = 0.73 - 0.94 \]

Scaling of regional amplitudes from large-scale nuclear explosions in studied in Western US

\[ b_{\text{nuclear}} = 0.8 \]
Spectral Ratios - Theory

Scaling at All Frequencies

\[ U_j(f) = R(f) \ P(f) \ S_j(f) \]

\[ U_j(f) \text{ observation} \]
\[ R(f) \text{ receiver function} \]
\[ P(f) \text{ path effect} \]
\[ S_j(f) \text{ source} \]

\[ U_1(f)/U_2(f) = \left[ R(f) \ P(f) \ S_1(f) \right]/\left[ R(f) \ P(f) \ S_2(f) \right] \]
\[ = S_1(f)/S_2(f) \]
Spectral Ratios - Observations

\[ \frac{U_4(f)}{U_3(f)} = \frac{S_4(f)}{S_3(f)} \]

Single-Fired

S3 - 5500 lbs

S4 - 6000 lbs
Spectral Ratios - Data and Model

\[ \frac{U_7(f)}{U_6(f)} = \frac{S_7(f)}{S_6(f)} \]

S7 - 50000 lbs    S6 - 16000 lbs
Coal Shots
Cast Shots
Peak Amplitudes for Coal, Cast and Single-Fired Shots
Models for Single-Fired Shots
Models for Cast Shots
Spectral Model of Cast Shots

Impulse Time Series

Cast Shot - 623 holes 4,500,000

Cast Shot - 308 holes 2,250,000 lbs

Impulse Spectra

Amplitude

Time(sec)

Frequency(Hz)

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Conclusions
Contained Single-Fired Explosion

• Source scaling models developed for contained single-fired explosions in a coal mine.

• Regional seismograms (100’s km) support scaling models similar to those for in-mine ground motion.

• Frequency dependent scaling relations are consistent with a model developed for nuclear explosions.
Conclusions
Delay-Fired Explosion

• Timing effects from delay-firing are modeled as impulse response.

• Significant destructive interference (factor of 60-300) found in the frequency band 1-20 Hz.

• Model predicts and data illustrates an insensitivity of peak amplitude in the 1-20 Hz band to the total amount of explosives.
Example from Another Mining Operation
Models of Three Blasts
Regional Data From the Three Blasts

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