PREDICTABILITY OF AIRBLAST AT SURFACE COAL MINES IN WEST VIRGINIA

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Abstract

This research report by the Office of Explosives and Blasting (OEB) deals with airblast measurements at surface coal mines in West Virginia and the predictability of airblast by acceptable methods. This research was initiated to address the growing number of complaints by the citizens of West Virginia concerned that blasting would cause damage to their homes. OEB inspector specialists have reported in the follow-up to many of the complaints that airblast and not ground vibration was the cause of the complaint. This study was designed to evaluate various methods utilized by the industry for predicting airblast, as well as to determine if airblast prediction is a realistic method to assure compliance with West Virginia blasting laws.

There are recognized formulas for predicting airblast based on cube root scaled distance formulas. These formulas use information that is required on the permittee's blast log which is maintained daily at the mine site for each blast detonated. Periodic seismograph blast monitoring is required in every blast plan as a spot check to verify that blasting does not exceed the regulatory limits. By evaluating the blast log data and the corresponding acoustic values of the seismographic monitoring data, comparisons can be made to industry-accepted predictive models to determine if the predictive method will reliably ensure compliance with regulatory limits.

The research project began by examining excessive airblast Notice of Violations (NOV) written in 2008 with the hope of developing criteria for predicting excessive airblast in the mountainous regions of West Virginia. The next step was to gather data from 71 coal mine blast events in 2009 that were not in violation of airblast regulation. A regression analysis chart based on the cube root scaled distance formula was generated. The correlation factor of the trendline generated was too poor to use the equation for predictive analysis. Since the accuracy of the data supplied by the coal mines could not be verified, the need for gathering blast data under more controlled conditions was desirable.

In a controlled study in 2010 at a cooperating coal mine, all blasts and seismographs were located by GPS coordinates and each event was digitally located using AutoCAD computer-aided design software and ArcMap Global Information System software. OEB used its in-house seismographs to monitor the blast events. The correlation factor for the resultant trendline from the regression analysis, though much better than the 2009 data, was still considered too low for reliable predictive analysis. When the 2010 data were separated by weather conditions, the regression analysis correlation coefficients for rainy days and for clear days were acceptable, but the correlation for cloudy days was too low.

Background, methodology, data and conclusions drawn from both phases of the study are included in this report. Recommendations are made to require airblast monitoring when specific conditions are encountered.

Introduction

Blasting is used to fragment the rock overlying the coal seams of West Virginia to facilitate surface coal mining. When the explosives are detonated, most of the energy is consumed in rock fragmentation. Unfortunately, energy not used to break rock radiates out from the blast site in the form of ground vibrations and airblast. As this energy reaches residential structures, the homes will vibrate and sometimes the owners file complaints with the OEB. The complaints may be for annoyance or alleged damage to homes.

Based on OEB data, blasting related complaints have decreased in the West Virginia coal fields. However, the percentage of airblast violations had an increasing trend from 2007 through 2009, and then dropped in 2010 as shown in Table 1.

Year	Complaints	Blasting violations	Airblast violations	Percent of total
2007	334	55	10	19%
2008	336	62	11	19%
2009	296	47	16	34%
2010	247	44	7	16%

TABLE 1
WV OEB Blasting related complaints

This research was initiated to address the large number of airblast-related violations and complaints by the citizens of the West Virginia concerned that blasting would cause damage to their homes.

Airblast Generation

"Airblast", as defined under the West Virginia Surface Coal Mining and Reclamation Act Title 199-2.2, is "an airborne shock wave resulting from the detonation of explosives." Airblast is a pressure wave and is also known as air vibrations, air overpressure or airborne shockwave.

Explosives are loaded into blastholes and confined in the ground by filling the top of the hole with inert stemming (usually drill cuttings or gravel). When detonated, the energy released is in the form of a shock wave and extremely high gas pressure. The energy is meant to fracture rock adjacent to the hole with minimal energy being released to the atmosphere. The amount of energy released to the atmosphere, or airblast, is directly related to the size of the explosive charge and the degree of confinement.

The confinement of a blast charge is dependent on; 1) the strength and density of the rock mass being blasted, 2) the effectiveness of the stemming used at the top of the borehole to confine the explosives, and 3) the orientation, number and characteristics of the exposed (free) rock faces. The burden, the distance from the blast hole to the nearest exposed free-face, must be sufficient to confine the explosive charge to prevent both illegal airblast and flyrock (rock thrown beyond the blast area).

Airblast can result from four mechanisms associated with blasting:

1) Air Pressure Pulse (APP): the movement of the broken rock which displaces air;
2) Gas Release Pulse (GRP); the venting or release of gases through the fragmented rock directly into the atmosphere;
3) Stemming Release Pulse (SRP): the gas release from stemming ejection; and
4) Rock Pressure Pulse (RPP): the vertical component of the ground surface movement as the seismic ground vibration wave approaches a structure.

Air Pressure Pulse is caused by the rapid physical displacement of the blasted rock, either vertically or horizontally. This piston-like movement causes a comparable displacement of the surrounding air, resulting in compressive waves that travel from the blast site. Blast delay timing, pounds of explosives per hole, and the geometric layout (burden, spacing and depth) of the blastholes determine the displacement velocity of the rock face, and the intensity of the resultant airblast wave. Most of the airblast energy resulting from this APP is at a frequency between two and twenty Hertz which is below the range of human hearing.

Airblast is also caused by the venting of gases through cracks and fractures in the rock mass being blasted (GRP), or from the ejection of stemming material (SRP) used to confine the explosives in the blasthole. These portions of the airblast are usually in the audible range and will be used to describe “how loud” the blast was. Expanding explosive gases can vent through natural cracks, faults, joints, or fissures that existed before the rock was blasted. For progressive blasting activities, the preceding blast can have significant impacts on the overall rock mass by creating cracks and fractures in the rock mass that is to be drilled and blasted later. These cracks and fractures can allow rapid explosive gas release resulting in high levels of airblast.
The airblast associated with the seismic ground surface wave components (RPP) are measurable, but are typically very small compared to the other mechanisms.

Airblast Characteristics

When explosives are detonated, a pressure wave travels though the elastic medium of the atmosphere. The intensity of the wave fades with distance as does the sound of one’s voice. Sound waves travel through the air much slower than ground vibration, and are affected by temperature and wind direction. Airblast travels through the atmosphere at the speed of sound, which is approximately 1126 feet per second at 68°F in dry air, and at about 1100 fps at 45° F.

