LA-UR-97-2646

Approved for public release;
distribution is unlimited.

CONF-970967--Title:

COMPARISON OF SINGLE-FIRED AND DELAY-FIRED
EXPLOSIONS AT REGIONAL AND LOCAL DISTANCES

Author(s):

Brian William Stump, EES-3
David Craig Pearson, EES-3

Submitted to:

19th Seismic Research Symposium on Monitoring a
CTBT, Sponsored by Defense Special Weapons Agency

RECEIVED
NOV 03 1997
OSTI

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ph

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

COMPARISON OF SINGLE-FIRED AND DELAY-FIRED EXPLOSIONS AT REGIONAL AND LOCAL DISTANCES

Brian W. Stump and D. Craig Pearson
*Southern Methodist University, Department of Geological Sciences
and Geophysics Group - EES-3, Los Alamos National Laboratory*

Contract No. W-7405-ENG-36
Sponsored by U.S. Department of Energy

ABSTRACT

A wide range of blasting practices are utilized by the US mining industry resulting in dramatically different local and regional seismic signatures. This variability in blasting and resulting seismograms suggests that no single discriminant may be appropriate for identifying this class of sources. A range of blasting styles are identified in this paper and the distinguishing characteristics at regional distances are determined. The blasting styles are quantified with the help of mining company records and close-in acoustic, seismic and videographic data. The regional data consists of portable deployments of high frequency and broadband sensors as well as data from the International Monitoring System Primary Array at Pinedale, Wyoming.

Critical to the success of this study is the comparison of regional data from the mining explosions to data from contained, single-fired explosions. Two types of single-fired explosions are utilized, the first a *calibration* explosion (8 vertical boreholes with 5,000 lbs of explosives each) fired simultaneous. The second, single-fired explosion consists of a number of boreholes detonated simultaneously in the mine for the purpose of pre-splitting the material (driving fractures between boreholes) prior to a large cast shot. Data from these explosions provide the basis for identifying the source signatures of the more typical delay-fired explosions.

At high frequencies the single-fired and delay-fired explosions exhibit very similar waveforms at regional distances. Both event types show a high P/L_g ratio at the highest frequencies with L_g dominating at lower frequencies. Mining explosions that cast material show an enrichment in surface wave energy at relatively long periods of 4-12 seconds. Timing anomalies are identified in a high percentage of mining explosions designed to cast material. The accidental, simultaneous detonation of a number of boreholes has been observed in 2 of 9 carefully instrumented cast blasts. These produce regional waveforms that can have the characteristics of a single-fired explosion. Spectral scalloping is observed from some delay-fired explosions while not from others. The existence of these characteristics is dependent on the exact delay pattern utilized. Data from a single-fired explosion allows the assessment of local receiver effects that might appear as a characteristic of delay-firing.

Key Words: Mining explosion, single-fired, delay-fired, identification

OBJECTIVE

A number of mining explosions in the Powder River Basin of Wyoming are triggering the Prototype International Monitoring System. One of the largest events formed by the PIDC was a cast blast (designed to remove overburden) that included the simultaneous detonation of a significant amount of explosives (1 Aug 96). This event was identified as single-fired like with both the close-in observations (video and ground motion) as well as the regional observations. The event was observed at teleseismic distances and had magnitude estimates of $m_b = 4.0 \pm 0.1$ (2 measurements) and $M_L = 4.5 \pm 0.2$ (3 measurements). Cast blasts that perform normally (i.e. no sympathetic detonation or single-fired characteristic) appear to have M_L 's that are between 0.5 to 1.0 magnitude units smaller. Few if any of the coal shots (designed to fracture the coal) appear to trigger the PIMS. This observation is consistent with the experimental observation that the coal shots are a factor of 3 to 5 smaller in amplitude than the normally performing cast shots. This observation would suggest that they are 0.5 to 0.7 magnitude units smaller than the cast shots making them in the high 2's to low 3's. This magnitude is below that expected threshold of the IMS.

