REPORT
OF
SEISMIC RESEARCH

By:

WEST VIRGINIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
OFFICE OF EXPLOSIVES AND BLASTING

DECEMBER 31, 2004

TABLE OF CONTENTS

Abstract..Page 1

Terms..Page 3

Introduction..Page 5

Ground Vibration Review...Page 7

Air Overpressure Research ....Page 7

- Surface Explosions..Page 9
- Valleys..Page 12
- Rolling Terrain ....Page 13
- Steep Terrain...Page 15
- All Terrain...Page 16
- Attenuation Drop Rates ....Page 17
- USBM versus OEB Regression Equations ....Page 17
- Cube Root..Page 17

Conclusions..Page 18

Future Research...Page 18

Bibliography ....Page 20

ABSTRACT

The Office of Explosives and Blasting (OEB) analyzed ground vibration seismic recordings as a continuation of the 2003 legislative research paper. Site seismic data from 275 blasts over a 2-year period was graphed and compared against various ground vibration predictive models. Graphs and a statistical study show that ground vibration predictive equations can be effective as part of site-specific blast plans if performed properly.

In order to accurately predict airblast from surface coal mine blasting, research was conducted to gather data from various permits to evaluate and identify factors that affect airblast. OEB conducted a statistical analysis with these data sets to identify common factors and establish an accurate prediction model that could be used in blast design. These models can be used to predict and limit levels of airblast at structures to maintain compliance with regulatory standards and allowable blasting limits.

TERMS

Airblast – See Overpressure.

Amplitude – Measured in inches, it is the maximum positive or negative value of one period in a cyclic changing quantity.

Attenuation – Rate at which a seismic wave decays over distance.

Compliance - Standards from West Virginia Code of State Regulation Title 199 (199CSR1).

Ground Vibration – The operator shall not exceed the maximum weight of explosives (lbs.) to be detonated in any eight millisecond period calculated using the following scaled distance formulas, without seismic monitoring:

SCALED DISTANCE FORMULA	DISTANCE FROM THE BLASTING SITE TO THE NEAREST STRUCTURE (FEET)
$W = (D / 50)^2$	0 – 300
$W = (D / 55)^2$	301 – 5,000
$W = (D / 65)^2$	5,001 or greater

W = Weight of explosives in pounds
D = Distance to the nearest structure

The scaled distance formulas need not be used for any particular blast if a seismograph measurement at the nearest protected structure is recorded and maintained for the blast. The peak particle velocity in inches per second shall not exceed the following values at any protected structure:

SEISMOGRAPH MEASUREMENT (IPS)	DISTANCE FROM THE BLASTING SITE TO THE NEAREST STRUCTURE (FEET)
1.25	0 – 300
1.00	301 – 5,000
0.75	5,001 or greater

Airblast – Airblast shall not exceed the maximum limits below at the location of any dwelling, public buildings, school, church, or community or institutional building outside the permit area.

LOWER FREQUENCY LIMIT OF MEASURING SYSTEM (Hz) ($^{+/-}$3 dB)	**MAXIMUM LEVEL (dB)**
0.1 Hz or lower	134 peak or (.0139 psi)
2 Hz or lower	133 peak or (.0131 psi)
6 Hz or lower	129 peak or (.0081 psi)
C weighted	105 peak or (.0005 psi)

Concussion – The inaudible part of an air blast.

Contour – Special blasting method used where special care is taken to avoid overbreak and downslope placement of blasted material.

A-Scale – The scale of a sound measurement instrument in which an in-built filter discriminates against low frequencies.

C-Scale – The scale of a sound measurement instrument that only slightly filters low frequencies.

Decibels (dB) – A unit of sound pressure. It must be noted that overpressure dB's are different than community noise dB's. Noise measurements are made with sound level meters with filters that alter the true pressure readings. Seismographs and pressure gages are designed to record true airblast overpressures. Seismographs will record directly as dB or pounds per square inch (psi). The conversion of dB to psi is accomplished with the formula: $\text{psi} = \log^{-1}$ ((dB – 170.75/20)).

Far-Field – The distance from a point of interest in relation to a geometric quantity. For OEB purposes, far-field is anything over 500' from the blast.

Frequency – Number of cycles per unit of time, usually seconds, also called hertz (Hz).

Inversion – An atmospheric condition where the air temperature increases with altitude.

Mountain Top – See Production.

Near-Field – The distance from a point of interest in relation to a geometric quantity. For OEB purposes, near-field is anything under 500' from the blast.

Overpressure – The pressure exceeding the atmospheric pressure generated by rock movement or sound waves from blasting.

Parting – Rock mass located between two seams of coal.

Production – Blast method used where the primary activity is to remove material down to coal seam.

Scaled Distance – Factor obtained by dividing the distance (in feet) from the blast to the point of observation by a square root of the explosive mass (in pounds) per delay.

Scaled Distance Formula – See Compliance.

Supersonic Speed – Speed greater than the speed of sound (1,086 feet per second at 32 degrees and sea level).[1]

INTRODUCTION

OEB, in compliance with West Virginia Code §22-3A-10, conducts research to develop scientific data on blasting concerns and effects of the West Virginia natural terrain on blast vibrations, both ground and air. The 2003 legislative research paper entitled "Report of Seismic Research" focuses on ground vibrations and the potential for predicting ground seismic waves using regression analysis. Per the 2003 report, the ground vibration predictive model format is:

$PPV = k * (D / W^{.5})^{A}$

where:

PPV = Predicted Peak Particle Velocity in inches per second (ips)
k = Blast site constant or y-intercept on PPV vs. Scaled Distance Regression Curve
D = Distance from the blast to seismograph in feet
W = Maximum pounds per delay of explosives
A = Slope of regression curve.

Therefore, to predict a ground vibration below 1.0 ips for a structure 310 feet from a blast, you should not exceed the variable of 166 pounds per delay.

During the course of the research project in late 2003, seismograph arrays placed ahead of mining revealed that the original ground vibration prediction equation would not always be in compliance with West Virginia blasting laws and regulations if blast designs stayed constant. This is true for structure #82 and #97. (See Figure 1on page 4) In order to increase the safety factor in the predictive model, OEB approved a new site constant (k) of 240 submitted by the permittee.

The permittee collected ground vibration recordings over a two-year period that OEB analyzed as a continuation of the 2003 report. OEB sorted the data and performed regression analysis on various structures to determine the validity of ground vibration predictive equations as part of the site-specific blast plan. The average PPV for all structures studied was 0.47 ips for the original blast design. OEB calculated an average PPV of 0.16 ips when the permittee used the predictive equation as the basis of their blast design. At this particular site, ground predictive equations used as a compliance method were successful.

OEB used seismic recordings obtained during 2004 in air overpressure prediction calculations. This research considers topography such as valleys, and flat, rolling, and steep terrains.

Airblast measurements were recorded on unconfined surface detonations on flat terrain as baseline worst-case mining scenarios. These predictions were then compared against the United States Bureau of Mines (USBM) regression results from Report of Investigation (RI) 8892. Although some air overpressure data sets are small, trends do appear. Data sets reveal that valleys generate the highest airblast potential, followed by steep and then rolling terrain. Other environmental parameters such as wind speed and direction, temperature inversions, confinement, etc., were not included in the present study. Future research must consider these variables to accurately predict airblast in the West Virginia coalfields.

