Current Technologies to Resolve Blasting Related Citizen Complaints[1]

by

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Abstract: The Surface Mining Control and Reclamation Act of 1977 requires that blasting be conducted so as to prevent injury to people and damage to public and property. The three adverse effects are flyrock, ground vibrations and airblast. Blasting close to people frequently results in complaints of annoyance or damage. Federal and State personnel are responsible for evaluating the validity of the complaint. The elements to be evaluated include: reviewing blast logs, inspecting the mine, inspecting the house, measuring ground, air and structure vibrations, and predicting vibration levels. Lotus and Excel spreadsheets, with their graphical capabilities, will be used to show how data can be cross tabulated to verify data accuracy. Statistical analyses of vibrations require more powerful software to make vibration predictions.

Additional Key Words: Blasting, Complaints, Damage.

Introduction

Blasting is a critical part of surface mining. To access coal reserves, the rocks overlying the coal are broken with explosives. Without blasting, a vital part of the nation's energy reserve would be inaccessible. The rock can be broken in place (conventional blasting) or broken and partially displaced into the adjacent pit (cast blasting). In any blast, the majority of energy is spent breaking rock. The balance of energy emanates from the site into the environment as either seismic or airblast energy.

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) mandates that OSM must ensure the prevention of injury to people and damage to public or private property during blasting. SMCRA also requires that complaints be addressed by the regulatory authorities. Complaints related to blasting are the most frequent type received by the Office of Surface Mining Reclamation and Enforcement (OSM) and the State regulatory authorities.

The side effects of blasting that have a potential to create offsite damage or injury are flyrock, ground vibrations and air vibrations or airblast. The most dangerous and apparent of these is flyrock. Injury or death to people and property damage may happen when a piece of rock is thrown beyond the permit boundary. The blaster is responsible for preventing flyrock. OSM oversees the only national program to certify blasters. Blaster training provided by individual states address the control of flyrock by the appropriate use of explosives and hazard recognition in the field. Flyrock is usually obvious and complaints are resolved accordingly.

The other two side effects, ground vibrations and airblast eventually leave the mine and arrive at adjacent properties. The energy is then transmitted into the buildings; ground vibrations through the basement, airblast through the roof. In turn, the buildings respond or shake, sometimes at levels greater than the incoming energy. When people feel their houses shake and they associate damage to their homes as being a direct result of blasting. Homeowners then want compensation for damage they perceive is being caused by blasting at the mines.

If ground vibrations and /or airblast are strong enough, the building may be damaged. OSM limits the amount of energy received at the building regardless of how blasting is being conducted at the mine. The limits apply to all structures outside the permit area and are set to reasonably protect most residential structures. When the limits are exceeded, violations are written. Occasionally, damage to homes is possible at vibration levels below the limits (Siskind et al, 1980 and Crum

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1997). In these situations, the states are responsible for investigating the damage claim and adjusting limits to prevent further damage. Often the damage is from normal relief of stresses or environmental conditions (wind, temperature variations, etc.).

More often, people are annoyed by the blasting that shakes their homes. They claim that blasting is too hard, blasting is shaking their house, they fear damage or blasting is loud. Some residents can feel vibrations from blasts that are as little as 2% of the legal limit. Thus depending on ones's sensitivity, any given blast may be offensive.

Citizen Complaint Review

Most blasting complaints are either annoyance to the occupant or damage to property. Each requires different levels of effort for successful resolution. Resolution is achieved when all the pertinent facts and data have been reviewed and an objective determinations is made by the investigator. This may or may not appease the complainant.

The following three basic facts are important to keep in mind when reviewing a complaint:

1. Vibrations attenuate with distance in the same direction;
2. Vibrations may be higher in different directions; and
3. Vibration amplitudes are dependant on the charge weight detonated in each delay interval.