The purpose of this work is develop a collection of tools that can be used for identifying the different types of mining explosions that will be observed by the International Monitoring System. Fundamental to this study is the development of a physical understanding of these identifying characteristics so that there applicability in a range of different environments can be assessed. In order to reach this goal, a series of data sets have been developed that combine mine records, close-in observations of the mining explosions and regional seismograms have been developed. These data sets are then utilized to assess identifying characteristics of the different explosion types.

RESEARCH ACCOMPLISHED

Experimental Design

In order to accomplish the objectives of this research program a combination of portable and permanent seismographic stations were utilized to study signals from two mines in Wyoming. The mine locations, permanent stations (PDAR and RSSD) and portable stations (BHS, TIS, MON) are illustrated in Figure 1. PDAR is the IMS Primary Array. Additional instruments were deployed in each mine in order to quantify physical processes accompanying each mining explosions. Ground acceleration, velocity, acoustic and videographic data were recovered from within each mine. The cooperating mines provided explosive design information as well as access to mine property.

A number of different types of mining explosions were conducted in each of the mines. Both mines are recovering coal at depths between 20 and 60 m. Each mine removes the overburden with cast blasting. Pre-split explosions are employed at one of the mines. In this case, explosives are emplaced in boreholes along the back row of a cast blast and detonated simultaneously, prior to the associated cast blast. These explosions are designed to drive fractures between boreholes in the back row so that when the cast blast is detonated a competent high wall is produced. A single-fired *calibration* explosion was conducted at one of the mines for purposes of positively identifying the effects of delay-firing observed

from the other explosions. Smaller explosions are detonated in the exposed coal for the purposes of fragmentation and improved resource recovery.

Figure 1: Location map including the permanent seismic stations (PDAR and RSSD), the portable stations (MON, TIS, BHS) and the two mine locations.

Peak Amplitudes

P and L_g amplitudes for both coal and cast shots were measured and compared to total amount of explosives detonated (Figure 2). For both the coal and the cast shots there was no apparent increase in peak amplitudes for either phase as a function of explosive weight. Standard delay-firing techniques which are designed to reduce peak amplitudes in the near-source region apparently also control peak regional amplitudes. The coal shots ranged in explosive weight between a few thousand pounds to several hundred thousand pounds while the cast shots ranged from over a million pounds to over eight million pounds. The population of coal shots were a factor of 3-5 smaller in peak amplitude than the cast shots indicating that the style shooting may effect the absolute amplitudes to some degree. The two cast shots that had single-fired characteristics were the exception to this rule. These anomalies produced the largest regional amplitudes in both P and L_g , as much as a factor of 3 to 4 greater amplitude than the cast blasts with normal performance.

Figure 2: Comparison of peak P and L_g amplitudes from cast, coal and single-fired explosions observed at a single element of the Pinedale array.

High Frequency Discriminants

Large scale cast shots (and coal) excite P and L_g in a similar way to a contained single fired explosion (Figure 3). At high frequencies ($>4-8$ Hz) the waveforms are dominated by P wave energy relative to L_g . The L_g amplitudes dominate at lower frequencies (1-2 Hz). This observational result is consistent with the success of high frequency P/ L_g discriminants for single-fired nuclear explosions in other parts of the world. The key to this comparison was the detonation of a modest size (~40,000 lbs.) single-fired contained explosion in the same mine where normal mining explosions were being detonated. These results further suggest that larger mining explosions might be utilized as a surrogate for developing high frequency discriminants for single-fired explosions.

Surface Wave Generation by Mining Explosions

There are observational differences between single-fired explosions and the large cast explosions in the mine. The large mining explosions generate surface waves in the period range of 4 to 12 seconds (Figure 3). No energy in this period range is observed above background noise for the single-fired explosion. The high frequency P/ L_g ratio can be used to identify the explosions and the existence of the long period regional surface waves may provide the opportunity to separate the large cast shots. Additional analysis of earthquake signals from the same region may provide the opportunity to compare these explosion generated regional surface waves to those resulting from earthquakes.