---

[1] Agne. Rustan, et al., Rock Blasting Terms and Symbols, (Rotterdam, Netherlands: A.A. Balkema, 1998). pp. 7 - 156

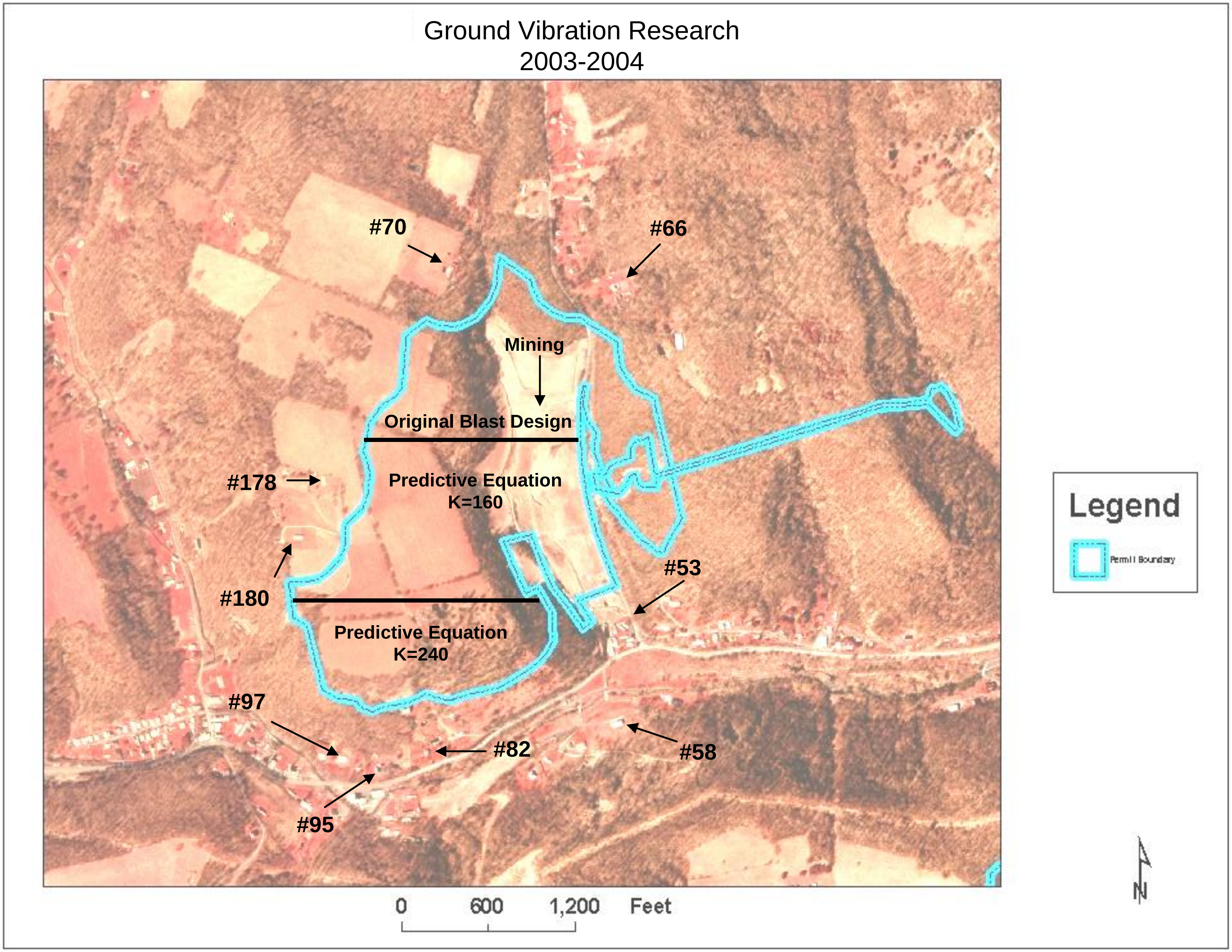

Ground Vibration Research
2003-2004
#70
#66
Mining
Original Blast Design
Predictive Equation
K=160
#178
#180
#53
Predictive Equation
K=240
#97
#82
#58
#95
Legend
Permit Boundary
0
600
1,200
Feet
N

Figure 1

GROUND VIBRATION REVIEW

OEB analyzed seismic records from 275 blasts from August 26, 2002 thru September 27, 2004. Figure 1 is the plan view of the permitted area divided into blast design zones. These zones include the original blast design, predictive equation k = 160, and predictive equation k = 240. Also noted are the locations of the structures where seismograms were recorded. Mining started at the northern end of the permit and progressed south. The seismic data is as follows:

DATES	NUMBER OF RECORDS	AVERAGE PPV	AVERAGE DISTANCE
(Pre-Prediction) 8/26/02 – 5/30/03	141	0.48 ips	591 feet
(Post-Prediction) 8/4/03 – 9/27/04	134	0.16 ips	694 feet

Information above shows a significant decrease in PPV when using the regression predictive method instead of the original blast design and all structures are considered.

OEB studied seismograph readings at particular structures to determine the benefits of using predictive equations as part of a site-specific blast plan.

DATES	BLAST DESIGN	STRUCTURE	NUMBER OF RECORDS	AVERAGE PPV	AVERAGE DISTANCE
9/18/02 – 1/17/03	Original	66	26	0.50 ips	413 feet
8/27/02 – 2/27/03	Original	70	90	0.43 ips	613 feet
8/26/02 – 5/30/03	Original	178	23	0.63 ips	698 feet
8/4/03 – 9/27/04	k=160	178	26	0.21 ips	534 feet
1/27/04 – 1/30/04	k=160	180	15	0.13 ips	847 feet
3/10/04 – 3/30/04	k=240	180	12	0.15 ips	788 feet
11/3/03 – 1/16/04	k=160	53	24	0.09 ips	687 feet
8/2/04 – 9/27/04	k=240	97	13	0.12 ips	581 feet
1/23/04 – 9/27/04	k=240	95	17	0.14 ips	864 feet
3/3/04 – 9/8/04	k=240	82	17	0.14 ips	714 feet
3/1/04 – 3/8/04	k=240	58	9	0.18 ips	686 feet

The findings above show by using a predictive equation for blast design, a decrease in PPV occurs. Decrease in PPV may be attributed to a 40% reduction in the maximum charge weight per delay when using the predictive models.

Figure 2 on page 6 is a graph showing the regression curve where k = 160 and displays the results of seismic data in comparison to the predictive curve. Sixty-eight seismic records were plotted with six having higher PPV's than predicted. Therefore, 91% of the PPV predictions fell below the regression curve, but all records were in compliance.

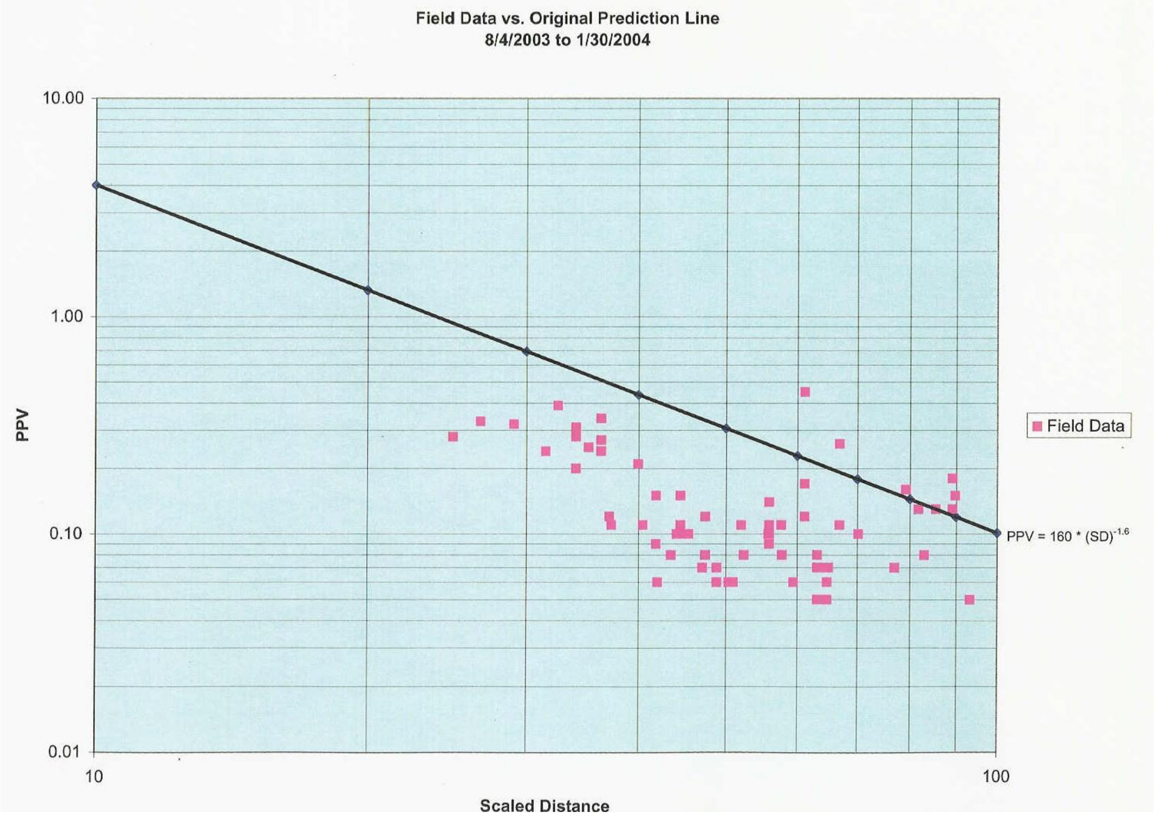


Figure 2

Figure 3 shows the regression curve where k = 240. Sixty-nine seismic records were plotted with two having higher PPV's than predicted. The results show 97% of the predictions fell below the regression curve and are compliant. Of the 3% above the regression curve, only one record was non-compliant.

