ASSESSMENT OF BLASTING VIBRATIONS FROM SURFACE MINE BLASTING

IN PEABODY'S UNIVERSAL MINE, BLANFORD, IN.

Prepared for the Office of Surface Mining
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OBJECTIVE

This report is an assessment of blasting vibrations in the area around Blanford, Indiana. These vibrations result from production blasting in the nearby Peabody Universal surface coal mine. Questions examined in this preliminary study are:

1) Does a real physical problem exist resulting in the abnormal community response? Are the blast vibrations abnormal in frequency character, amplitude or duration?

2) If so, hypothisize the cause(s) including the possibility of the influence of existing abandoned underground mine workings under and around Blanford.

3) Provide recommendations for follow-on work to better understand the problem and assist in establishing procedures to minimize it.

This analysis was performed by David E. Siskind, Group Supervisor, Blasting Technology, Twin Cities Research Center, Bureau of Mines as a result of a request from James Gilley and Louis McGee of the Eastern Technical Center of the Office of Surface Mining, Pittsburgh, Pennsylvania. Assisting in the data assembly were the Indiana Dept. of Natural Resources (DNR) and Andrew Gilmore from the Indianapolis office of O.S.M.

SUMMARY ASSESSMENT

An analysis was made of blasting records, logs and other information collected during and following a visit to Blanford, IN, April 16, 1985. Propagation plots, vibration character comparisons, frequency, and amplitude assessments were made from 432 vibrations measured at 7 residences in and around Blanford from 235 production blasts between May 15, 1984 and April 25, 1985.

The vibration amplitudes were found to be large relative to other measurements at these scaled distances. Most were greater than the mean from the surface coal mine summary published in BuMines RI 8507 (1980), figure 10. Many even exceeded the envelope of maximum observed values in RI 8507. At this time, it is not possible to say if this is from abnormal generation (related to the blast design) or results from structural or geological conditions favoring efficient propagation. Some additional vibration measurements should answer this question.

Vibration characteristics are also not typical of measurements made elsewhere. The prominent and clear very low frequencies, 3-4 Hz, are almost certainly surface waves (Rayleigh and Love). These low frequencies and long durations are greatly in excess of those from other studies in Indiana and neighboring states. They resemble blast records reportedly obtained in the water-saturated hydraulically-filled ground in Dade County, Florida. Low frequency blast vibrations of sufficient amplitude could produce excessive structural displacement and strain, as described in BuMines RI 8507, (1980).

The likely cause of the high level and surface wave-dominated blast vibrations is the geologic structure. Either a low-velocity natural layering or extensive underground working provides a strong seismic wave reflection. In this way, Rayleigh and Love waves are formed and reinforced. Recommendations for follow-on work are provided.

DATA AVAILABLE

Information was collected from the Indiana D.N.R., the mine (Peabody Company) and the Blanford Action Committee (B.A.C.) of local town residents during a visit to the site on April 16, 1985 and by mail immediately after. Following an initial examination of the data, requests were made to D.N.R. and Peabody for additional records, mainly seismic traces of specific blasts. This report was prepared from data on hand on May 15, 1985. Any additional information will be used for a follow-on analysis, should one be done.

The D.N.R. had seismographs installed in the following homes during a part of the period under study:

1) Massa
2) Volk
3) Hollingsworth
4) Zell

The Peabody Company had seismographs in the following homes:

1) Massa
2) Polomski
3) Jackson
4) Verhonick

For the D.N.R. sites, time histories of all three motion components were available. Only a few time histories were obtained at the time from Peabody. Most of the Peabody vibration amplitudes were from their blasting logs and consist of a single vibration value, the maximum single-component peak partical velocity, and the peak airblast. However, none of the D.N.R. records included shot-to-site distances, some of which were calculated from triangulation on the area map using Peabody's distances. Additional distances and seismic records have been requested.