The amount of ground vibration or airblast energy that arrives at a house is key to evaluating a complaint. Ground vibrations are measured as a time history, where amplitudes are measured in particle velocities (in/s) and frequencies in Hertz (Hz). Airblast is also measured as a time history where the amplitudes are measured in decibels (dB). Measured levels at the house are preferred. But both may be estimated by calculating the scaled distance (SD) if the blast logs are accurate.

$$SD = D/CW^{1/2} \qquad (1)$$

Where D is the distance and CW is the charge weight of explosives detonating at any given time. In this relationship as distance increases and amount of explosives decrease the scaled distance increase. As scaled distance increases the vibrations will attenuate or decrease (Siskind, 1980).

Annoyance complaints can be resolved by a show of compliance at the nearest structure and the showing of the spatial relationship between the blast, the compliance house and the complaint house. If the complainant is in the same direction and further away than the compliance house and the vibrations are within limits, vibrations can be assumed to attenuate and the complaint can be resolved. However when evaluating airblast, the levels may not attenuate predictably or may increase. They can be focused to create higher levels at larger distances by atmospheric conditions related to wind direction and temperature inversions.

Conversely, if the complainant is on the opposite side of the permit from the compliance house, vibrations may be higher due to directional differences. A change in the blasting plan may be warranted to assure the vibration limits are maintained.

Damage complaints require three additional steps to be resolved. First, the vibration levels (ground and air) at the house must be estimated , second the frequency of the ground vibration needs to be determined and third the damage in the house must be documented along with the type of house.

If ground vibrations are below 0.5 in/s the complaint can be resolved because the probability of damage is near zero (Siskind, 1980). If vibrations are over 0.5 in/s, damage must be evaluated based on the vibration frequency and the kind of damage alleged. At this level, damage to only the superstructure components of a residential building is possible. If airblast is under 134 dB, the probability of damage is near zero. Over 140 dB the first sign of damage is window breakage (Siskind, 1980).

At a minimum, the response to each complaint "type" should contain the following information in a report back to the homeowner.

1. Annoyance.
- A map showing blast location, compliance house and complaint house.
- At the compliance house discuss the scaled distance, peak particle velocity (PPV), and airblast levels.
- A discussion of any violations that were found and any blast plan modifications required.

2. Damage.

- A map showing blast location, compliance house and complaint house.
- At the compliance house discuss the scaled distance, PPV, and airblast levels.
- An estimate of the ground vibration and airblast levels at the complaint house.
- Show the location and type of alleged damage in the house and if available, compare with the preblast survey.
- A discussion of the alleged damage and vibration levels in reference to the current scientific literature.
- A discussion of any violations that were found and any blast plan modifications required.

The spatial relationships between the blast, compliance structure and complainant structure can be established using a variety of surveying techniques, including GPS. The maximum charge weight in the blast to predict vibration levels is obtained from the blast logs. But first, the log must be verified for accuracy. Once verified, vibration levels can be predicted using national, regional or site specific attenuation relationships.

Blast logs

Blast logs are the single most important bit of information available to the investigator. The records are kept by the blaster at each mine site as required in the Federal regulations (30 CFR 816.68). The investigator must first evaluate the accuracy of the blast logs by cross tabulating some of the data fields. This can be arduously done by hand or entered into a spreadsheet. The advantage of a spreadsheet is that the data can be graphically summarized. **The key items to verify are the maximum charge weight per 8-millisecond delay and the distance to the nearest structure.** For the purpose of this discussion, two or more charges that detonate within any 8-millisecond window are considered on the same delay.

Data Input

The Blast Log Evaluation Program (BLEP) was developed in Lotus and Excel to perform this task. All but three of these fields are copied directly from the blast log: *Distance Measured; Blast Timing Correct?; and Actual Charges per Delay.* By determining these fields, the blast log data can be verified and cross checked. Up to 50 blast logs can be entered. The data fields are listed in Table 1.