Anomalous Mining Explosions

The existence of regional waveforms from a contained, single-fired explosion provides a calibration event for the area of interest. The regional seismograms generated by this event

**Black Thunder Single and Cast Shots at Pinedale (~ 360 km)
Short Period Array Element PD03.sz
different frequency bands**

Fig 3: Comparison of vertical seismograms of the single fired explosion and three cast blasts observed at one element of the Pinedale Array.

can then be compared to waveforms from standard mining explosions in order to identify single-fired explosion characteristics. Correlation analysis was performed on both P (Figure 4) and L_g parts of the regional waveforms. The P wave cross correlations suggest that two of the nine cast shots have impulsive characteristics. The anomalies have a very impulsive character indicating that a moderate to large amount of explosives was simultaneously detonated during the mining explosions. Close-in ground motion, acoustic and videographic data from these two shots support this interpretation.

Typical mining explosions are designed with a number of small explosions that detonate sequentially. This detonation pattern is intended to reduce ground motions from the cumulative explosive while fracturing and breaking rock in an optimal way. This explosive design results in waveform characteristics that are quite distinct from a single-fired explosion. The accidental detonation of a significant amount of explosives simultaneously during typical mining explosions have been documented in this study of mining explosions. Two of the nine cast blasts that have been studied show single-fired explosion characteristics that are a factor of 3 to 4 larger than the largest amplitudes from the parts of the explosion that performed as designed. These results suggest that in a monitoring environment that such anomalies will have to be identified. One explosive engineer

estimates that as many as 1 in 20 carefully instrumented shot shows some abnormal performance.

Figure 4: Cross correlation function between seismic P observations at Pinedale. The single-fired data is cross correlated with itself and data from each of nine cast blasts. Two of the cast blasts have a significant single-fired component in the P waves.

Spectral Scalloping

The entire suite of cast blasts were investigated for evidence of spectral modulation using data from the Pinedale array (mine to the NE of Pinedale, Figure 1). The bandwidth of the observational data at these stations (~360 km) limited analysis to approximately 10 Hz and below (Figure 5). Two approaches were followed in analyzing the data. Standard time varying spectral estimates with overlapping windows were first applied. A variety of window lengths and smoothing functions were applied with limited success in identifying consistent patterns of spectral scalloping. The single-fired explosion was used as a reference point as it contained the effects of propagation path that were common to all the shots (Figure 6). No consistent pattern of spectral scalloping was identified in the cast shots that could be associated with the blasting process in a predictive manner. Qualitatively the cast shots produced spectra that had more variation as a function of frequency than the smoother single-fired explosions. A mean spectral estimate for each regional seismogram was also computed by summing all the individual spectra from the moving window estimates. The resulting spectrum were then searched for spectral holes and enhancements. There was some indication of effects at the lower frequencies (<4-5 Hz) although no consistent pattern developed between the different cast shots. It is not surprising that high frequency spectral scalloping is not observed since these mining shots used 35 ms delays between shots in a hole and typically delays of 125, 400, 600, 800, 1000, 1200 and 1400 ms between rows. The cast shots which were anomalous produced relatively smoother spectra not unlike those observed from the single shot.

Figure 5: Time varying spectral estimates from a cast blast (mine NE of Pinedale) that was delay-fired observed at the Pinedale Array.

Figure 6: Time varying spectral estimates from a single-fired explosion (mine NE of Pinedale) observed at the Pinedale Array.

Mining explosions with simple detonation patterns do produce spectral scalloping that can be identified. The mine to the SE of Pinedale (Figure 1) employs a simpler timing pattern

in its cast blasts. One explosive hole from each row is detonated every 100 ms during these cast blasts. As Figure 7 illustrates the results is an enhancement of spectral energy just above 10 Hz. Data taken from within the mine where the bandwidth is greater supports this interpretation and shows a second peak above 20 Hz.