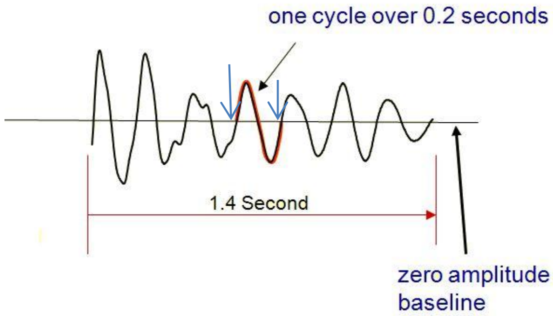

Figure 1
Airblast waveform

The pressure components of airblast are not linear and most often have pulses or cycles that emanate away from the blast site in nearly concentric series of circular waves, just like when a pebble is dropped into undisturbed water. Airblast as a sinusoidal pressure wave is shown in Figure 1. The x-axis represents time (seconds) and the y-axis represents pressure, normally recorded in pounds per square inch (psi) and reported in decibels (dB). In the above figure, the airblast event lasts for 1.4 seconds. The red highlight represents one cycle that lasts about 0.2 seconds. The frequency of this cycle would be one cycle divided by 0.2 seconds, or 5 cycles per second (5 Hertz). The amplitude or intensity of airblast decays with distance. Typically, airblast decay relative to distance (attenuation) is much greater than the decay rate of much faster travelling ground vibration waves.

Airblast may be in the form of noise and/or concussion waves. Humans have a hearing frequency range of about 20 Hz to 20,000 Hz under ideal conditions, and the range shrinks during our lifetime, usually beginning around the age of 8, with the higher and lower frequencies fading. Hertz (Hz) is the number of sinusoidal cycles per second in the wave form…the more hertz the higher the pitch: for example, high C vibrates faster (at a higher frequency) than low C on the music scale. Airblast is audible to the human ear at frequencies above 20 Hertz and may be called sound or noise; at frequencies below 20 Hertz airblast is inaudible and is commonly referred to as concussion.

High airblast from blasting may not be very audible (loud) to a person standing in the vicinity because coal mine blasting typically produces low-frequency waves. However, it is worth noting that inaudible sound waves can be felt by humans via infrasonic physical body vibrations in a range of 4 to 16 Hz and airblast from surface coal mine blasting typically contains a lot of energy in the frequency range of 2 – 25 Hz.

Airblast intensity and attenuation rates are affected by other factors such as atmospheric conditions and wind speed and direction, and the effects at ground level can be enhanced by cloud cover, rain, topography and atmospheric temperature inversions. Wind speed has the effect of extending the distance where the effect of an airblast event is felt in the direction of the wind. Studies conducted on airblast and wind speed have found as much as a 30% increase in attenuation distance downwind of a blast for wind speeds from 7 to 16 mph, and decreases of up to 16% attenuation distance on the upwind side of the blast. The effect of atmospheric temperature inversions on air blast is illustrated in Figure 2. Temperature inversions may be problematic as well because they refract airblast waves back to the earth and may concentrate the air overpressure at a particular structure which may be thousands of feet or even several miles away, the distance depending on the elevation of the inversion above the blast.

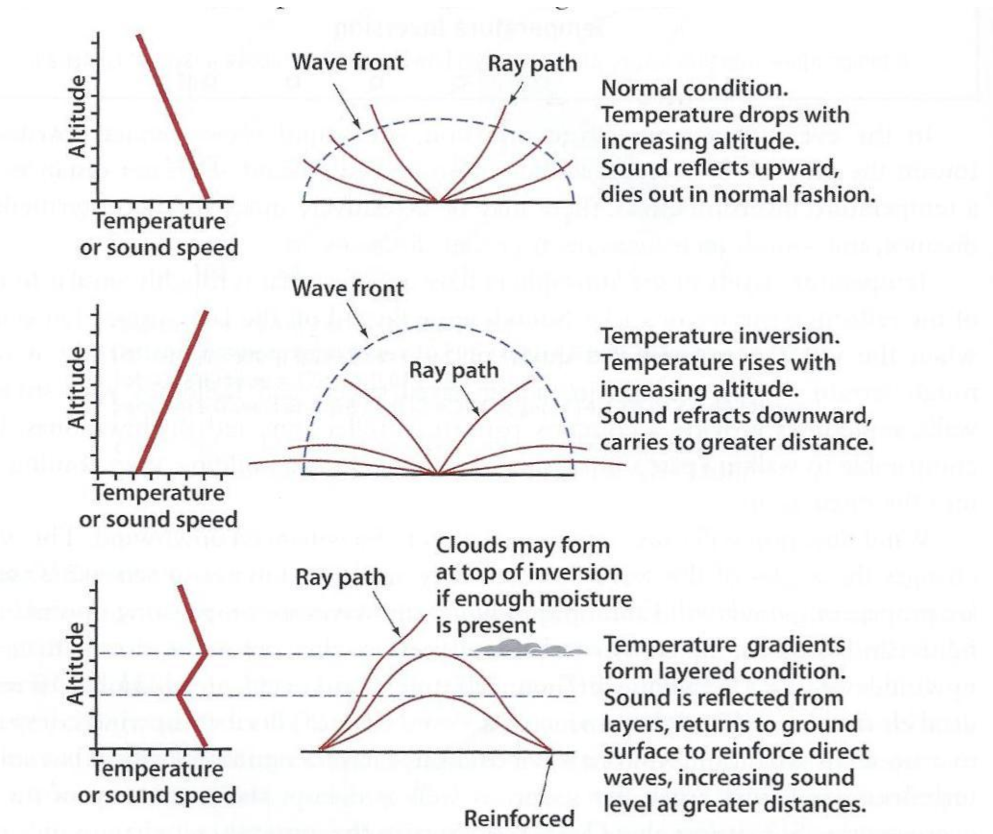

Figure 26.18 - Effects of temperature gradients on sound transmission.
(Source: ISEE Blasters' Handbook™, 17th Ed. figure 38.9)

Figure 2
Atmospheric Impacts

Airblast Measurement

Blasting seismographs are used to measure both ground vibration and airblast. Ground vibrations are measured with a seismic geophone sensor and airblast is measured with a microphone designed to measure and record air pressure changes over time. Airblast is measured in pounds per square inch (psi), millibars (mb), or pascals, and is often reported in decibels (dB).