Input data must be based on the hole that can receive the most explosives. Ideally the log has a diagram of the hole with the most explosives. If not, the input data must represent the most conservative values on the log that will maximize the amount of empty hole length able to receive explosives. For example, if a range of hole depths is given, the deepest hole must be entered. On the other hand, if a range of stemming (backfill on top of the explosive column) is given, the lowest value must be entered. Then the program will conservatively estimate charge weight.

Table 1. Data input variables.

Permit Number	***Charges per Hole**
Blast Date	**Explosive Type**
Blast Time	***Explosive Density**
Coal Seam	***Reported Explosives / Hole**
Nearest Structure	*** Reported Explosives / Delay**
***Distance Reported**	**Reported Powder Factor**
****Distance Measured***	***Blast Timing Correct?***
***Burden**	****Actual Charges per Delay***
***Spacing**	**Number of Holes**
***Hole Depth**	**Material Blasted**
***Hole Diameter**	**Reported Total Lbs.**
***Stemming**	**PPV Reported**
Backfill	**Airblast Reported**
Decking	**PPV Frequency Reported**

* Essential variables.

Distance Measured. The logs must contain the location of the blast within the permit area. The reported distance needs to be compared with a verified or measured distance based on the location. To be able to verify the reported distance to the nearest structure, the blast should be located with an accuracy of two significant digits (i.e. < 1000 feet, reported to the nearest 10 feet). The blast location can be determined by survey, GPS, grid map or other method that gives acceptable results.

Actual Charges per Delay. Critical to the control of vibrations is the detonation of individual charges far enough apart so that the vibrations are not reinforced. An adequate time separation is 8-millisecond (ms) as specified in the Federal rules. Sometimes the firing times are shown on the log and simply need checked. If not, the investigator must determine the firing time of each charge in the blast by adding all the surface and down hole delay times in series. Any firing times within an 8-ms window are assumed to reinforce vibrations and are considered one charge. Based on the firing times, the investigator enters the actual number of charges detonating in any 8-ms window.

Blast Timing Correct? If more or less charges are detonating at a time than reported on the log the blast timing is incorrect.

Graphical output

The BLEP generates a series of graphs to illustrate the accuracy of the record. If all the data points plot within acceptable ranges or close enough to the reference lines, the logs can be deemed adequate. If data points fall outside acceptable ranges, then either the record keeping is bad, quality control in the field is poor or data entry errors occurred. Most important is that when the cross tabulated data is plotted graphically and falls within expected ranges, the confidence level of the blast logs is high. The outliers are likely to represent problem blasts that warrant closer scrutiny. Caution: The blast log for each data point that falls outside the expected envelopes must be rechecked prior to any violations.

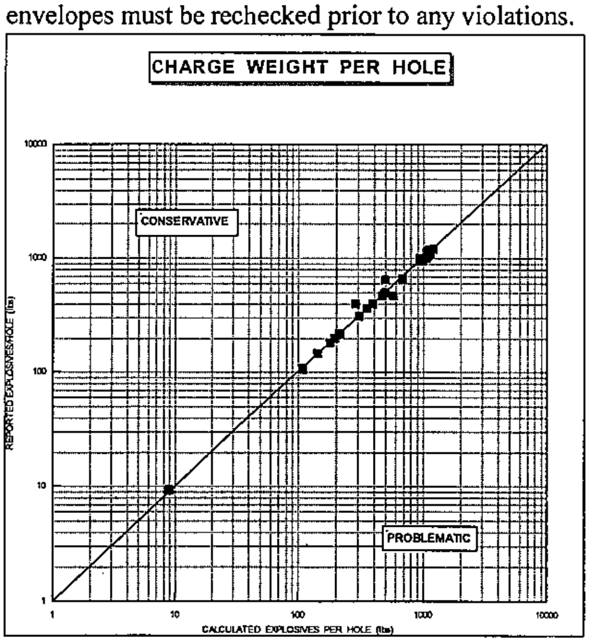

Figure 1 Charge weight per hole.

