REPORT
OF
SEISMIC RESEARCH

Conducted By:

WVDEP
OFFICE OF EXPLOSIVES
AND
BLASTING

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Prepared By:

James E. Ratcliff, Assistant Chief
Brian G. Wingfield, Blasting Specialist

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INTRODUCTION

In response to citizens' concerns and a number of blasting non-compliances found at a northern West Virginia surface mine, the Office of Explosives and Blasting (OEB) initiated a research/study project in 2003. These non-compliances violated sections of West Virginia Code §22-3A and Title 199CSR1. These violations included: exceeding the legal peak particle velocity (PPV) at the nearest protected structure (199-1-3.6.i.); failure to follow the approved blasting plan (199-1-3.2.a.); and failure to maintain accurate explosives and blasting records (199-1-3.5.a.).

The initial investigation was conducted to identify causation of reported high ground vibrations. This study emphasized that any future blasting activities at this site would prevent non-compliant ground vibrations at the nearest protected structure.

The investigation included a detailed review of the following:

1. approved blasting plan;
2. site-specific blast design for blasting within 1,000 feet of protected structures;
3. blast logs including seismic readings;
4. explosives records for the current blasting period; and
5. seismic data collected from OEB seismographs located at protected structures.

MINING OPERATION BACKGROUND

According to the approved mining permit, the mining operation is a multiple seam contour surface mine proposing to disturb 98 total acres in order to extract the Waynesburg "A" and Waynesburg seams of coal. The geology is predominately sandstone with minor shale layers immediately overlying the coal seam.

Aerial View of Mining Operation

The blasting section (Section T) of the permit package indicates that 245 protected structures are located within ½ mile of the permitted area, including 90 structures that are presently, or will be, positioned within 1,000 feet of blasting.

Department of Environmental Protection (DEP) records indicated that only one blasting complaint was received in 2002, but, increased to eight complaints from January to October of 2003.

METHODS FOR MAINTAINING BLAST COMPLIANCE

Maintaining compliance with allowable ground vibrations involves using one of two approved methods. The first method is the scale distance formula whereby distance from the blast to the nearest protected structure is used to calculate the maximum weight of explosives per delay period that a blaster can detonate and prevent damage to a protected structure. The second method is use of a blasting seismograph to measure the actual ground vibrations. Both federal and state regulations establish maximum allowable ground vibrations at protected structures when using seismographs for compliance. The allowable vibrations vary depending on the distance of the blasting activities to the protected structure. These limits are as follows:

Seismograph Measurement (Peak Particle Velocity or PPV)	Distance to the Nearest Protected Structure
1.25 inches per second (ips)	0 - 300 feet
1.0 inches per second (ips)	301 - 5,000 feet
0.75 inches per second (ips)	5,001 feet or greater

The two most commonly quoted standards for limiting ground vibrations from blasting operations are the regulations of the Office of Surface Mining (OSM) and the recommended guidelines of the former U. S. Bureau of Mines (USBM). The USBM guidelines were adopted in Title 199 and represent particle velocity intensities intended to prevent threshold damage even to substandard housing construction.

INVESTIGATION - FINDINGS

OEB reviewed blast records and procedures and determined that ~~a~~ revision of the site-specific blast design and blasting plan were required.

The submitted site-specific blast design indicated a typical burden and spacing of 9 feet x 9 feet with a 4-inch diameter blast hole. Hole depths were not to exceed 30 feet. Upon review, typical bench heights ranged from 65 to 85 feet and blasting dimensions of 12 foot burden and 15 foot spacing. Shot sizes ranged from 12 to 30 holes per blast. Blast hole diameters ranged from 6 ¼ inches to 6 ¾ inches. Normal blasting practices involved decking the blast holes with two or three explosive charges per hole to maintain compliance with the regulatory limitations of maximum pounds of explosives per delay. The review of the blast logs revealed that the site-specific blast design was not being followed. This was confirmed with field observations and measurements.

The blast logs were also evaluated utilizing the OSM Blast Log Evaluation Program ("BLEP"). BLEP is a computer model that analyzes data from the logs to indicate compliance with standard trends for blasting operations and areas of inconsistency compared to industry accepted ranges.

OEB also discovered that seismic monitoring practices and procedures were questionable and could be a source of inconsistent and inaccurate measurements of ground vibrations. In response, OEB discussed the appropriate standards for seismograph installation and monitoring with personnel at this facility.

Aerial View Structure#PAT178 and #PAT180 Relative to Blasting Operations

Subsequently and without the permittee's knowledge, OEB installed a seismograph at the nearest protected structure, Structure #PAT178. OEB utilized the seismic results to validate the monitoring methods and records produced by the permittee for vibration and airblast compliance.

OEB continued to monitor ground vibrations at Structure #PAT178 from August to October 2003. The continuous monitoring station was then moved to Structure #PAT180 which became the nearest protected structure. OEB continues to monitor at Structure #PAT180.