The formula for converting pressure in psi to dB is;

$$\text{SPL dB} = 20 \text{ Log}_{10} \text{ P} + 170.8$$

Where: SPL dB is sound pressure level in decibels
P is the measured air pressure in psi

Or;

$$\text{SPL dB} = 20 \text{ Log}_{10} (P/P_o)$$

Where: $P_o = 2.9 \times 10^{-9}$ is base relative pressure
P = Measured air pressure in psi

Decibels (the bel, named in honor of Alexander Graham Bell of telephone fame) are based on a logarithmic scale for sound pressure which takes into account levels of human hearing. When evaluating airblast in decibels, care should be taken to not make comparisons directly with hearing noise data which are measured differently. Sound level meters or noise meters have internal weighting scales and filter components. These filters distort the actual pressure readings and are not the same as pressure readings recorded by blasting seismographs.

The graph on Figure 3 relates levels of airblast in decibels and pounds per square inch. For relevance and magnitude of scale, it is important to recognize that for every increase of 6 dB, the associated air overpressure in psi doubles. Therefore, an airblast of 126 dB would have twice the air overpressure of an airblast measured at 120 dB. A citizen experiencing 126 dB is more likely to complain than with 120 dB. Another way of relating dB to psi is that a change in 20 dB relates to a change of ten times the air overpressure in psi. For example, 120 dB = 0.0029 psi and 140 dB = 0.029 psi.

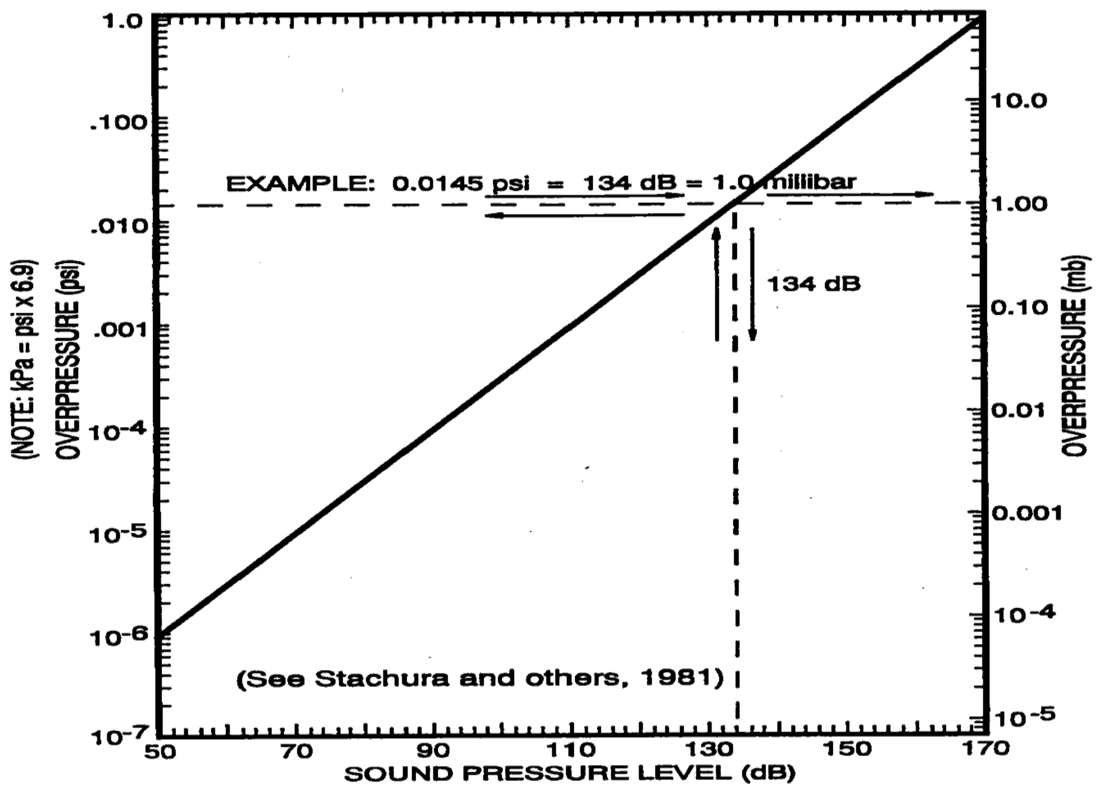

Figure 3
Graphical conversion of dB to psi and millibars

Effects of Airblast

The United Stated Bureau of Mines (USBM) studied airblast and structural response produced by surface mine blasting in the 1970's to evaluate annoyance and damage potential to residential structures. The results of its studies recommended safe levels of airblast that would ensure a high probability of non-damage to structures, and were published in USBM Report of Investigations 8485 (1980). These recommended levels were adopted by the Office of Surface Mining Reclamation and Enforcement and subsequently by the West Virginia DEP.

The USBM RI 8485 report measured structural responses to both ground vibration and airblast. During this USBM study, both corner and mid-wall responses of the structures were measured for many shots. The researchers found that, "Relevant to the airblast problem are the whole-building response (corner measurements indicating racking effects on the frame) and midwall response (best correlated with secondary effects; such as window sashes rattling, dishes and knick-knacks falling, etc.)."

Houses have a resonant frequency (a tendency to vibrate at higher amplitude) in the range of 4-25 hertz, unfortunately in the same frequency range as coal mine airblast waves. Therefore, it is common for homeowners to attribute the house shaking with ground vibrations, when the structure could actually be responding more to the blasting-induced air pressure pulses. Although lower than allowable levels of airblast may not cause damage, they can be very annoying and are commonly related to citizens' complaints. It should be noted that annoyance is not a regulated component of blasting. Table 2 describes various levels of airblast and related damage.

Typical Air Overpressures and Associated Effects		
dB	psi	
180	3.000	Severely Damaged conventional structure
171	1.000	General window breakage
151	0.100	Some window breakage
140	0.029	reasonable threshold to prevent glass and plaster damage, USBM
133	0.015	fall of loose plaster flakes, USMB RI 8485 and WV regulatory limit
120	0.003	rattling of windows, feelings of annoyance

Table 2

The current peak permissible airblast levels in West Virginia are based on the accuracy to +/- 3 dB of the microphone at low frequencies. The Table 3 levels are the legal maximums at any protected structure. Almost all commercial seismographs currently in use are +/- 3 dB @ 2 Hz, and, therefore, the regulatory limit is usually 133 dB.

Lower frequency limit of measuring system, in Hz (+/- 3 dB)	Maximum level, in dB
0.1 Hz or lower--flat response[1]	134 peak
2 Hz or lower--flat response	133 peak
6 Hz or lower--flat response	129 peak
C-weighted--slow response[1]	105 peak dBC

[1] Only when approved by the regulatory authority.

Table 3 - WV Airblast regulation limits

Airblast Prediction

When evaluating airblast, the most significant blast design parameters that contribute directly to the overall intensity of the air overpressure pulses are: (1) the charge weight per delay: and (2) confinement of the explosive energy. The intensity at any measuring point is also dependent on the distance from the blast site.