In addition to the two sets of seismic records and Peabody's blasting logs, the following information was available for this analysis:

1) A regional map showing the mine layout and measuring site locations (from Peabody).

2) Fifteen drilling logs from spots near the town and the mine's north end (from Peabody).

3) A "perception log" of house vibrations kept by Alice Massa (from the B.A.C.), September 1984 to April 1985.

(4) Observations of B.A.C. members on the blasting situation, previous underground mining, and the structural condition of their homes.

Notable is the lack of specific information on the previous underground mining. Depth and extents of mining area are not known except for some general B.A.C. observations:

"Fifth vein is extensively mined"
"Fourth vein is partially mined"
"Workings are flooded"

It is expected that any study to determine the relationship between vibrations, subsidence, and structural impacts on the community will require information on the workings and local geological structure.

Some of the "events" recorded did not appear to be blasts or did not correlate with the mine's blasting schedule. Examples are the Massa record for January 4, 1985 at 11:42 A.M. and also the following:

January 6, 1985	13:30
January 7, 1985	11:30
January 11, 1985	18:17

Time history records (seismic traces) are highly desirable over simple peak values in order to differentiate between blasts and other events.

SITES

The general mine layout and town of Blanford are shown in figure 1. A closer view of the town and the mine's north end are shown in figure 2. Volk and Polomski are neighbors, as are Zefl and Massa. Hollingsworth is approximately on a straight line and about 1400 feet farther from the blasts than Volk and Polomski. Jackson's in the closest house, being at times within 1,000 feet. Verhonick is far east of the other sites.

The mine map (fig. 1) does not show the locations for specific blasts, but those in broad time periods. Combining this with inconsistancy between the coordinates of the homes on this map and as listed in the mine office, no reliable estimates could be made for the missing shot-to-home distances. A few were calculated using distances from Peabody's blasting logs and triangulation.

Fifteen drilling logs were provided by Peabody for holes between the current mining and the town. Generally, the top zone is characterized as "sand and drift" and is 60-75 ft thick. Below this is coal, shale, or material classified as "coal and jack." Some topographic relief is provided by surface streams in the area. The logs do not include any information on voids or old underground workings. Presumably, the "coal" referred to is the No. 6, being currently worked.

VIBRATION LEVELS AND PROPAGATION PLOTS

Scale distances were calculated for the seven sites corresponding to the 432 vibrations. They were plotted by site and in various combinations. (One copy of the 43-page Data Table was supplied to O.S.M. and not made part of this report.)

The propagation plots are provided in this report as follows:

1) Figure 3 Volk Summary
2) Figure 4 Polomski Summary
3) Figure 5 Hollingsworth Summary
4) Figure 6 Massa Summary
5) Figure 7 Jackson Summary
6) Figure 8 Verhonick Summary
7) Figure 9 Polomski and Volk combined
8) Figure 10 Polomski, Volk, Massa, Jackson, Hollingsworth combined
9) Figure 11 All sites

Where available, individual vibration components are plotted, transverse, vertical and longitudinal. For most of the shots, only single maximum velocities were given. Note that there were no distances given for the few measurements made at Zell's. This site should not differ much from the nearby Massa house.

Superimposed on all the propagation plots are lines representing the mean propagation from the coal mine summary in BuMines RI 8507, figure 10, and also the maximum envelope from the same figure. This envelope "covers" (exceeds) all the measured peak particle velocities collected in the 1980 RI 8507 study.

For most of the sites, the vibration levels are higher than the mean from RI 8507. Many even exceed the maximum envelope, particularly the Polomski, Massa, Jackson, and Verhonick measurements. Causes could be that the individual charges in the delayed production shot are interacting, generating high vibrations, or that the propagation of vibration from source to monitoring site is unusually efficient. As discussed later, many of the vibrations are dominated by strong low-frequency surface waves to a degree not seen in previous studies. These do not attenuate with distance as rapidly as "normal" seismic body waves. Some closer-in measurements (scaled distances of 10-30 $ft/lb^{1/2}$) should identify the blast design influences on vibration generation.