PREDICTIVE EQUATIONS FOR GROUND VIBRATIONS

The permittee submitted the revised blasting plan and site-specific blast design utilizing a predictive model for ground vibrations based on distance to the nearest protected structure and pounds of explosives per delay. OEB reviewed and approved the submitted blasting plan and site-specific blast design. OEB required specific reporting requirements as a condition of the approval.

One approval requirement was that the permittee report any ground vibrations exceeding 0.60 inches per second to OEB within 24 hours of such an occurrence. This requirement was included to allow enough time for revising the predictive equation variables, if necessary, so maximum ground vibration thresholds would not be exceeded.

Although several ground vibration predictive models exist, all have a similar format recognized as:

$$PPV = k * (D / \sqrt{W})^A$$

where:

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

The submitted blast design had values of k = 160 and A = -1.60 included in the predictive equation. This meant that at a distance of 310 feet between the blast site and the protected structure only 166 pounds per delay should be fired in order to predict a ground vibration below 1.0 inches per second. To verify the validity of the equation, an array of seismographs were placed in a line between the blast site and a nearest protected structure. Steps used in these arrays included:

1) arranged arrays at concerned protected structures. This involved placing seismographs at various points between the blast site and a protected structure in a line or array;
2) recorded distances of seismographs from the blast site using a Global Positioning System (GPS);
3) determined maximum pounds per delay detonated from information obtained from conversations with the blaster or the blasting record;
4) recorded ground vibrations and air blast readings from various blasts;
5) downloaded seismic events from seismographs in the seismic array;
6) performed regression analysis on seismic data to determine quality of data or "Goodness of Fit" and calculated a predictive equation; and
7) compared values of actual field data against the predictive equation to determine validity of the submitted equation.

Seismograph Set-up at Structure #PAT178

OPERATION UTILIZED PREDICTIVE MODEL FOR COMPLIANCE

During this research period, OEB placed a series of seismograph arrays to monitor ground vibrations for several blasts. These arrays provided data used to validate the predictive model utilized by the operator. Arrays were placed at different locations to monitor blasting activities as mining progressed. The arrays provided an additional compliance tool for OEB to ensure that ground vibrations would not have any negative impacts on the nearest protected structure. OEB maintained a seismograph at the nearest protected structure to validate both ground vibrations reported by the operator, as well as, variables associated with the predictive model.

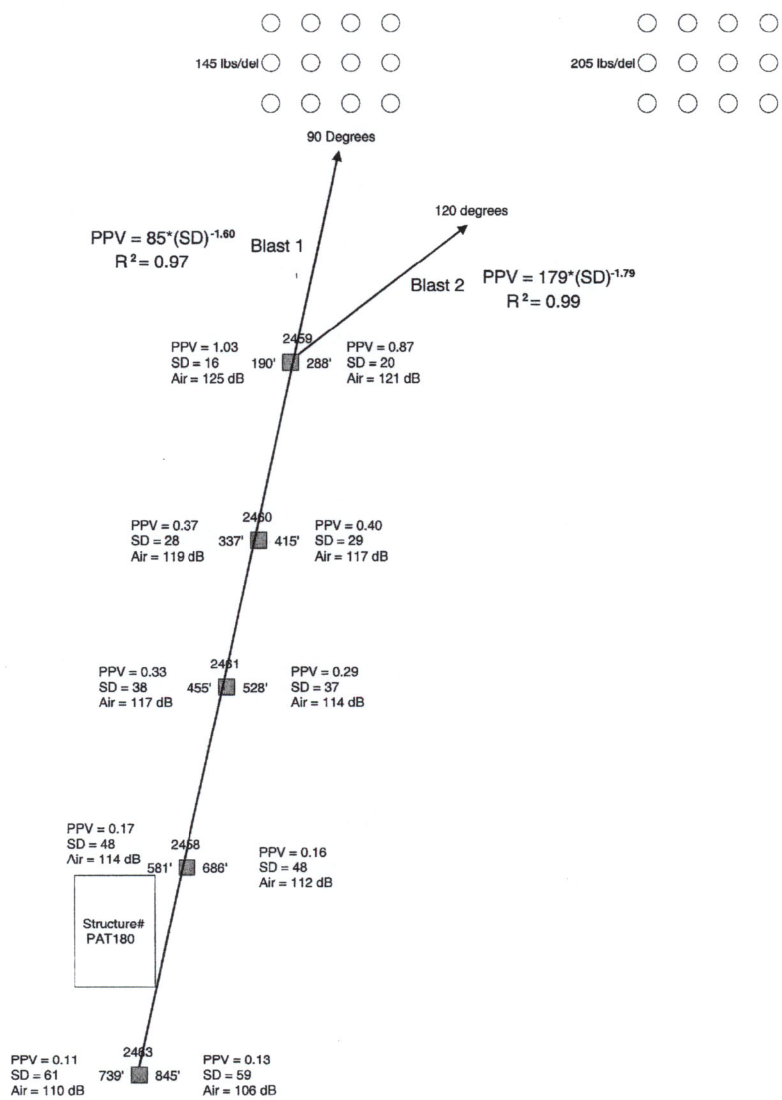
As the mining operation progressed, Structure #PAT180 became the nearest protected structure. After analyzing the subsequent arrays near Structure #PAT180 and blasts associated with those arrays, OEB determined that the predictive models were still accurate for maintaining compliance and predicting ground vibrations at these nearest protected structures. Other arrays were placed where mining would eventually occur.