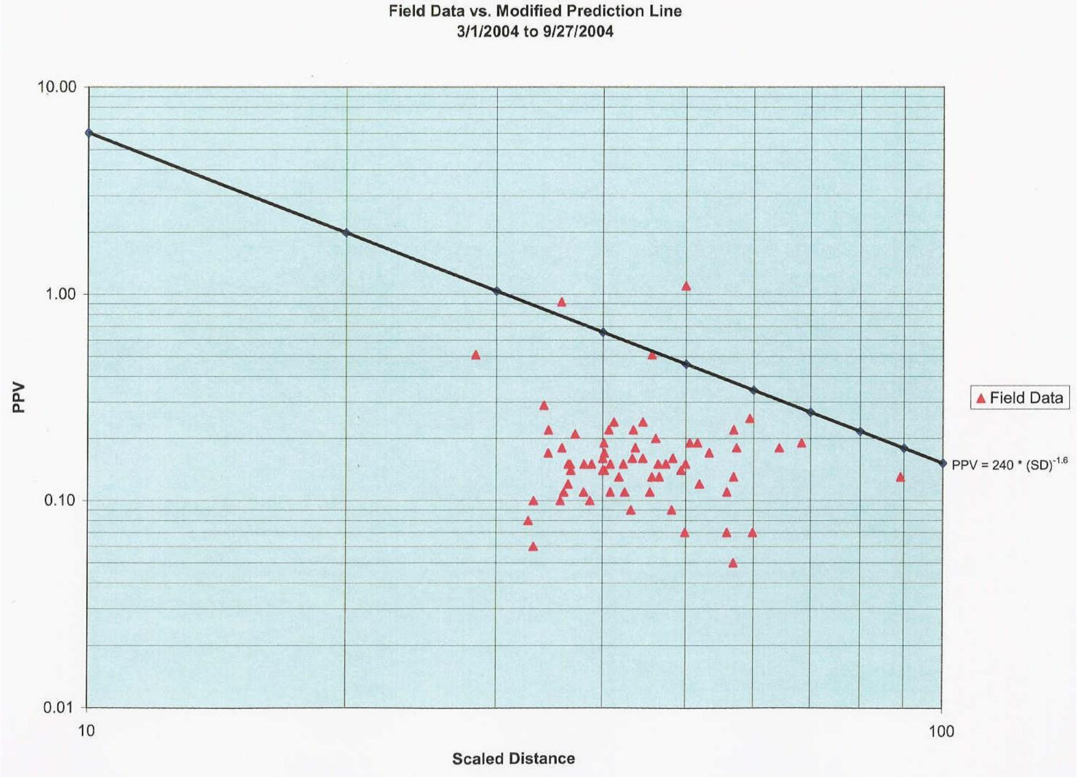


Figure 3

Data that did not fall below the regression curve may have been attributed to no seismic array data, geophone coupling, and variations in detonator firing times.

AIR OVERPRESSURE RESEARCH

OEB continues air overpressure research. This is partly due to air prediction models encountered in submitted blast plans, but also the potential for future surface detonation data.

Seismic arrays placed in strategic positions recorded air overpressure levels. OEB processed collected data using regression analysis to generate a predictive equation. This equation is created on a log-log graph with the x-axis being the cube root scaled distance, and the y-axis representing psi of air overpressure. Cube root scaled distance is $D/W^{.333}$. D is the distance between the blast and seismograph, and W is the maximum charge weight per delay. Figure 11 on page 11 illustrates this concept. The "goodness of fit" (R^2) describes the processed data quality and for prediction model integrity is 0.70 or greater.

Airborne energy called airblast is created during the detonation of a coal mine blast. The compressed airwaves travel through the air such as they would through water or ground. Airwaves are audible if they fall within a 20 – 20,000 Hz range. Although frequency less than 20 Hz is inaudible, it creates secondary audible sounds in the form of rattling windows or doors.

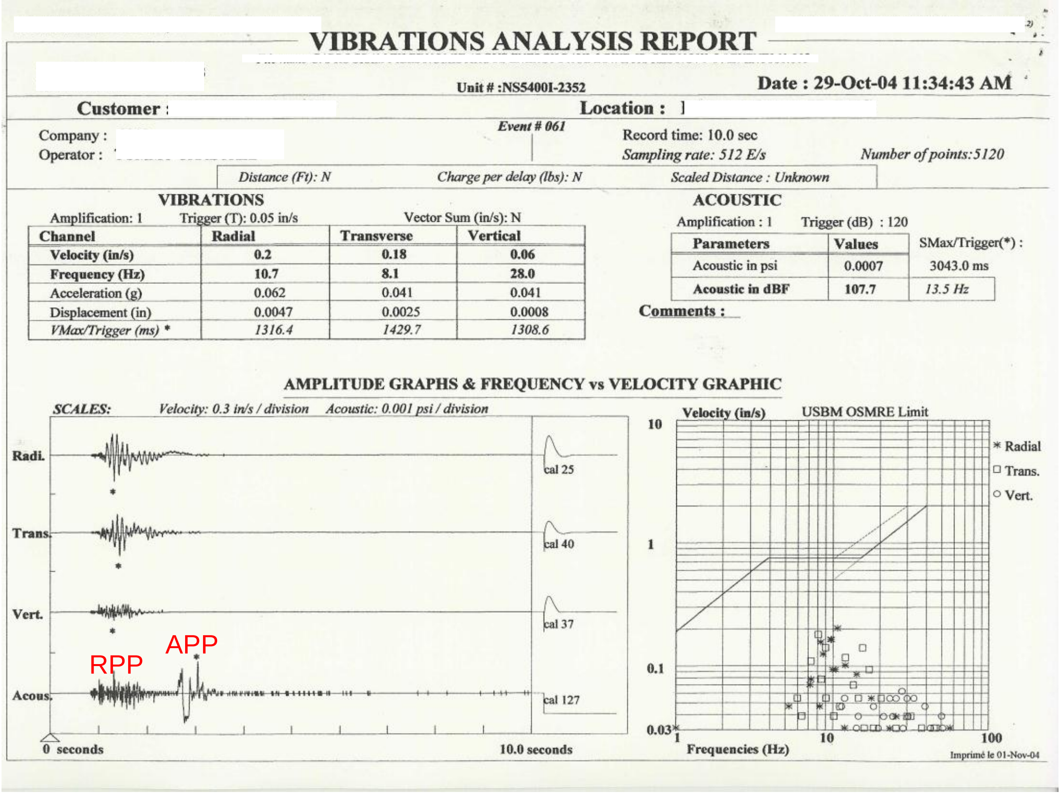
Variables that affect the intensity of air overpressure are charge weight per delay, spatial relationships, detonator delay intervals, confinement, highwall orientation, wind speed and direction, air temperature, topography, depth of charge burial, exposed surface detonating cords, and volume of displaced rock. These factors make it more difficult to predict airblast than ground vibrations (PPV).