Figure 1, a log-log graph, compares the maximum amount of explosives reported to be in a hole versus the calculated amount based on the deepest hole minus stemming, backfill and decking (Figure 2). All the points that touch the line are acceptable. The size of the plotted blocks allow for 10 to 15% spread in the data. Figure 2 illustrates the calculation for calculated explosives per hole. The loading density (LD) is first calculated from the hole diameter and the explosive density, and then the charge weight (CW) is determined from the LD based on the remaining hole void (depth of hole, 30' minus the stemming, 13' and decking, 3').

EXPLOSIVES / HOLE

$$LD = 0.34\,(d)^2 \times \rho$$
$$= 0.34\,(6.75)^2 \times 0.92$$
$$= 14.6\ \text{lb/ft}$$
$$CW = 14' \times 14.6 = 205\ \text{lb}$$

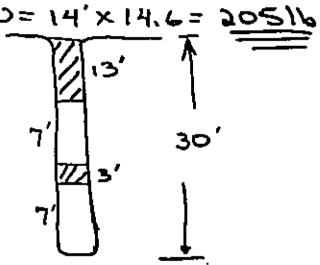

Figure 2 Blast hole cross section.

The most important element for gauging the adverse effects of blasting is the amount of explosives detonated per delay. In Figure 3, the reported value is plotted against the calculated explosives per delay. The calculated explosives per delay take into consideration the number of decks in the hole and the actual number of charges detonating on the same delay (within 8-ms) or overlaps. When cross checked the values should match.

The graph shows two points well off the line. The point below the line indicates that more explosives may be detonating than reported on the same delay interval. The blast log needs to be checked more closely. If more explosive are being detonated than reported, this may be the cause of the complaint.

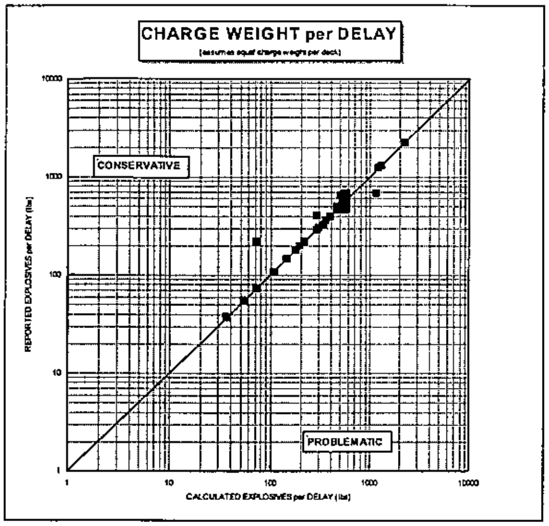

Figure 3 Charge weight per delay.

The second most important element for evaluating the adverse effects of blasting is the distance to the nearest house or compliance structure. In Figure 4, the distance reported is plotted against the distance measured. If the distances cannot be measured based on an inadequate location, compliance with the scaled distance equation cannot be verified or the data will plot errantly with the vibration data (discussed later). Five of the blasts were conducted closer to the compliance structure than reported. If scaled distance was used to determine the maximum charge weight, more explosive than allowable would have been used.

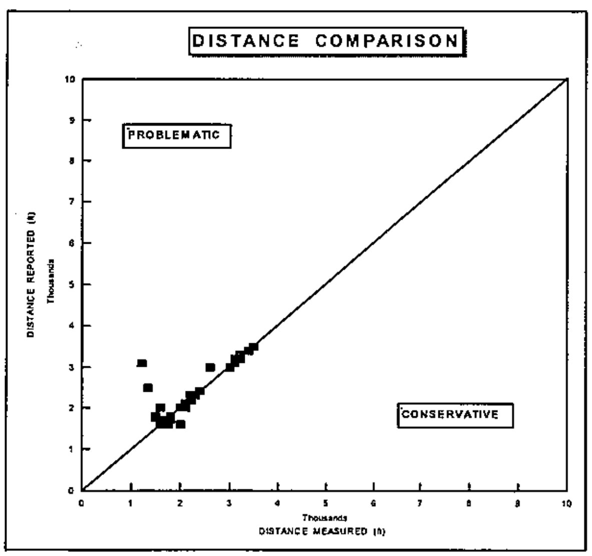

Figure 4 Distance to the nearest house comparison.