Most regulatory agencies allow the use of a square root scaled distance formula in lieu of seismic monitoring. This formula is used for predicting ground vibration. Since the intensity of airblast decreases with distance more rapidly than ground vibrations, the cube root of the charge weight, instead of square root, is more useful for predicting intensity.

The Cube Root Scaled Distance (SD_3) used to predict airblast intensity is:

$$\mathbf{SD_3 = D / W^{1/3}}$$

Where;

SD_3 = cube root scaled distance factor
D = Distance from the blast to a point (ft)
W = Maximum weight of explosives per delay (lbs)

Airblast can be estimated from the cube root scaled distance factor using published graphs like the one in Figure 4, or by using the equations that represent the lines on the graph. Once the cube root scaled distance and the type of blasting are determined, the appropriate line on the graph in Figure 4 can be selected to predict airblast intensity. Follow the SD_3 value (30 on the example shown) on the graph vertically until it intersects with the type of blasting line (coal mine highwall on example) and then follow the graph horizontally until the air pressure value is found on the vertical axis (0.01 in the example). Then the pressure value must be converted to decibels. For more accurate estimates of air overpressure utilize the equations in Table 4.

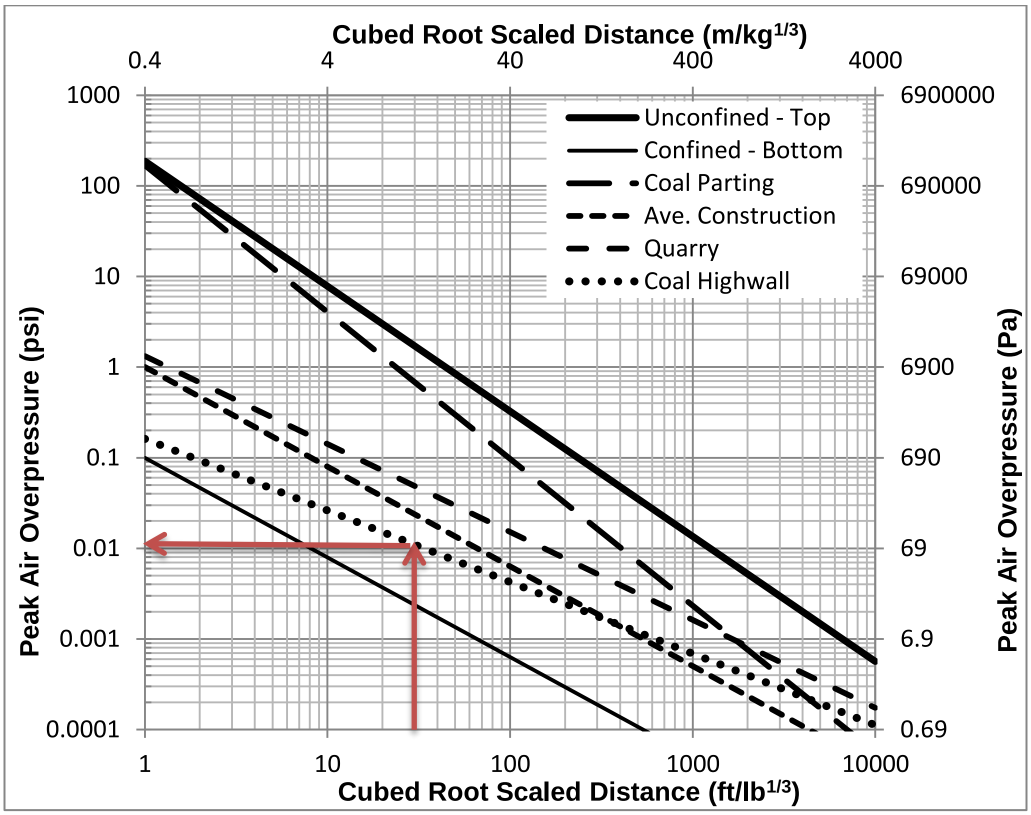

Figure 4 (from ISEE Blasters' Handbook)

Table 4 - Airblast prediction equations (ISEE Handbook)

Blasting	Imperial (psi)	Statistical type	Source
Open air (no confinement)	$P = 187(SD_3)^{-1.38}$	Median	Perkins
Coal Mines (parting)	$P = 169(SD_3)^{-1.62}$	Median	USBM RI 8485
Coal Mines (highwall)	$P = 0.162(SD_3)^{-0.79}$	Median	USBM RI 8485
Quarry face	$P = 1.32(SD_3)^{-0.97}$	Median	USBM RI 8485
Metal Mine	$P = 0.401(SD_3)^{-0.71}$	Median	USBM RI 8485
Construction (average)	$P = 1(SD_3)^{-1.1}$	Median	Oriard
Construction (highly confined)	$P = 0.1(SD_3)^{-1.1}$	Median	Oriard
Buried (total confinement)	$P = 0.061(SD_3)^{-0.96}$	Median	USBM RI 8485

Where: P = pressure of the airblast in psi
D = distance from the blast in feet
W = weight of explosives in pounds per delay
SD_3 = cube root scaled distance

Information is required on blast logs to document the location of the blast site and the location of the nearest protected structure, distance between these, and the amount of explosives detonated per eight millisecond delay. The cube root scaled distance factor can be calculated from this data and entered into an appropriate equation to predict air blast. Because of the variability of predictive equations that use this cube root formula, previous researchers have felt that predictive equations were not adequate for use as an airblast compliance tool.

The USBM RI 8485 predictive modeling concepts are compared in this research report to actual data gathered at surface mines in West Virginia during this two-year study.

Many of the USBM blast sites for RI 8485 were in relatively flat areas of the Midwest. USBM report RI 8892 is from a later study of steep-sloped Appalachian terrain and it concludes: "Airblast and ground vibration generation and propagation from steep-slope contour mine blasting were found to differ from those in other types of surface coal mines…resulted in the generation of both higher levels and higher frequencies for airblast. By contrast, ground vibrations were lower." The conclusion of the report goes on to state, "Instead of the expected -9.8 dB attenuation per doubling of distance for high-frequency airblast over flat terrain, values were between -5.4 and -7.9 dB." The report further concludes, "This combination of high frequency and high source level of airblast, and abnormally low attenuation within topographic valleys suggest airblast as the main cause of complaints from Appalachian blasting."

Methodology and Data

The OEB's research goal was to evaluate existing methods of predicting airblast and to recommend practices to help reduce high airblast occurrences. The focus of the preliminary study was to gather available data on excessive airblast events at surface coal mine sites in West Virginia.