The four causes of air overpressure are:

1) Rock Pressure Pulse (RPP)
2) Air Pressure Pulse (APP)
3) Gas Release Pulse (GRP)
4) Stemming Release Pulse (SRP)

Vertical ground displacement from the seismic wave, which generates small air pulses, creates RPP. This component of airblast has the smallest amplitude and highest frequency. Amplitude, approximated at 1/650 of the vertical PPV, arrives at the seismograph at the same time as ground vibration. Figure 4 on page 8 shows this phenomenon. The acoustic waveline shows the microphone has recorded the RPP as it arrives simultaneously with the transverse, vertical, and longitudinal ground vibrations.

In a proper blast design, APP is the dominant pulse in the total air overpressure pulse and is created from movement of the rock face in a forward or upward motion. Figure 4's acoustic waveline shows the APP spike after the RPP has been recorded. Every hole initiated in a blast is a source of APP and timing between holes can usually be detected when seismographs are used near-field. Dispersion and refraction of the individual pulses and the ability to determine blast timing becomes more difficult as far-field distances are approached.



[redacted] **VIBRATIONS ANALYSIS REPORT** [redacted]

[redacted]

[redacted]

Unit # :NS5400I-2352

Date : 29-Oct-04 11:34:43 AM

Customer : [redacted]

Location : [redacted]

Company : [redacted]
Operator : [redacted]

Event # 061

Record time: 10.0 sec
Sampling rate: 512 E/s
Number of points:5120

Distance (Ft): N
Charge per delay (lbs): N
Scaled Distance : Unknown

VIBRATIONS

Amplification: 1
Trigger (T): 0.05 in/s
Vector Sum (in/s): N

Channel	**Radial**	**Transverse**	**Vertical**
Velocity (in/s)	**0.2**	**0.18**	**0.06**
Frequency (Hz)	**10.7**	**8.1**	**28.0**
Acceleration (g)	0.062	0.041	0.041
Displacement (in)	0.0047	0.0025	0.0008
*VMax/Trigger (ms) **	*1316.4*	*1429.7*	*1308.6*

ACOUSTIC

Amplification : 1
Trigger (dB) : 120

Parameters	**Values**	SMax/Trigger(*) :
Acoustic in psi	0.0007	3043.0 ms
Acoustic in dBF	**107.7**	*13.5 Hz*

Comments :

AMPLITUDE GRAPHS & FREQUENCY vs VELOCITY GRAPHIC

SCALES: *Velocity: 0.3 in/s / division* *Acoustic: 0.001 psi / division*

Imprimé le 01-Nov-04

Figure 4

GRP and SRP are the most detrimental and controllable aspects of airblast. The GRP results from expanding gases escaping through weak geologic zones such as mud seams, natural cracks, or joint systems; or through cracks developed during the blast. Proper communications between blaster and driller minimizes GRP. The driller should note the depths and thicknesses of any geologic anomalies encountered while drilling and communicate this information to the blaster. The blaster should take face burden measurements and view the face before hole loading begins. Stemming ejection causes SRP. Proper stemming material of sufficient thickness and good burden-to-hole depth ratio will minimize SRP. The ratio should be less than one.

Airblast is categorized according to frequency. A Type I airblast is 5 – 25 Hz and Type II is less than 5 Hz. Type I is more serious in terms of potential damage as structures natural frequency response is 5 - 25 Hz frequency range.

Although frequency is an important parameter in airblast phenomena, this report will focus more on decibel prediction results for West Virginia surface coal mines. Existing regulatory blasting compliance using scaled distance does not require measurement of airblast.

Although existing USBM research shows that ground vibration and air overpressure frequency have a relationship to a building's natural frequency and damage level, this report will focus on decibel prediction results for West Virginia surface coal mines. Current Surface Coal Mining and Reclamation Act (SMCRA) and West Virginia Code of State Regulation Title 199 (199CSR1) seismic monitoring standards do not include frequency as part of structure damage criteria.

SURFACE EXPLOSIONS

OEB participated with the Federal Bureau of Investigation (FBI) on training exercises to obtain data on surface detonations and placed two seismic arrays to record the surface explosions. It was surmised the airblast generated by a surface detonation would be worse than that generated by a contour, production, or parting shot.

Figure 5

Figure 6

Figures 5 and 6 show the truck and car bombs involved with this training exercise.

Figure 7

Figure 8

Figure 7 is the fireball produced from the car detonation. Figure 8 is the crater produced from the truck detonation and Figure 9 is the crater and debris field from the car detonation.

Figure 9

Figure 10 shows the locations of the seismographs for this exercise.

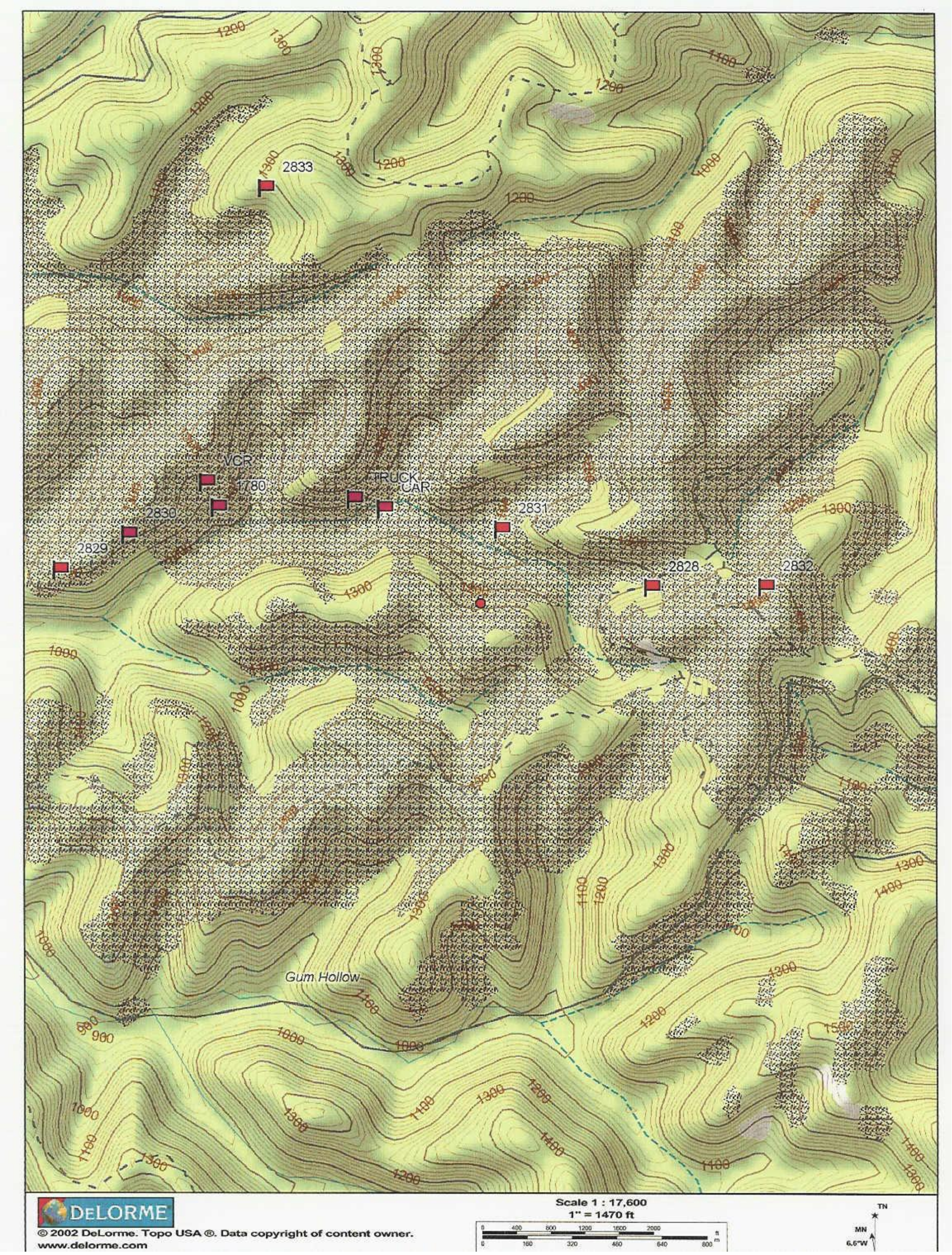


Figure 10

The general terrain was flat with some shrubs and trees. The table below shows the distance and airblast data.