Figure 5 shows compliance with the calculated scaled distance at the nearest structure based on calculated or verified values from figures 3 and 4. The plot is measured distance versus calculated scaled distance. The reference line is the allowable scaled distance at distances from 0-300', 300- 5000' and >5000' (30 CFR 816.67). Points below the line fail to be legal. If all the points are above the line, the graph clearly and conservatively shows compliance.

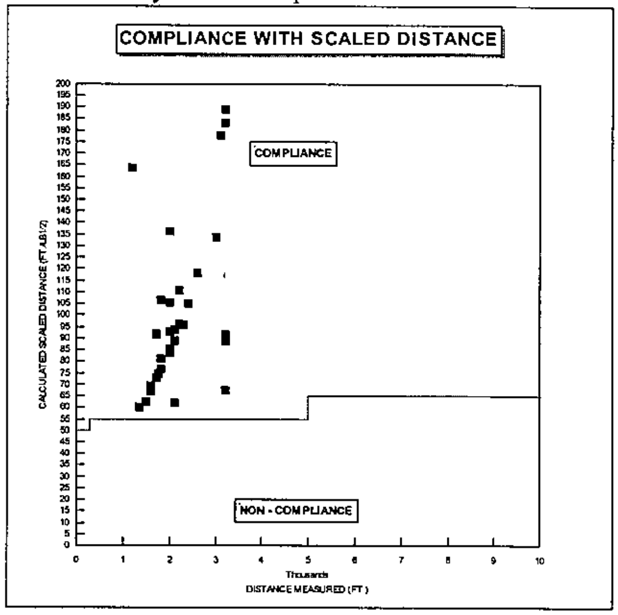

Figure 5 Compliance with scaled distance limitations.

Figure 6 shows compliance with the peak particle velocity limits at the nearest structure. The plot is measured distance versus reported peak particle velocity (PPV). The reference line is the allowable PPV at distances from 0-300', 300- 5000' and >5000' (30 CFR 816.67). Points below the line are legal.

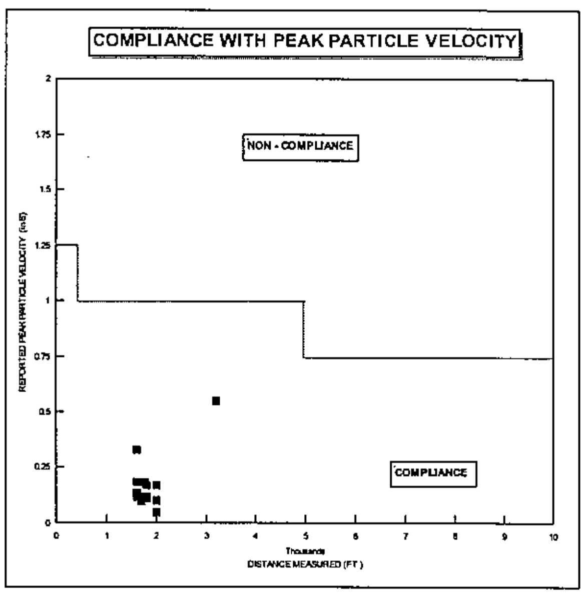

Figure 6 Compliance with PPV limitations.