It must be pointed out that these vibrations are higher that expected for the given distances, but are not high in an absolute sense. Few exceed the safe level criteria of RI 8507, and those that do by a small amount were from the close-by Jackson residence. From the amplitudes alone, no structural damage is expected based on Bureau of Mines' Response and Damage Studies, RI 8507 and RI 8896 (fatigue). The vibrations levels are not consistent with the damage which appears to be occurring in some of the homes.

Airblasts do not appear to be a problem at this mine, with very few values exceeding 120 dB. Consequently, no plots were made, nor any detailed characterization analysis.

VIBRATION CHARACTERISTICS

Many, if not most, of the blasting vibrations measured at Blanford are characterized as having very prominent low frequencies following the initial arrivals by about one second. These appear very much like surface waves with clear sinusoidal vibrations having frequencies of 3-4 Hz. Total vibration durations exceed 3 seconds in many cases. Both the prominent low frequencies and extended vibration durations are not typical of the many blasting vibrations measured elsewhere in Indiana and other states in previous studies by the Bureau of Mines (RI 8507, 1980 and RI 8896, 1984).

Two basic surface waves exist:

1) Rayleigh waves are vertically polarized with retrograde elliptical particle motions. They should give significant motion in the longitudinal and vertical directions, and little in the transverse. The generation of these waves requires only a single free surface (the ground or sharp acoustic contrasting layer at depth).

2) Love waves are horizontally polarized shear waves. They should be strong only in transverse components. Generation of love waves requires a layer with top and bottom boundaries having good reflection properties. Extensive underground voids could provide such a reflecting surface, as could any low velocity layer.

For comparison purposes, a set of 46 3-component seismic records were selected covering all 7 monitoring sites. Of these, 26 were available for this analysis, and the others requesed from D.N.R. and Peabody. These vibration records were characterized for quick comparison according to this scheme:

TYPE	CHARACTERISTICS
A	All components have significant, clear and/or dominant low frequency of about 4 Hz,
B	Only transverse components have clear and prominent low frequency,
C	Longitudinal and vertical components have prominent low frequency. Transverse has only high frequency (>10 Hz) or is complex in form.

Figures 12 through 16 show 5 examples of the 26 studied. These are typical of all shots, although some appeared intermediate and not as clear as these.

Analysis of vibration character was done three ways:

1) Comparisons of amplitudes and frequencies with BuMines' safe level criteria from RI 8507, appendix B. Figure 17 has selected and typical values ploted on the RI 8507 appendix B criteria. Although none of the values exceed the Bureau's criteria, they are close to the turn-down point where frequency is critical and displacements must be limited to insure that excessive

strains are not produced. These waves will produce signficent structural response, and combined with their long duration, are likely to produce significant reactions from those impacted. Note that inclusion in this plot requires the dominant frequency, and hence the seismic time histories. Vibrations from Jackson, for instance, could not be plotted as they consisted only of peak amplitudes. Some vibration amplitudes from Jackson were greater than those plotted.

2) Comparisons between shots at a given monitoring site:

Table 1 shows the data available for shot and site comparisons and the further data requested for a possible follow-on study. Table 2 shows a quick summary of the shot types (A, B, or C). Shot comparisons are made by reading down and site comparisons by reading across. One complete copy of a detailed 20-page shot analysis was prepared for O.S.M. but not made a part of this report.