SURFACE CHARGE	SEISMOGRAPH NUMBER	DISTANCE FROM BLAST (FEET)	AIRBLAST (dB)
600 lbs. Array 1	1780	1,589	145
	2830	2,661	148
	2829	3,522	143
600 lbs. Array 2	2831	1,763	148
	2828	3,633	145
	2832	4,905	142
60 lbs. Array 3	1780	1,948	134
	2830	3,010	136
	2829	3,854	130
60 lbs. Array 4	2831	1,383	148
	2828	3,252	138
	2832	4,525	132

Although the seismographs were set-up to record their maximum level of 148 dB, the level was surpassed when the seismographs were within 2,661 feet of the 600-pound charge and 1,400 feet of the 60-pound surface charge. Regression analysis used these recordings and the calculated regression "goodness of fit" was acceptable. Another dilemma encountered was anomalous readings of seismograph #1780. It is not known whether the seismic recordings were due to a faulty machine, or shrubs and trees that shielded this equipment. This data cannot be discounted, but it was not used in any calculations.

OEB prepared a combined data regression curve using Arrays 2 and 4 in Figure 11, which also plots the coal parting regression curve from USBM RI 8485. It is plainly visible that the unconfined detonation will produce a higher psi level than a parting shot if all other blasting parameters remain the same.

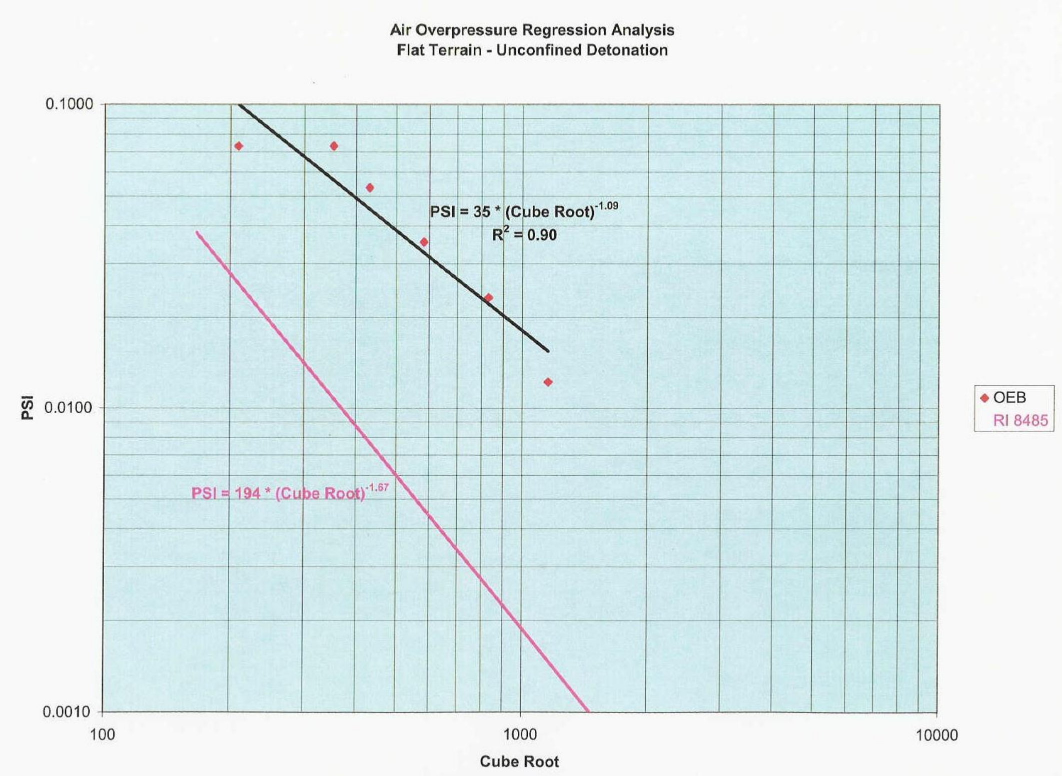


Figure 11

VALLEYS

OEB recorded and processed data from other surface mine coal blasts. The arrays were sorted according to topography. USBM RI 8485 states, “Topographic effects may be responsible for high airblast levels reported in the valleys of the Appalachian Mountain during mining.”[2] Research conducted in non-mining situations recorded a 300% increase is possible in air overpressure in valleys and hollows compared against flat terrain.

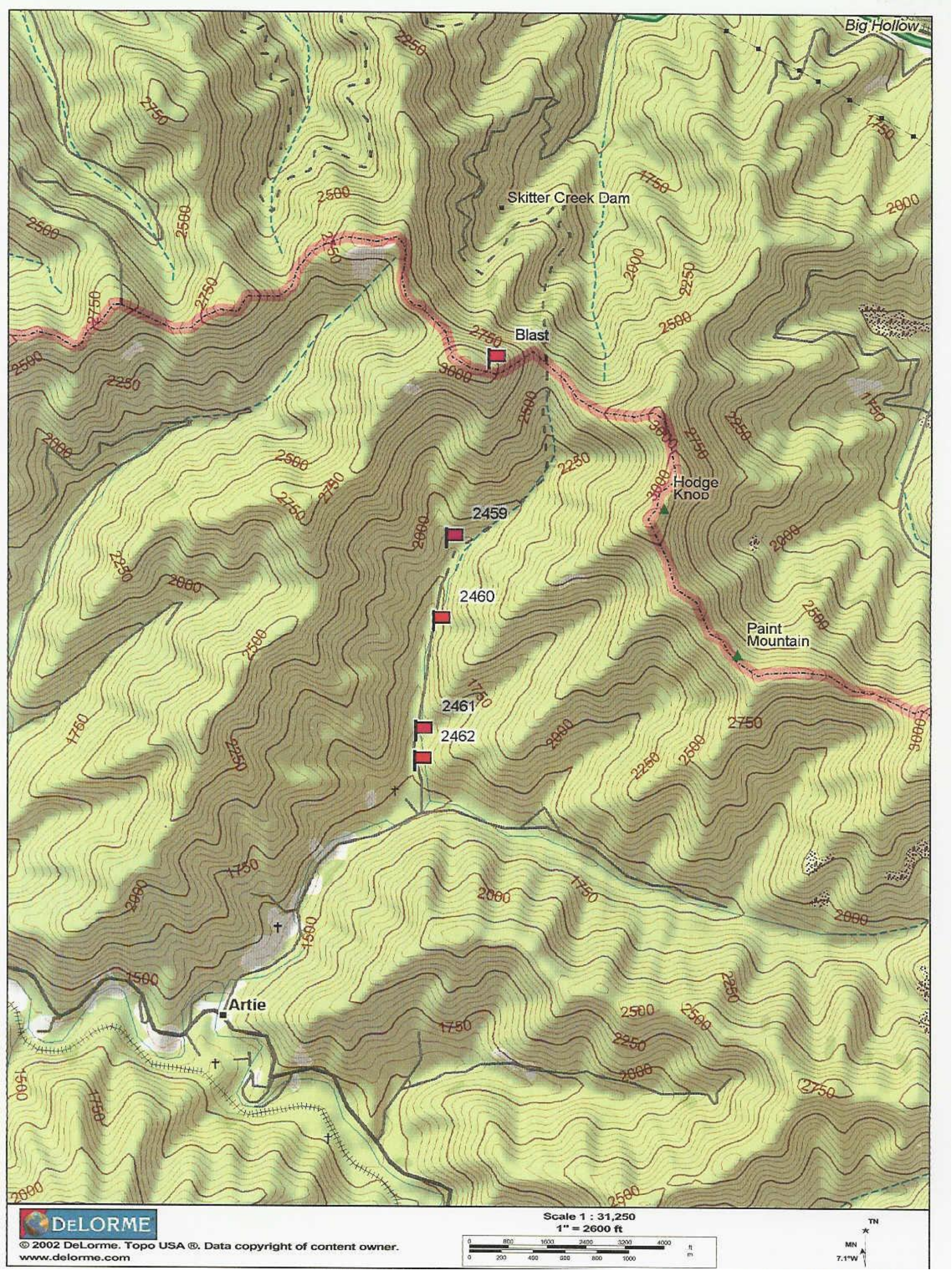


Figure 12

---

[2] D. E. Siskind, et al., “Structure Response and Damage Produced by Airblast from Surface Mining,” in USBM RI 8485, (1980), p. 67