Figure 7: Time varying spectral estimates from a cast blast (mine SE of Pinedale) that was delay-fired observed at Pinedale.

At the same mine SE of Pinedale single-fired explosions are conducted on a regular basis for pre-splitting the back row of a cast prior to the cast blast. This mining practice consists of drilling a series of holes in the back row of the proposed cast blast and loading them with explosives. Some time period before the cast blast (days) these holes are simultaneously detonated. The purpose of this type of explosion is to drive fractures between the boreholes. These fractures then allow for a well controlled high wall after the cast blast. Comparison of the vertical seismograms from the cast blast (Figure 7) and the Pre-Split explosion (Figure 8) illustrates that the generation of these fractures between boreholes results in enhanced shear wave generation. Comparison of the time varying spectra from these two explosions illustrates that the high frequency enhancement observed in the cast blast (~10 Hz) is not observed from the simultaneously detonated explosion. As illustrated in the previous example, the spectra from the simultaneously detonated explosion is much smoother than that observed from the delay-fired explosion.

Near-source and Regional Comparisons

A number of comparative studies were made between near-source observations and the regional seismograms for the purposes of quantifying the importance of source processes that contribute to the regional seismograms. It is this aspect of the study that is unique in

Figure 8: Time varying spectral estimates from a Pre-Split explosion (mine SE of Pinedale) that was simultaneously detonated.

determining the efficacy of regional discriminants and may provide a physical basis that can be used to assess possible tools for other regions of the world. The near-source data includes the design parameters of the explosive arrays, the three dimensional topography of the source region, video of the explosion, ground velocity and acceleration, acoustic measurements and pre and post shot surveys of the material. One useful tool has combined the video, ground motion, acoustic and design information into a visualization tool of the explosion. The video images of the explosion are combined with the motion/acoustic data as well as the a model of the detonation process (Figure 9). Time aligned images allow one to interpret how the progression of the detonation process generates the near-source wavefields. This visualization provided the first evidence of the accidental simultaneous detonation of a large amount of explosives at the end of one cast shot. This same event produced regional seismograms that were most like the single-fired explosion that was part of this experiment. These visualizations also illustrate the long source duration of these cast shots that must be taken into account in any attempt to model these types of events. The material that is cast into the pit following the initial detonation of the explosives can increase the source duration of 50% or more if it is important. The video in combination with the ground motion records provides the mechanism for quantifying the timing and strength of these secondary effects.

CONCLUSIONS AND RECOMMENDATIONS

Results from an empirical study of identifying characteristics of seismic signals from mining explosions have been presented and support the contention that a suite of identification tools will have to be employed in order to effectively characterize these types of events. The need for this collection of tools is the wide variety of mining practices employed not only in the U.S. but throughout the world.

Figure 9: Single frame of combined video, ground motion (Z-vertical, E-east to west, N-north to south), acoustic (A) data along with a model of the design detonation pattern. In this frame at 4.467 s the shot is over three quarters complete. The large amplitude at this time, vertical bar across all time traces, is a result of the accidental simultaneous detonation of a significant number of boreholes at the end of the shot pattern.

A partial list of possible tools has been investigated. These include: (1) A high P/L_g ratio at the high frequency; (2) Enrichment in surface wave energy at relatively long periods of 4-12 seconds; and (3) Spectral scalloping is observed from some delay-fired explosions while not from others.

Data from single-fired explosions is critical to the assessment of these discriminants. Pre-splitting explosions may be a source of such data. Relatively large, simultaneous detonations have also been identified to occur accidentally during a typical delay-fired explosion.

M98000600

- ⑱ DOE, XF
- ⑲ UC-900, DOE

DoE

19971202 069