Four sites had usable shot comparison data:

a) Volk: For the closest shots (4000-5000 ft), records showed clear dominant low frequencies on all 3 components, type A. However, shots at greater distances (5800-6400 ft) have complex and mainly high-frequency transverse components, identified as Type C. Note from figure 1 that the angle and wave travel path to Volk also slightly changes with the increased distance.

b) Zell: Both records are type B, with clear low frequency in transverse components. The May 15, 1984 blast has some low frequency in the longitudinal, suggesting that this is a case in transition, as may be true for all type Bs.

c) Massa: The early Massa records are too small to reliably classify (December 1 and 6). Those measured February 19 and 21, 1985 are clearly type C. Note that Zell and Massa are neighbors being within about 300 ft, and would not be expected to produce differing records.

d) Hollingsworth: All shots at this site are type A with only the closest (February 9, 1985, 5880 ft) not having clear dominant low frequencies.

Concluding this comparison, there does not appear to be much change at a given site from shot-to-shot. Each site mainly is self-consistent except for a possible distance effect. Clear identification of these relationships will require additional monitoring such as with multi-instrument gauge arrays and/or using closer-in measurements for identification of surface wave generation as opposed to possible blast design influences.

3) Comparisons between sites for a given shot:

As with comparisons between shots, distance appears to be a possible factor. Clear delineation of this effect will require additional measurements. The shots at Volk were either type C or A. At Hollingsworth, 1300-1400 ft farther away, they were all type A, consistent with the hypothesis that surface waves require a large travel distance to form. Alternately, the sites can be structurally different. Also interesting is the increase of the transverse amplitudes at the large distance, while the other components behaved normally, decreasing in amplitude. The close-in shots (e.g., February 2 to 19, 1985) have type A characteristics at both sites, a phenomenon which is difficult to explain.

Side-by-side comparisons are available for a few shots. The Volk versus Polomski record of February 19 is strange. (Note that the houses are 340 ft apart and the shot is 3705 ft from the closer home.) They are similar in appearance, but Polomski, although farther, had an abnormally large longitudinal component, almost twice that measured at Volk. It is also very low frequency at 3.5 Hz.

The other side-by-side comparison is Zell and Massa, but does not compare the same shots (see table 2). The two sites are not similar, from the limited data available.

Concluding the comparisons, site difference appears real but variations between shots do not, with the possible exception of a distance effect. When the requested data becomes available, many more and complete comparisons will be possible including five and six sites for a given shot.

MASSA'S IMPACT LOG

During the period September 1984 to April 1985, Alice Massa kept a log of how she perceived the severity of the blasts. All her "events" which could be correlated against the Universal mine's blasting logs are given in table 3, along with vibration levels as measured at the Massa residence and other homes. For strong events, rated "heavy" and "worst", the airblasts (in dB) are also included. No clear trend is visible, except that all shots over 0.21 in/s are "worst." However, there are a few low-level blasts in the "worst" and "heavy" category (0.05-0.10), and also some higher level vibrations in the "light" and "moderate" category (0.18 in/s). As the airblast values also appear ambiguous, an explanation of these discrepancies is not now available.

CAUSES OF UNUSUAL VIBRATIONS

At this stage, causes are speculative. Sufficient time was not available for an analysis of blast designs; however, comparisons suggest that site differences are more significant than shot differences. Closer-in measurements are going to be required before the influence of blast designs can be definitely identified. The appearance of strong long-lasting surface waves suggests a structural condition favoring their generation and sustenance. Extensive underground workings are a strong candidate, or some other structure acting as a reflecting low velocity layer. Layer thicknesses can be related to predominant frequency, but should have reliable propagation velocities.

RECOMMENDATIONS

The following are recommended for follow-on work in and near Blanford to understand the abnormal vibrations:

1) Near-field vibration measurements to identify the ground vibration generation.

2) Propagation analysis for separate wave types, using existing and additional seismic data.

3) Correlations of vibration amplitude and frequency with other factors such as freeze periods and use of explosive casting.

4. Information collection on subsurface workings, extents and depths.

5. Surveys by transit and level for determination of subsidence.

6. Examination of blast designs versus vibration generation.

7. Inclusion of missing 20 shots (time histories needed) in comparison analyses, plus possible additional shots.

8. Soil property analysis.