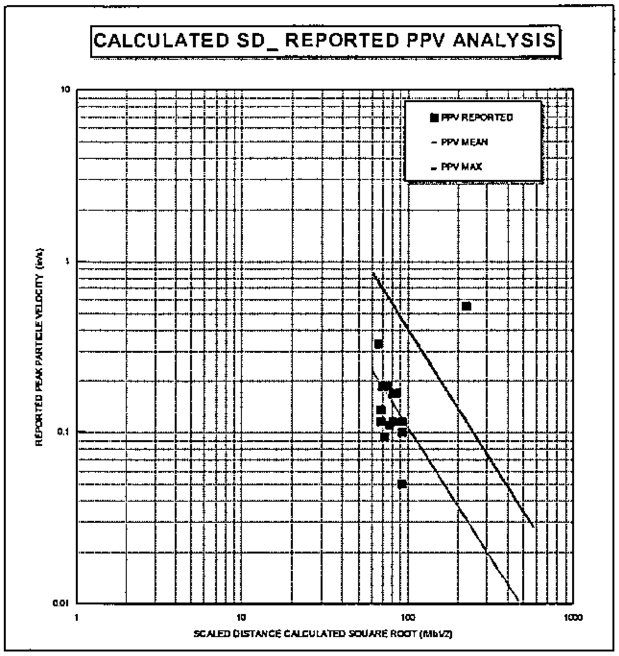

Figure 7 Scaled distance vs particle velocities compared to the national attenuation relationships for coal mining.

Figure 7 is calculated scaled distance versus reported peak particle velocity at the compliance structure. The reference lines are attenuation relations of ground vibrations for coal mines nationally from Report of Investigation (RI) 8507 (Siskind, 1980). The lower line represents the mean of the data set and the upper two standard deviations from the mean (worst-case). The worst-case line has the equation:

$$PPV = 438\ (SD)^{-1.52} \qquad (2)$$

This equation also equates the scaled distance and the ground vibration relationship based on distance as specified in the Federal rules. Data points above the worst-case line are blasts where vibrations are above the values that would be expected nationally. In essence either the blast was bad , the log data is poor or the vibrations in the area travel uniquely. The point above the line on Figure 7 is because the seismograph was place at the wrong house and thus paired with the wrong scaled distance.

Figure 8 is particle velocity versus frequency. Points above the line have a higher potential to create damage to residential structures and provides the best gauge for evaluating damage claims. Often the frequency information is not reported on the front of the blast log. However, the time history data of the vibration must be made part of the official record and the frequency data can be obtained.

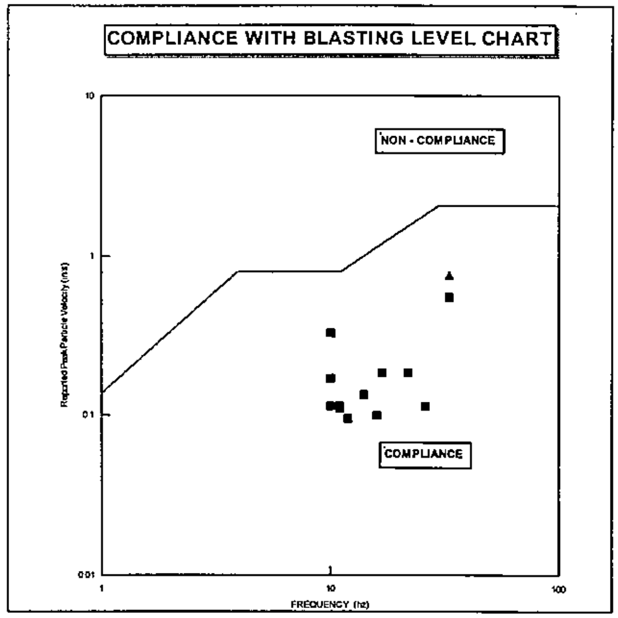

Figure 8 Compliance with blasting Level Chart limitations.