OEB placed seismographs in a valley to record airblast data to determine the decay of the air overpressure over distance. Figure 12 on page 12 shows the approximate location of the blast, seismograph locations and topographic features. Seismic parameters for the blast were as follows:

SEISMOGRAPH NUMBER	DISTANCE FROM BLAST (FEET)	ELEVATION (FEET)	AIRBLAST (dB)
2459	3,722	1,811	132
2460	5,491	1,681	127
2461	7,748	1,533	123
2462	8,395	1,508	122

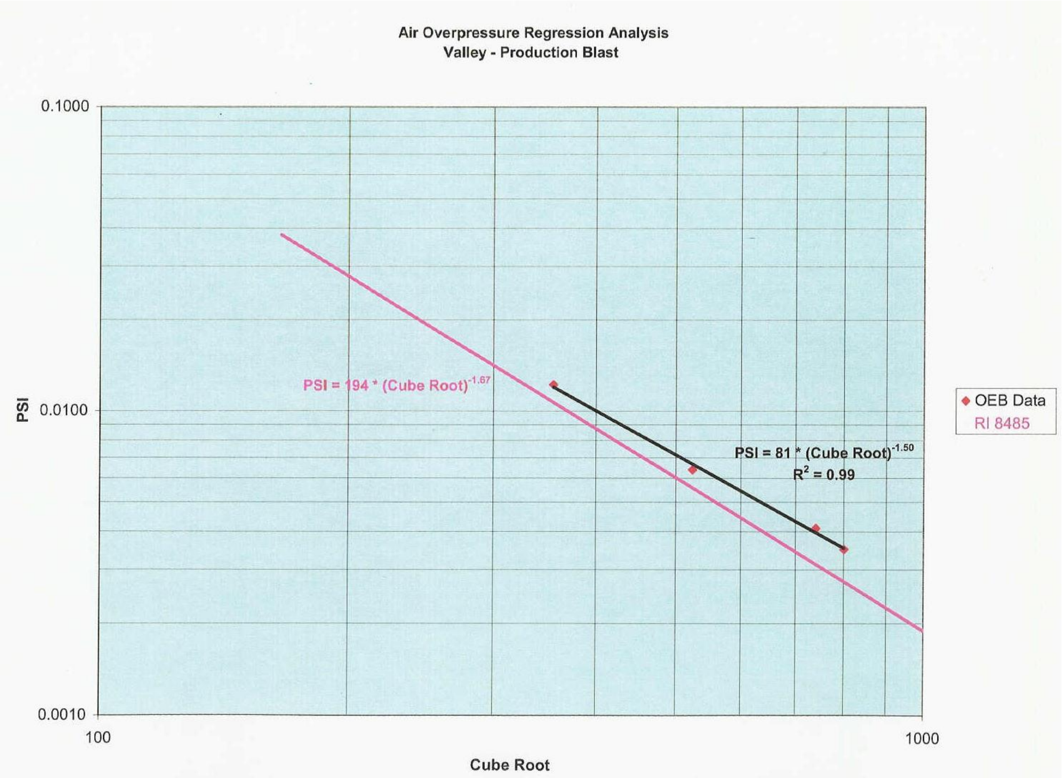


Figure 13

Figure 13 is the plotted results of the experiment. The results show the airblast prediction curve is very similar to the USBM RI 8485 coal parting regression curve. Other environmental variables that could have affected the results were wind speed (approximate 5 – 15 mph), and wind direction (SW – direction of valley) as reported by the blaster-in-charge. Additional research is needed in the valleys of West Virginia to ascertain the effects of wind speed and direction on airblast intensity.

ROLLING TERRAIN

Nine separate seismic arrays were used in northern West Virginia by OEB to calculate airblast prediction curves for rolling terrain. Figure 14 on page 14 is a topographic map of two seismic arrays. A total of 37 seismic points were collected.

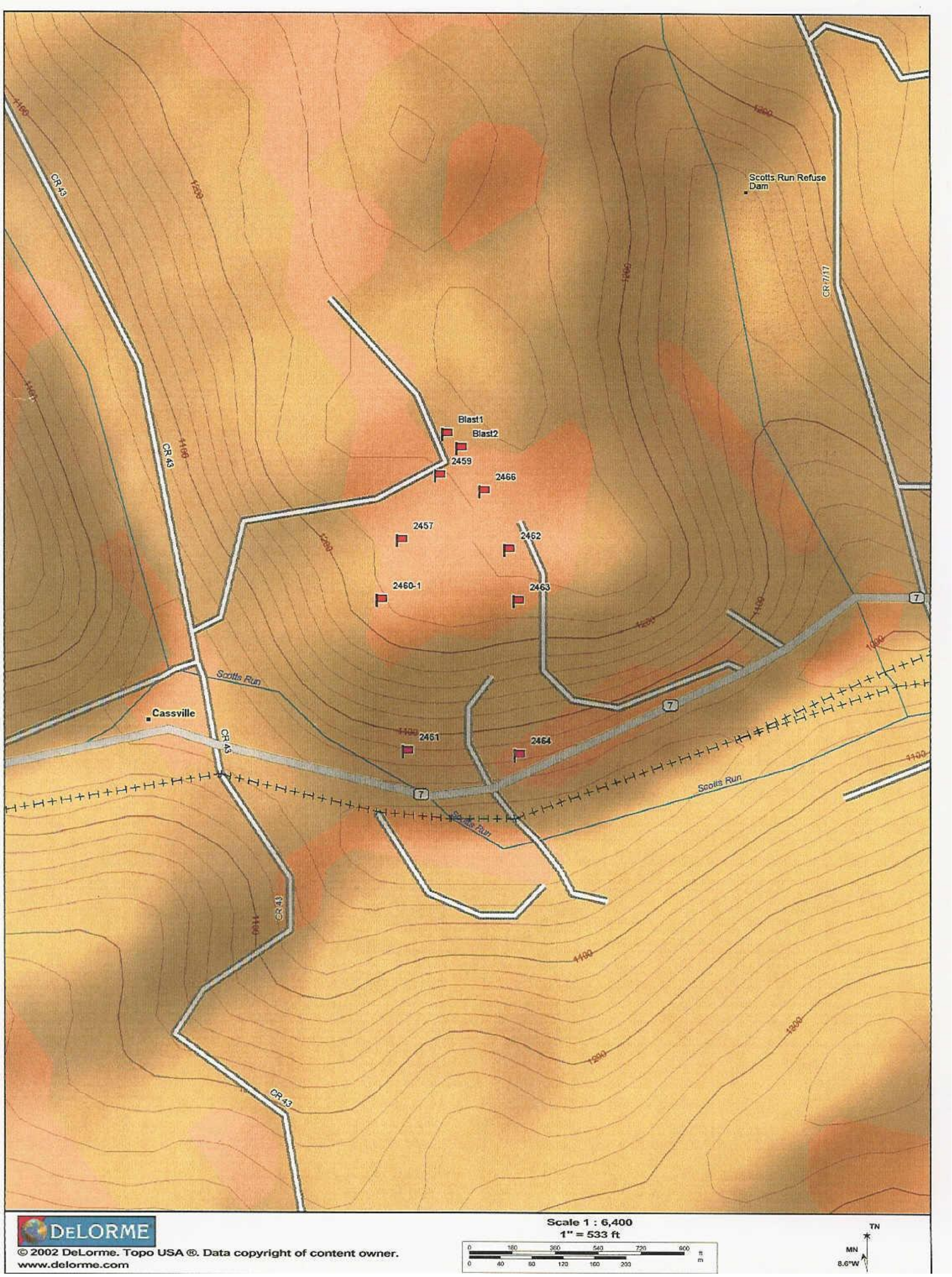

Blast1
Blast2
2459
2466
2457
2462
2460-1
2463
2461
2464
Scotts Run Refuse Dam
Cassville
CR 43
CR 7/17
7
Scotts Run
1100
1200
DeLorme
© 2002 DeLorme. Topo USA ®. Data copyright of content owner.
www.delorme.com
Scale 1 : 6,400
1" = 533 ft
0
180
360
540
720
900
ft
m
0
40
80
120
160
200
TN
MN
8.6°W

Figure 14

Figure 15 is the final regression curve. R^2 of 0.77 is sufficient for regression analysis.