In 2009 a search was made of the WVDEP database to determine where Notices of Violation were issued for excessive airblast events over the 133 dB limitation in the regulations. This search found that11 violations were issued for excessive airblast involving 20 separate blasts at nine different mines during the 2008 calendar year.

West Virginia coal mines are required to record specific blast parameters for each individual blast on an OEB designed blast log (form EB-37), and are required to keep these blast logs for a minimum of three years. The next step in the data collection process was to conduct onsite visits to obtain more detailed information relating to the high airblast events from the blast logs and to study similar blasts at each site. During these visits, the blasters in charge for these particular blasts were interviewed, when possible, to determine if there were any unusual circumstances associated with these blasts that were not readily apparent or documented on the blast logs. Following the site visits, the Blasting Inspector Specialist that issued the Notice of Violation was contacted to glean additional information on the non-compliant blasts. The major conclusion discerned from these interviews was that rarely could anyone pinpoint the cause of the excessive airblast.

The next step in the 2009 phase of the study was to collect data for 71 blast events that did not exceed regulatory limits, and to compare the data with USBM prediction formulas. Seismograph records and blast log data were randomly selected from 11 surface coal mine sites in seven counties in West Virginia. The chart in Figure 5 was developed from data collected and exemplifies the problem using the USBM highwall formula in predicting air blast in West Virginia. The only trend seems to be that USBM Highwall predicted airblast level is normally higher below 122 dB and lower above 122 dB.

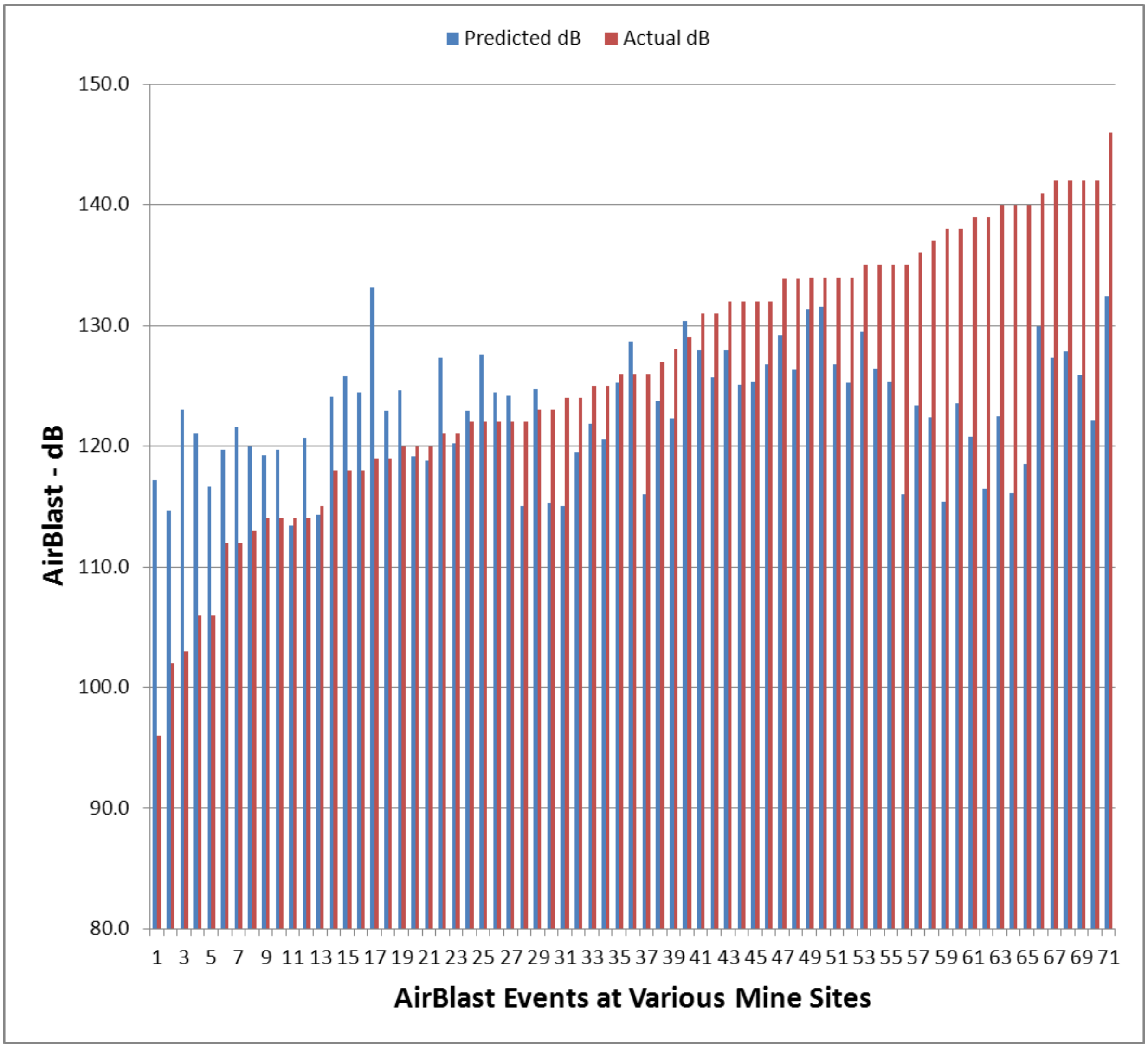

Figure 5

Comparison of Actual Airblast to Predicted Airblast using Cube Root Scaled Distance and the USBM Equation

A regression analysis was performed on the 71 data points and the results are shown on Figure 6. The correlation coefficient (R^2) of the trendline is only 0.15 whereas a minimum desired correlation factor is generally accepted to be 0.70 for good trend analysis. The data from the blast logs that was entered into the regression analysis that couldn't be verified for accuracy was the distance from the blast to the seismograph location. It became apparent that for valid regression analysis, OEB would need to closely monitor future blasts for data accuracy and other observed conditions i.e. weather, depth to burden ratio, and open-face direction in relation to seismograph location, etc.