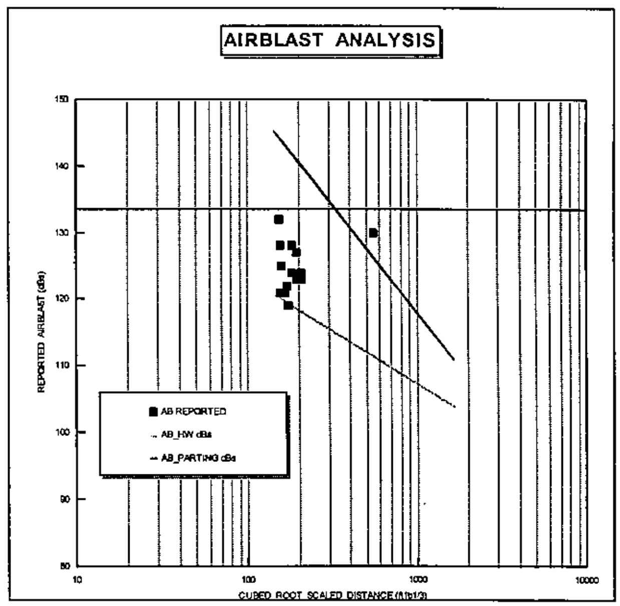

Figure 9 Compliance with airblast limitations.

Figure 9 is the cubed root scaled distance versus airblast. In addition to charge weight and distance influencing airblast, confinement of the explosives is also important. The reference lines are from the RI 8485 (Siskind, 1980) for coal mine highwall blasts and parting blasts. The flat 134 dB line is the Federal limit for airblast.

Airblast levels above the line are unusual and may be the cause of the complaint. The one point above the line on Figure 9 was probably caused by a blowout of one of the blast holes or a venting of gases out of the highwall face. The record should be checked for the cause and/or blasts in the future should be monitored more closely.

Spatial Relationships

To resolve citizen complaints, the location of the blast within the permit boundary, the location of the compliance station and the location of the complainant's house relative to the blast are extremely important (Figure 10). Vibrations, both air and ground, vary depending on the direction and soil/rock type or atmospheric weather conditions (i.e. propagating medium). All distances from the blast should be to two significant digits to ensure meaningful estimates.

Permit maps are the best single source to establish the spacial relationships. With the emergence of electronic permitting, digital maps will become more commonplace. If the complainant's house is not on the map, an accurate location mus be obtained using a USGS topographic map, surveying or GPS. Keep in mind the relative accuracy of the selected method.

GPS may be the best choice from a current technology stand point. Its limitations and utility are to be discussed elsewhere in these proceedings and will not be discussed here.

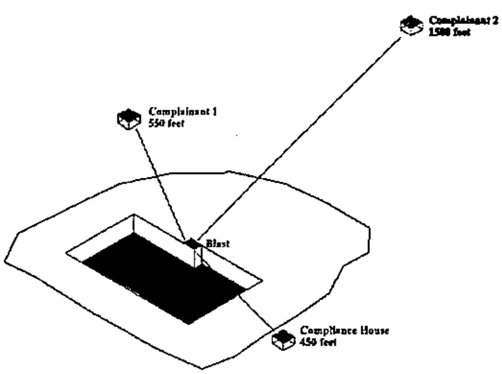

Figure 10 Spatial relationships between the blast, compliance structure and complainant house.

Attenuation Relationships

Ideally when evaluating a damage complaint, vibration data is available at the complainant's house. But most often, vibration data is available at the compliance house, not at the complaint house. Once the spacial relationships and blast log data are verified, vibration predictions can be made using national averages or site specific attenuation relationships. For brevity, only site specific ground vibrations will be discussed. The methodology is similar for airblast (except that the cubed root scaled distance is appropriate).

To conclusively evaluate a damage claim, vibration levels must be predicted at the complainant's house for comparison with the existing scientific literature on damage. Earlier discussion has focused on charge weights, distances and scaled distance verification and comparison with the historical data. If the historical relationships based on national observations were used to predict vibration levels, the levels would be overly conservative and unrealistic. National relationships like equation 2 should be used only when no other data exists.