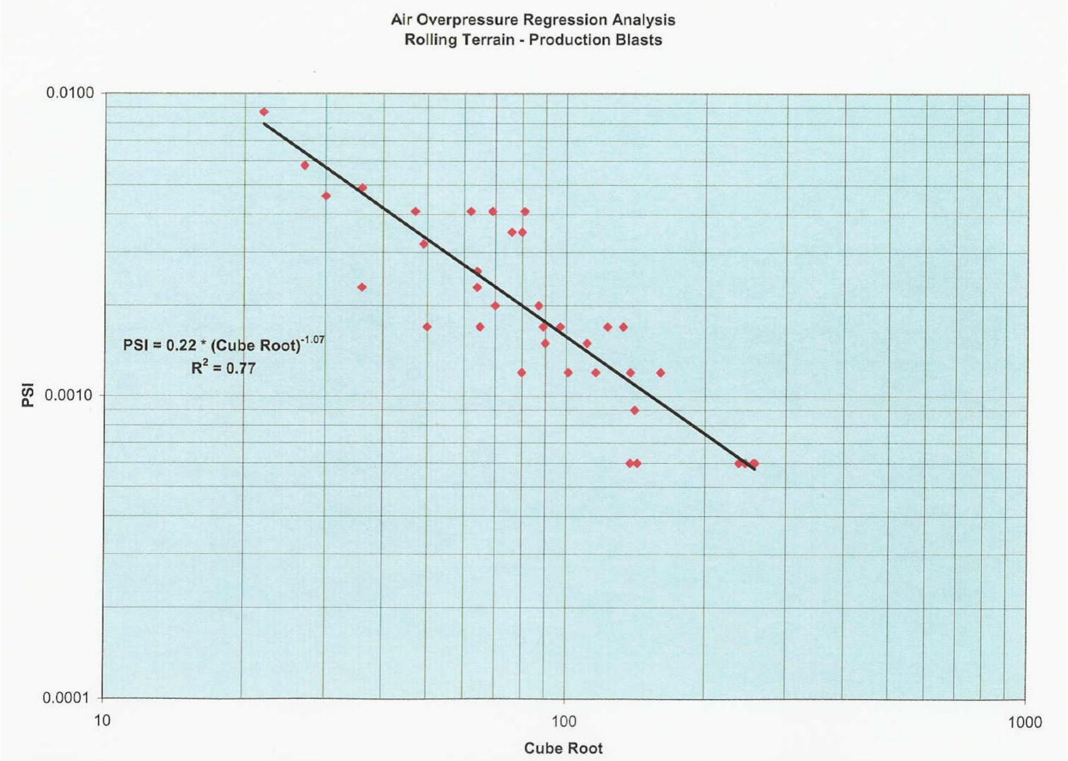


Figure 15

STEEP TERRAIN

OEB collected data from four separate seismic arrays in southern West Virginia to calculate airblast prediction curves for steep terrain features. Figure 16 is a topographic map of one array. OEB used three seismic points from each array.

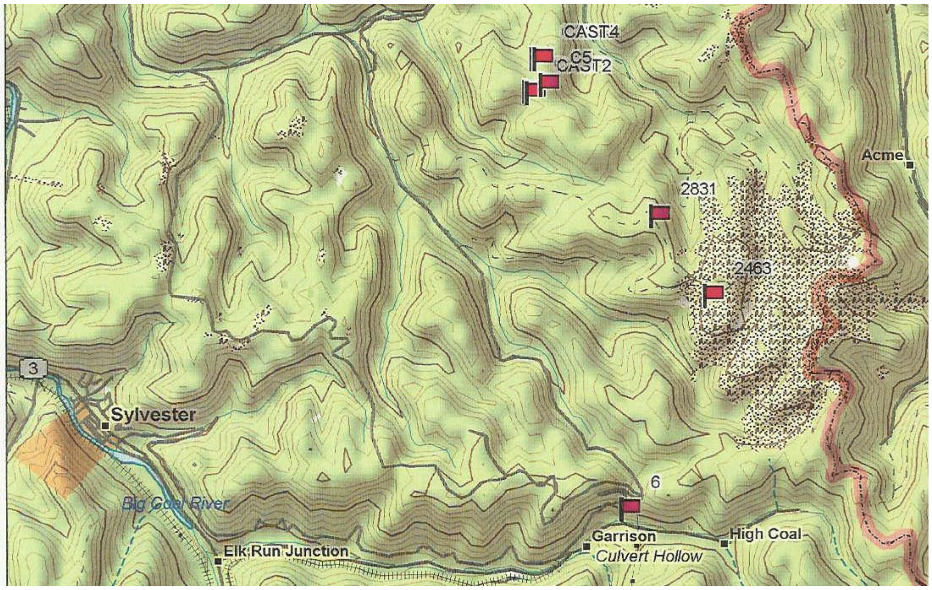


Figure 16

Figure 17 is the final regression curve.

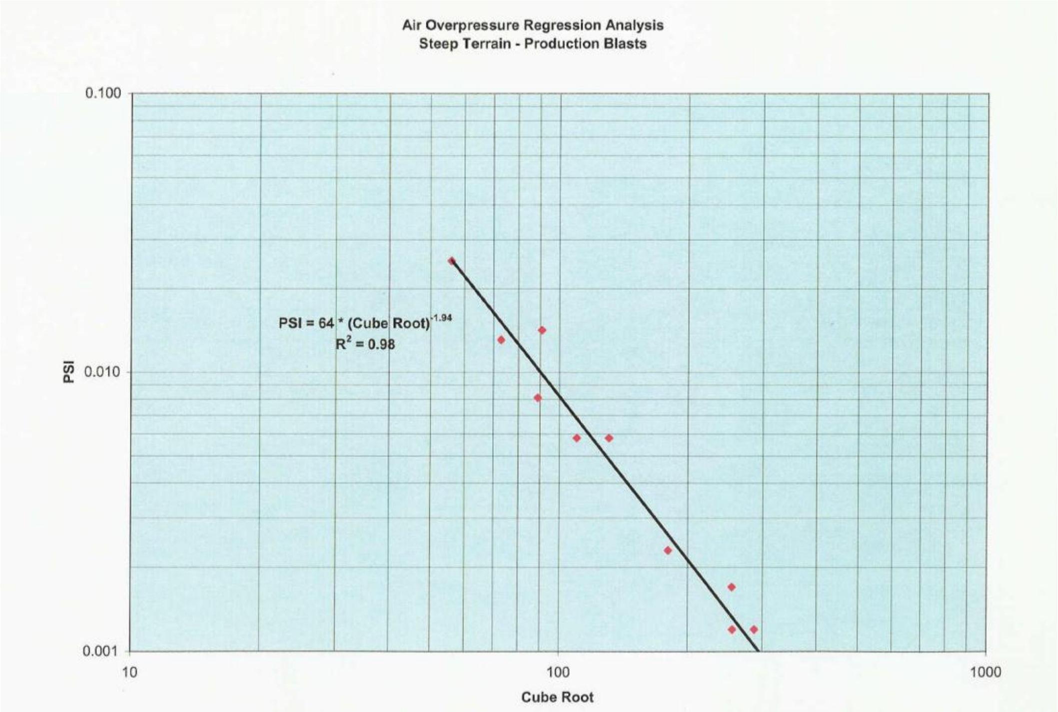


Figure 17

ALL TERRAIN

Figure 18 represents air overpressure information obtained on all types of terrain. Unconfined surface detonations have the highest potential for airblast followed by valleys, steep, and rolling terrain.