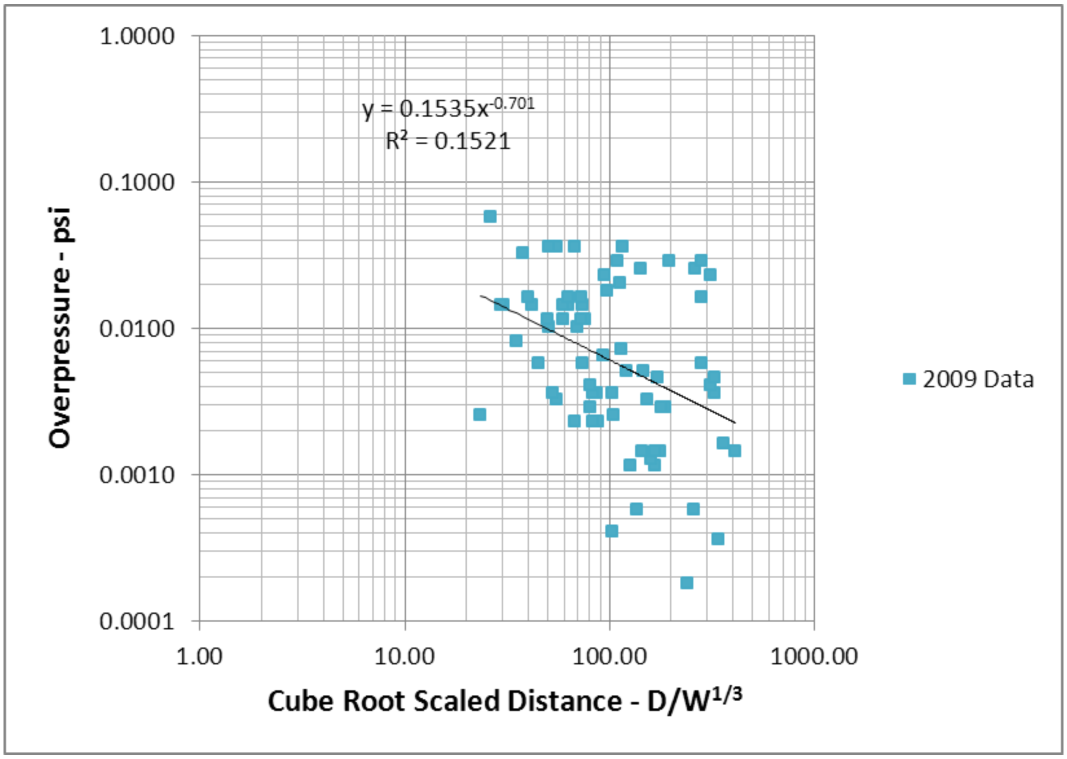

Figure 6

Regression Chart of the 71 Airblast Recordings in 2009

In 2010, the project focused on recording more accurate and verifiable data sets, tracking weather and geometric relationships, and attempting to correlate the airblast recordings with levels predicted by the cube root scaled distance formulas. OEB personnel installed arrays of seismographs at a cooperating coal mine site. GPS coordinates were taken of all blast sites and seismograph locations. ArcMAP and AutoCAD mapping software were utilized to assure the accuracy of the distance calculations for proper analysis of the airblast recordings.

In 2010 multiple seismographs were setup at one WV coal mine site and recorded 72 airblast readings for 20 blast events. The correlation factor of the trendline for this 2010 data increased to 0.4771 compared to 0.1521for the 2009 data, which was still considered too low for regression analysis predictive methods. This data is shown charted in regression format in Figure 7. It should be noted from the data points on the chart, that no airblast exceeding the 133 dB regulatory limit was recorded above the cube root scaled distance value of 100. A comparison of cube root scaled distance values will be addressed later in this report.

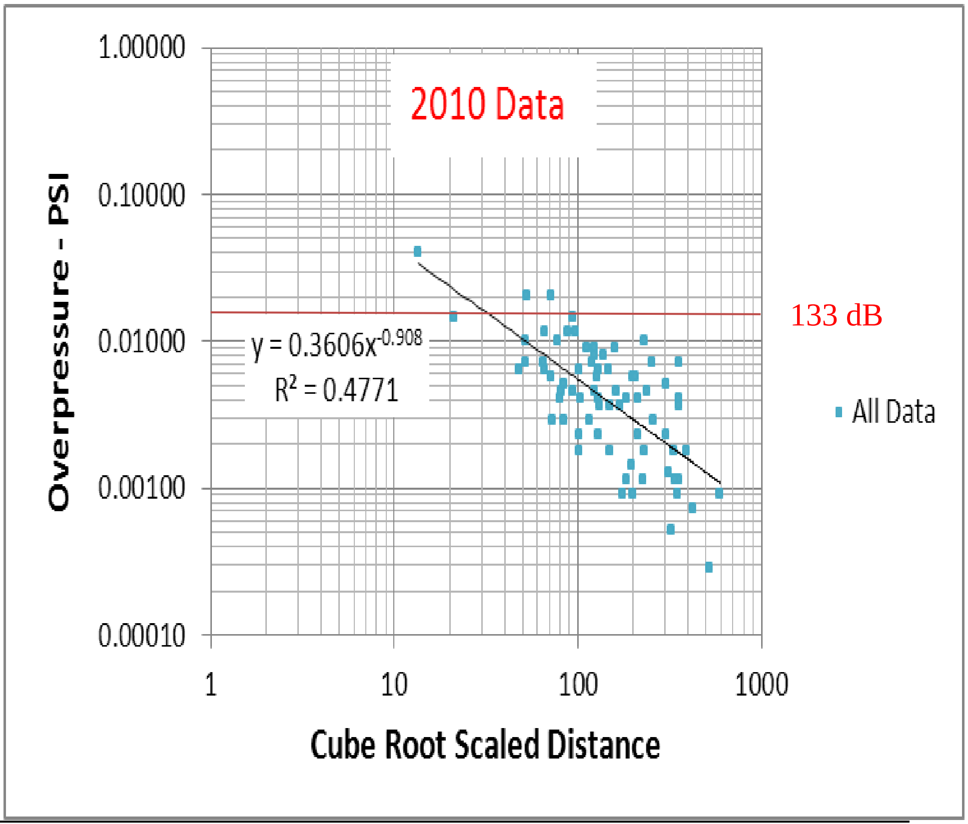

Figure 7

Regression chart of the 72 airblast recordings made by OEB staff in 2010

The next step in the analysis was to try to explain why the regression analysis had a very low correlation factor of 0.4771, whereas a correlation factor of 0.70 is generally considered the minimum for acceptable data correlation and trendline analysis.
The data were then analyzed by coal seam. The resultant correlation factors were improved from the 0.477 to about 0.60 for three of the four coal seams, but the factor was under 0.30 for one of the seams. The data were also analyzed by borehole depth with no apparent effect. Analyzing the data by weather conditions had the most dramatic effect on correlation factors and weather is a main focal point of the rest of this report.
When the data were separated into the categories of rainy, clear, and cloudy days the correlation factors on clear days and on rainy days increased to acceptable correlation factors above 0.70. However, the data for blasts on cloudy days did not correlate well. The variation in type, elevation, and thickness of clouds was not specifically identified in the blast data, but was encompassed in the general term "cloudy", which could account for the lack of correlation. The chart in Figure 8 illustrates the three separate atmospheric data sets, the regression trendlines, and their corresponding correlation factors. Also shown are the trendlines based on the USBM highwall and parting formulas.