When vibration data are available, either collected by a mine operator or the investigator, a site specific equation should be developed to accurately predict vibration levels at the complainant's house. The methodology of performing a least-squares regression analysis in relation to coal mine blasting is described by Rosenthal (1987). Any statistical software (e.g. StatGraphics, MiniTab) can be used to conduct a regression analysis of square-root scaled distance versus peak particle velocity. Spreadsheet such as Excel and Lotus can perform Trend analysis on log-log relationships but only give the mean line equation. The regression in Figure 11 was conducted with StatGraphics and yielded the equations:

Mean	$PPV = 26(SD)^{-1.39}$	(3)
2 Sigma	$PPV = 71(SD)^{-1.39}$	(4)
	$R^2 = 0.73$	

Equation 3 represents the line that predicts the mean of the data set where 26 is the y-intercept on a log-log plot at a scaled distance of 1 and the exponent, -1.39 is the slope of the line. The r-squared or "goodness of fit" value represents how well one variable can predict another. Whenever the r-squared value is greater than 0.7 the data set can be considered valid. A lesser r-squared value means that errors were made in the record keeping or data collection. If all the data were derived from blast log data, the investigator has good reason to consider the logs suspect.

Two standard deviations from the mean represents the worst-case estimate of vibrations 95% of the time. Equation 4 represents the line that has a confidence level of 95%. This means that the ground vibration at a location based on the scaled distance at that point will be lower than the predicted level 95% of the time. With the site specific attenuation relationship vibration levels can be predicted conservatively but reasonably. When compared to the existing literature on blasting induced damage, a conclusive defensible determination on the damage can be made.

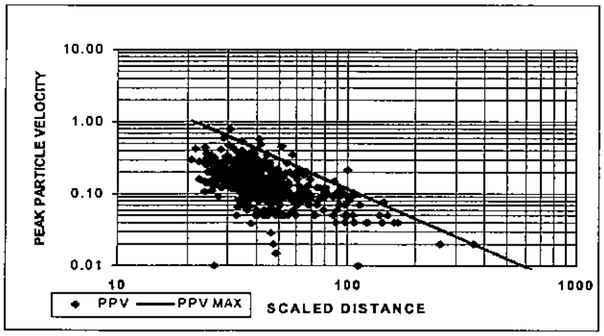

Figure 11 Regression analysis of blasting data.

Vibration and Damage Assessment

Once the blast logs are verified to be correct and statistical analysis are performed, a defensible determination on the damage allegations is possible. For the blast that was monitored in Figure 10, the following conclusions can be drawn for a blast of 205 pounds of explosives per delay and a reported vibration level of 0.20 in/s at the compliance structure;

- Both homes allege damage to basement walls.
- A vibration level in excess of 3.0 in/s is necessary to cause such damage.
- The scaled distance at the compliance structure is $450/205^{1/2} = 31$.
- If the SD of 31 plotted with 0.2 in/s on Figure 7, the point is well below the mean line (0.60 in/s) and the blast fits within the national data set. It is also within the local data set of Figure 11. Thus equation 4 can be used to conservatively estimate vibrations where seismic data does not exist.
- The SD at complainants 1 and 2 are 38 and 105, respectively.
- The highest possible ground vibration levels at complainants 1 and 2 fron equation 4 are 0.45 in/s and 0.11 in/s, respectively.
- The alleged damage at the complainant's homes was not due to blasting.
- Airblast does not exert a force on basement walls and thus the alleged damage is not airblast related.

Conclusion

New electronic tools and computer programs are available for evaluation of ground vibration and airblast related citizen complaints. If the blasting data if verified and adequately complied, a conclusive defensible decision on the disposition of the complaint can be made. A good report that clearly describes the findings will show the complainant the level of effort expended on the investigation, boost their confidence in the reviewer and provide adequate information by which the complainant can go for a "second opinion" if they are uncertain of the findings.

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