Blasting Operations Relative to Structure #PAT180

DATA ANALYSIS

Data represents measurements of ground vibrations associated with blasting at the mining operation taken from various blasts, on different dates, and at a range of locations. A regression analysis was performed to assess the statistical quality of the vibration measurements. The data must meet a minimum standard to be utilized in a predictive model. The minimum standard is 0.70 "Goodness of Fit" for regression data to be used where 1.0 is considered perfect data. The information represented in this study had a "Goodness of Fit" that ranged from 0.895 to .980. Below is a plan view of one array.

Seismic Arrays & Regression Analysis
Structure #PAT180
October 20, 2003



To further explain segments of the chart shown below; *Scaled Distance* is a calculated number utilizing the distance and the maximum pounds of explosives per delay; *Actual PPV* is a direct reading from the seismograph; and *Predicted PPV* is a calculated value from the predictive equation utilizing the scaled distance formula.

Structure #PAT178 Array

Date and Time of Blast	Distance From Blast	Scaled Distance	Actual PPV	Predicted PPV
8/5/03 16:11	193	15	1.40	2.04
8/5/03 16:11	273	22	0.97	1.17
8/4/03 14:12	334	26	0.31	0.85
8/5/03 16:11	353	28	0.36	0.78
8/4/03 14:12	374	30	0.25	0.71
8/4/03 14:12	414	33	0.24	0.60
8/5/03 16:11	433	34	0.22	0.56

Structure #PAT180 Array

Date and Time of Blast	Distance From Blast	Scaled Distance	Actual PPV	Predicted PPV
10/20/03 14:50	190	16	1.03	1.89
10/20/03 12:59	288	20	0.87	1.33
10/20/03 14:50	337	28	0.37	0.77
10/20/03 12:59	415	29	0.40	0.73
10/20/03 14:50	455	38	0.33	0.47
10/20/03 12:59	528	37	0.29	0.50
10/20/03 14:50	581	48	0.17	0.33
10/20/03 12:59	686	48	0.16	0.33
10/20/03 14:50	739	61	0.11	0.22
10/20/03 12:59	845	59	0.13	0.23

Structure #PAT82 Array

Date and Time of Blast	Distance From Blast	Scaled Distance	Actual PPV	Predicted PPV
12/15/03 15:26	151	13	3.00	2.64
12/15/03 15:31	249	20	0.60	1.33
12/15/03 15:26	416	35	0.67	0.54
12/15/03 15:31	515	42	0.28	0.40
12/15/03 15:26	634	54	0.33	0.27
12/15/03 15:31	739	60	0.22	0.23
12/15/03 15:26	1267	108	0.14	0.09
12/15/03 15:31	1373	111	0.08	0.09

Structure #PAT96 Array

Date and Time of Blast	Distance From Blast	Scaled Distance	Actual PPV	Predicted PPV
12/15/03 15:26	112	10	3.88	4.02
12/15/03 15:31	160	13	4.48	2.64
12/15/03 15:26	415	35	0.91	0.54
12/15/03 15:31	474	38	0.43	0.47
12/15/03 15:26	686	58	0.23	0.24
12/15/03 15:31	739	60	0.17	0.23
12/15/03 15:26	1267	108	0.12	0.09
12/15/03 15:31	1320	107	0.09	0.09

CONCLUSIONS

Research and investigation at this site is still ongoing. Therefore, conclusions are preliminary findings based on data and research available to date. The data analyzed by OEB indicates that predictive models can be accurate if data acquisition and processing are done correctly. As proof, seismic records reviewed from the 3-month periods before and after the new blast design, average PPV readings of 0.75 inches per second decreased to 0.24 inches per second. Predictive models may also provide adequate compliance and enforcement tools for the protection to structures. The reporting, investigation and research associated with this surface mining complex will continue with additional seismic analysis. OEB will continue to further scrutinize the use of this predictive model as mining progresses and as the blasting moves closer to other protected structures. OEB will provide a final report when sufficient data is collected and analyzed. Data from additional permits will also be collected in order to support the use of predictive equations.