The data suggest that rainy conditions might cause a significant dB increase for the same cube root scaled distance value. However, the amount of data for rainy conditions was limited to 10 data points from only three blasts.

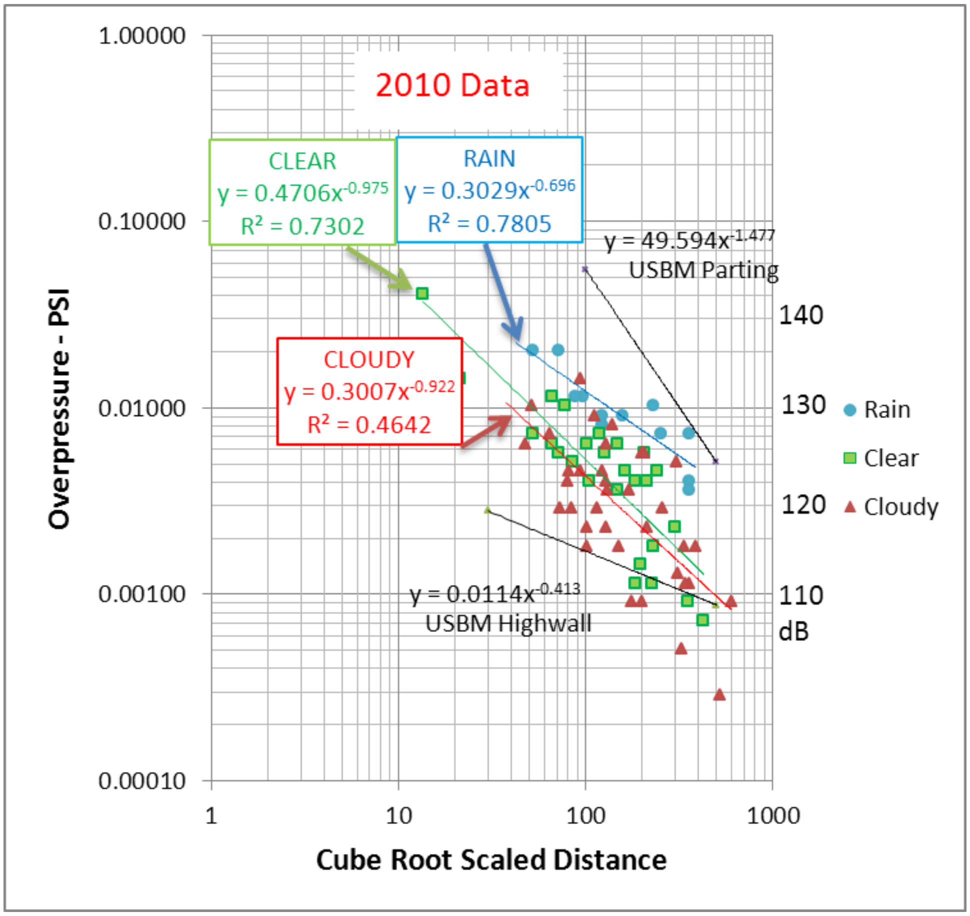

Figure 8
Airblast data separated by atmospheric conditions

With the blast events separated by weather condition, the apparent effects that weather conditions have in West Virginia seemed evident. Considering the impact of the scaled distance value and potential impact of weather on dB levels, the data collected for the 2008 violations were re-examined. The results are shown in Table 5. Of the 20 non-compliant events, 10 were below the scaled distance value of 100, and two others were below 120. Four of the other eight events involved extremely shallow holes, defined herein as: "the depth of the borehole less than the burden in feet". These holes tend to eject their stemming, resulting in high airblast levels. Extremely shallow holes are commonly used in the parting, binder, and boulder shots in West Virginia coal mines. Thirteen of the 20 non-compliant events occurred during inclement weather. Only two of the events were obviously caused by poor blasting practices; one, by not decking across a mud seam, and the other, a poor timing design of the delays between holes. Data available on the remaining two events were insufficient for analysis. Table 5 summarized the data for each of the 20 blasts. Particular attention should be drawn to the 'Analysis' column.

Date of blast	Air blast level dB (measured)	Weight of explosives per 8ms delay	Distance to AB reading	Cube Root Scaled Distance	Cloud conditions	Analysis
01/08/08	139.0	2,071	1,800	141	Overcast	Hole blew out due to mud seam
01/23/08	142.0	4,311	1,100	68	Cloudy	Cube Root Scaled Distance < 100 and cloudy
02/20/08	136.0	1,096	1,000	97	Snow	Cube Root Scaled Distance < 100 and Snow
02/27/08	140.0	753	1,000	110	Snow	Cube Root Scaled Distance = 110 and Snow
03/01/08	135.0	109	1,060	222	Fog	Binder shot and Fog – shallow depth
03/17/08	137.0	359	800	113	Clear	Cube Root Scaled Distance = 113
03/18/08	134.0	288	200	30	Clear	Cube Root Scaled Distance < 100
03/24/08	135.0	431	550	73	Cloudy	Cube Root Scaled Distance < 100 and cloudy
03/28/08	134.0	305	200	30	Cloudy	Cube Root Scaled Distance < 100 and cloudy
05/05/08	134.0	92	434	96	Cloudy	Cube Root Scaled Distance < 100 and cloudy- shallow depth
05/14/08	134.0	92	434	96	Cloudy	Cube Root Scaled Distance < 100 and cloudy
06/23/08	133.9	858	600	63	Clear	Cube Root Scaled Distance < 100
07/07/08	136.0	104	2,500	531	Rain	Binder shot and rain – shallow depth
07/07/08	133.9	600	350	42	Clear	Cube Root Scaled Distance < 100
07/17/08	141.0	2,398	2,750	206	Clear	Very poor delay timing in blast design
08/05/08	142.0	419	1,594	213	Overcast	No analysis – Data insufficient
08/29/08	143.0	485	3,678	468	Clear	No analysis – Data insufficient
10/11/08	134.0	12	4,745	2074	Clear	21 boulders
12/08/08	134.0	720	528	59	Overcast	Cube Root Scaled Distance < 100 and cloudy
12/10/08	136.0	19	2,250	847	Cloudy	Boulder Shot and cloudy – shallow depth