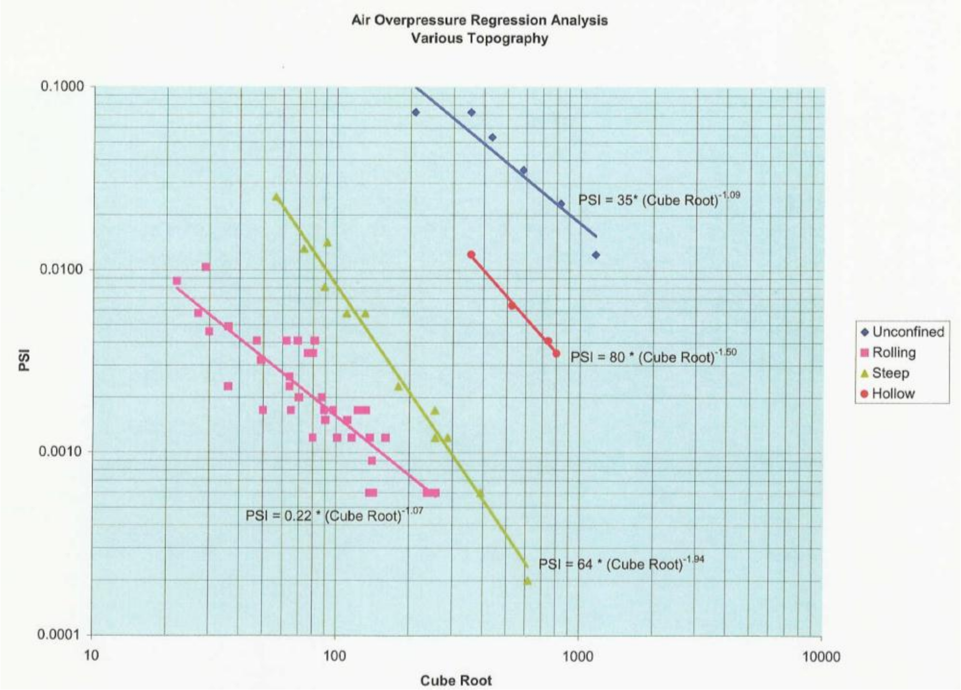


Figure 18

ATTENUATION DROP RATES

USBM RI 8892 states that by doubling the distance between the blast and seismograph a decrease in airblast of 5 dB is typical for flat terrain.[3] The table below lists the attenuation drop rates for the topographic features measured by OEB.

TOPOGRAPHY	BLAST TYPE	ATTENUATION DROP RATES (dB) PER DOUBLING OF DISTANCE
Flat	Unconfined	7
Valley	Production	9
Rolling	Production	6
Steep	Production	12

Flat topography data is comparable to USBM RI 8892. OEB calculated a 7 dB decrease when doubling the distance. No comparable data is available for valleys, rolling, or steep terrains.

USBM VERSUS OEB REGRESSION EQUATIONS

OEB calculated regression equations below and compared against USBM regression curves:

BLAST TYPE	SEISMOGRAPH SENSITIVITY (Hz)	TOPOGRAPHY	REGRESSION EQUATION	PREDICTION (CUBE ROOT=500) (dB)
USBM-Contour	.1	Valley	4*(Cube Root)$^{-1.32}$	111.6
OEB–Mountaintop	2	Valley	81*(Cube Root)$^{-1.50}$	127.9
USBM-Coal Parting	.1	Flat	169*(Cube Root)$^{-1.62}$	127.9
USBM-Coal Parting	5	Flat	194*(Cube Root)$^{-1.67}$	126.4
OEB-Unconfined	2	Flat	35*(Cube Root)$^{-1.09}$	142.8
USBM-Contour	.1	Rolling	.47*(Cube Root)$^{-1.01}$	109.7
OEB-Mountaintop	2	Rolling	.22*(Cube Root)$^{-1.07}$	99.8
USBM-Contour	.1	Steep	15*(Cube Root)$^{-1.59}$	108.4
USBM-Contour	5	Steep	.086*(Cube Root)$^{-.726}$	110.3
OEB-Mountaintop	2	Steep	64*(Cube Root)$^{-1.94}$	102.2

Seismograph sensitivity, blast type differences, sample sizes, and coefficient of determinations attribute to differences in values.

CUBE ROOT

USBM RI 8485 states, "In the absence of monitoring, the following minimum cube-root scaled distances should be maintained:

Coal Highwall	180 ft / lb $^{.333}$
Unconfined blasting	800 ft / lb $^{.333}$."[4]

---

[3] D. E. Siskind, et al., "Airblast and Ground Vibration Generation and Propagation from Contour Mine Blasting," in USBM RI 8892, (1984), p. 3

[4] D. E. Siskind, et al., "Structure Response and Damage Produced by Airblast from Surface Mining," in USBM RI 8485, (1980), p. 50

The data sets collected by OEB reveal the following minimum cube root scaled distances would be compliant.

TERRAIN TYPE	MINIMUM CUBE ROOT SCALED DISTANCE
Unconfined	1,156
Valley	355
Steep	91
Rolling	29

CONCLUSIONS

Future seismic research will incorporate information from the West Virginia Department of Environmental Protection (DEP) GIS and ERIS/RIMS systems. Use of the DEP technique will take into consideration changes in disturbed terrain and have sub-meter elevation accuracies. Current research relied on Topo4.0 mapping software used in conjunction with OEB's Garmin GPS system to determine spatial relationships.

OEB used seismic arrays in 2003 and 2004 to generate predictive equations for airblast and ground vibrations. Ground vibration research occurred mainly in northern West Virginia. Seismic arrays used over a nine-month period validated the use of ground vibration prediction models as a method of regulatory compliance. Average PPV's dropped from 0.48 ips to 0.16 ips when predictive equations were used instead of a typical blast designs. Regular seismic monitoring of blast designs based on predictive equations should be used for compliance. Field results show k = 160 and k = 240 blast design models do not provide adequate safety margins for actual ground vibrations all of the time. This is critical, especially if blasters are designing predictive ground vibrations based on the maximum allowable PPV (usually 1.0 ips).

Earlier research indicated seismographs with lower sensitivity were needed to gather more data to accurately model airblast and ground vibrations. OEB purchased seismographs in 2004 with the ability to record at very sensitive trigger levels. During this research project, these seismographs were used allowing OEB to obtain more seismic recordings over longer distances.

Field data obtained for the prediction of air overpressure was based upon terrain features. Processed seismic data has yielded predictive equations for topographic features such as flat, rolling, steep, and valley terrains. All flat terrain data was from unconfined surface detonations. This shows the highest potential for airblast. Valleys have the next highest potential for airblast. OEB valley terrain data is comparable to the USBM curve for coal parting shots.

FUTURE RESEARCH

The evaluation of seismic data in 2004 reveals the potential for higher levels of airblast in the valleys of West Virginia compared to rolling or steep terrain. This emphasizes the need for accurate reporting of wind direction, wind speed, and other environmental parameters.

The potential for other FBI or Bureau of Alcohol, Tobacco and Firearms (ATF) training exercises exists and future data will be collected for unconfined surface charges. Due to the possibility of high air overpressure, blasting demolition of structures should be monitored for compliance and research purposes.

Research conducted on ground vibration and air overpressure using regression analysis is helpful when encountering blast plans with regression equations used for compliance purposes. Site specific blast plans using predictive equations are approved and modified during the mining sequence due to OEB research. The modifications are monitored for effectiveness.

An article published by David Siskind, a known expert on seismic sciences, recommended enhancing USBM RI 8507 with continuing research projects.[5] These research projects involve seismic parameters such as structure response, frequency analysis, assessment of seismographs, blast vibration criteria for non-residential structures, and blasting near underground operations.

---

[5] D. E. Siskind, "Vibration Criteria for Surface Mine Blasting: Ten Years after Bureau of Mines RI 8507," (1991), pp. 7-8

BIBLIOGRAPHY

Rustan, Agne, et al., Rock Blasting Terms and Symbols, Rotterdam, Netherlands: 1998

Siskind, D. E., et al., “Airblast and Ground Vibration Generation and Propagation from Contour Mine Blasting,” USBM RI 8892, 1984

Siskind, D. E., et al., “Structure Response and Damage Produced by Airblast from Surface Mining,” USBM RI 8485, 1980

Siskind, D.E., “Vibration Criteria for Surface Mine Blasting: Ten Years after Bureau of Mines RI 8507,” 1991