Table 5
2008 airblast violations summary

Conclusions/Recommendations

Airblast is a significant adverse effect of blasting, particularly with regard to annoyance to neighbors. Continuing investigations of blasting complaints by the OEB indicate that airblast is a major contributing factor to complaints. Both federal (OSMRE) and West Virginia blasting laws require periodic seismographic blast monitoring to ensure blasting operations are not exceeding the maximum allowable limits on airblast and ground vibration (West Virginia rule 199CSR1-3.6.c.3.). Blast plans require random or infrequent monitoring for airblast. The required frequency of monitoring for airblast is at a minimum one blast event per calendar quarter, but may be more frequent with each permit depending on site specific conditions, i.e. the size of operation and the surrounding environment. These airblast monitoring requirements can vary from permit to permit and are detailed in the blast plan submitted by the permittee for approval by the OEB prior to the commencement of blasting. Many mines with close neighbors voluntarily monitor every blast. It appears that comprehensive monitoring of airblast at the onset of blasting at a new permit may have merit to determine the baseline levels of airblast at compliance structures. When following up on complaints, the OEB inspector specialists will often install the OEB's in-house seismographs to monitor blasts.

West Virginia and federal laws allow the use of "square-root" scaled distance equations rather than seismographic monitoring to comply with ground vibration regulations. The scaled distance equation is used for ground vibration compliance and not for airblast compliance. There is no provision in the laws for a similar type equation on pounds per delay relative to distance for airblast compliance, although "cube root" scaled distance is used to predict airblast levels. All of the data gathered in 2010 were in compliance when the cubed root scaled distance was over 120. Consideration should be given to require airblast monitoring when the "cube-root" scaled distance factor is below 120, which gives some margin of safety.

When the OEB separated the data by weather conditions, there was good correlation of the data on rainy and clear days. However there was not a good correlation of data on cloudy days.
The data did suggest that rainy weather might cause a significant increase in airblast level versus blasting on a clear day. The data indicated that shots with cubed root scale distance of approximately 100 or less on rainy days have potential to exceed the allowable airblast limits. These blasts should be avoided during inclement weather unless monitoring is provided. However, this study had only three blasts on rainy days with just 10 airblast readings. It was felt that more data was needed to confirm the conclusions in this report before recommending adjustments to existing regulations.

Shallow blasts, where the depth of the borehole in feet is less than the burden or spacing, can result in stemming ejection and excess airblast despite a high cube root scaled distance factor. Many West Virginia coal mines have parting, binder, and boulder shots that meet this definition of “shallow”. These boulder, binder, and parting blasts, have a tendency to cause higher levels of airblast. Therefore these types of shots should be avoided, if possible, especially during inclement weather, unless monitoring is provided, because of the increased potential for exceeding the allowable limits.

Accurate recorded data on blast logs are paramount in determining the overall performance of a blast and for determining the cause of adverse effects and non-compliance with regulations. Pounds of explosives detonated and distance from the blast are the two major factors in regulatory compliance. Proper location of the blast is required for calculating distance to structures that must be protected. GPS technology is inexpensive and its use should be required on all blasts and perhaps mandated that a minimum of two opposite corners of the blast be identified by GPS coordinates and that these GPS corner locations should be shown on the required blast log sketch.

When investigating blasting complaints, it is difficult to forensically determine the actual blast parameters and offsite effects in the absence of seismograph monitoring. There can be premature stemming ejection (rifling), blowouts, lightly burdened or shallow blasts that create high airblast that will go undocumented in the absence of seismographic monitoring. Predictive equations cannot compensate for poor blasting practices, unusual site conditions, or cracks in the rock formation to be blasted.
To help minimize cracks in the rock formation to be blasted, a technique called presplitting is recommended. Presplitting is a blasting method which consists of a series of closely spaced, lightly loaded blastholes that are detonated in advance of the production blast with the intent of creating a single crack (fracture plane) along the line of presplit holes. Rock fragmentation from a production blast should terminate at the presplit crack, minimizing the cracking of the rock mass that will be drilled in successive blasting activities. Presplitting also creates a safer highwall that will be exposed during the excavation process. This presplit method helps reduce gas venting from the face of successive blast events.

When seismographic monitoring is conducted and high levels of airblast are recorded, the primary task is to determine the blast parameter that contributed to the high airblast event. In the process of evaluating blast performance, it is necessary to review blasting plans and practices for development of remedial measures for a high airblast event. Developing a remediation plan can be very difficult when there is a lack of documentation on how that specific shot performed. Videoing of the blast during detonation is becoming common practice for many blasting contractors to help in evaluating blast performance. This is a valuable tool in determining the cause of high airblast and for targeting specific remedial measures that will address the causation and hopefully lead to the prevention of repeated occurrences.

GLOSSARY

ANFO - non water resistant explosive ideally composed of 94.0-94.3 percent ammonium nitrate (AN) and 5.7 to 6.0 percent fuel oil (FO).

airblast - the airborne shock wave generated by an explosion.

attenuation - decrease in amplitude of a wave as a function of distance of propagation from its source.

blast log - a written record of information about a specific blast as required by regulatory agencies.

blast vibration - the energy from a blast that manifests itself in earthborn vibrations that are transmitted through the earth away from the immediate blast area.

borehole - a hole drilled in the material to be blasted, for the purpose of containing an explosive charge.

compression wave - a mechanical wave in which the displacements are in the direction of wave propagation. Because this wave shows the highest velocity, it is called the primary wave (P-wave).

confinement – constraining effect of the borehole, stemming, and surrounding rock mass on the explosive charge.

correlation coefficient (R) - a number expressing the fitness of a curve to measurement data. R varies between 0 - 1 where 1 represents the case when all measurement points are located on the fitted line.

decibel (dB) – the unit of sound pressure, commonly used when expressing airblast by converting from psi.

free-face - an unconstrained rock surface within the blast site (normally a high wall or end wall) that is free of confinement; a rock surface exposed to air, water, or buffered rock zone that provides room for expansion of the blasted material at time of detonation.

millisecond - one thousandth (.001) of a second

peak particle velocity (PPV) - a measure of the intensity of ground vibration, specifically the time rate of change of the amplitude of ground vibration.

overpressure - the pressure exceeding the atmospheric pressure and generated by sound or concussion waves from blasting.

scaled distance - a factor relating similar blast effects from various size charges at various distances. It is obtained by dividing the distance of concern by a fractional power of the weight of the explosive materials.

seismograph - an instrument useful in monitoring blasting operations, that records ground vibration and air blast.

shallow hole - a borehole whose depth is less than the distance to horizontal relief i.e. burden.

shock wave - a transient pressure pulse that propagates at supersonic velocity.

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