Regulatory Review of Blasting Related Citizen Complaints

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 or private 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. Computer spreadsheets, with their graphical capabilities, will be used to show how data can be cross tabulated to verify data accuracy. Complete statistical analyses of vibrations require more powerful software to make vibration predictions. Once all available data are gathered and verified, a decision on the complaint can be made.

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 the Office of Surface Mining Reclamation and Enforcement (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 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 and 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 walls and roof. In turn, the buildings respond or shake, sometimes at levels greater than the incoming energy. When people feel their houses shake, 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 a home is possible at vibration levels below the limits (Siskind et al, 1980 and Crum 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 satisfy the complainant.

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

1. Vibrations amplitudes attenuate with distance in the <u>same</u> direction;
2. Vibrations amplitudes may be higher in different directions at the same distance;
3. Vibration amplitudes are dependant on the charge weight detonated in each delay interval; and
4. Vibration frequencies become lower with increasing distance or soil thickness.

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 as pressure and reported 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.

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

Where D is the distance and CW is the charge weight of explosives detonating at any given time. In this relationship, as distance increases or the amount of explosives decreases, the scaled distance increases. As scaled distance increases the vibrations will 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. Conversely, if the complainant is on the opposite side of the permit from the compliance house, vibrations may be higher due to directional differences (see Figure 1). A change in the blasting plan may be warranted to assure the vibration limits are maintained. For example, another monitoring site may be needed on the other side of the permit.

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.

Damage complaints require three additional steps to those discussed above for annoyance complaints 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 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. Keep in mind that the true gauge of damage is related to how much the house vibrates. If the type of house is unusual or atypical (e.g. log or adobe homes) compared to the kind of homes evaluated historically in the research, the structure response may need to be evaluated to resolve the complaint.

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). Airblast is much harder to predict than ground vibrations because of atmospheric conditions. Airblast monitoring is almost always essential. Particular attention should be paid to the type of blasting at the mine. Thin overburden (<20'), parting and coal blasts frequently cause high airblast. The type of house is also important as discussed above. If the structure response is evaluated, it should include airblast as well. Often the airblast is shown to be the cause of the strongest response.

At the completion of the investigation, the complainant should be provided a report that describes the items reviewed , the findings made and the actions taken. The report can then be given to a third party by the homeowner for a “second opinion”. At a minimum, the response to each complaint “type” should contain the following

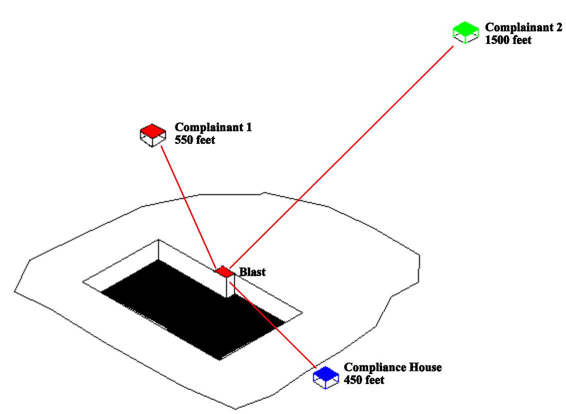

Figure 1 Spatial relationships between the blast, compliance structure and complainant house.

information.

Annoyance Complaints

- 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.
- At the complaint house, discuss the relevance of the data at the compliance house and if possible predict the vibration level.
- A discussion of any violations that were found and any blast plan modifications required.

Damage Complaints

- 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 for the time the damage was alleged.
- 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. They are kept by the blaster at each mine site as required in the Federal regulations (30 CFR 816.68). The first step in the investigation is to verify the accuracy of the blast logs. This is done by cross tabulating some of the data fields. It can be done by hand or easily entered into a spreadsheet. The advantage of a spreadsheet is that the data can be graphically summarized over a broad period of time, including when annoyance or damage was alleged. The Blast Log Evaluation Program (BLEP) was developed in Excel to perform this task.

The key items to verify in the blast log review are the maximum charge weight per 8-millisecond delay and the distance to the nearest structure. As discussed above, these two variables are used to estimate ground vibration and airblast levels. If the blast log data cannot be verified by cross calculating blast hole specifics, then extrapolation of vibration levels to the complaintant's house will be inaccurate or impossible.

Data Input:

Up to 50 blast logs can be entered into the BLEP. 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.

All but two fields are copied directly from the blast log: *Distance Measured; and Actual Charges per Delay.* By determining these fields, the blast log data can be verified or cross checked.

Table 1. Data input variables.

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

Distance Measured. The reported distance needs to be compared with a verified or measured distance based on the location. The log must contain the location of the blast within the permit area by survey, GPS, grid map or other method that gives acceptable results. The blast location should be referenced with an accuracy of two significant digits (i.e. < 1000 feet, reported to the nearest 10 feet) to be able to verify the reported distance to the nearest structure. In particular, if the location cannot be determined and scaled distance is the compliance method, then the investigator cannot determine if the proper amount of explosives was used.

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 of each hole are shown on the log and simply need to be 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.

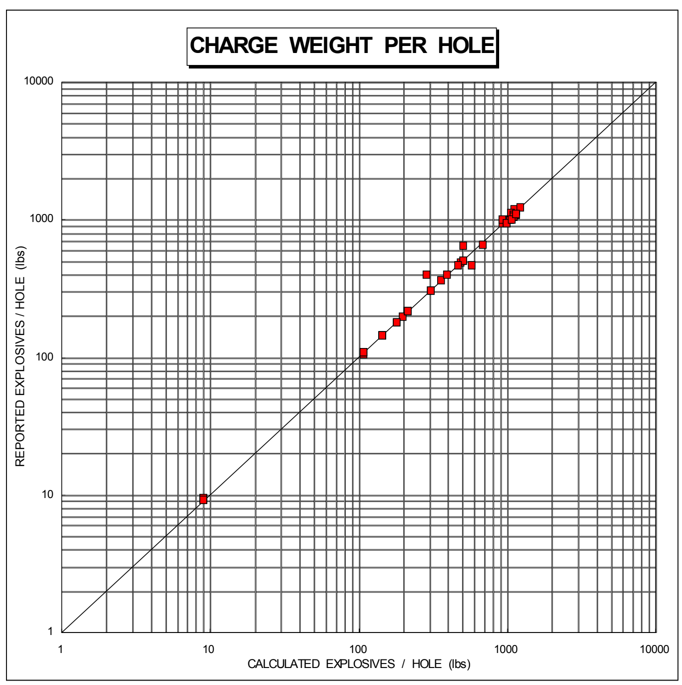

Figure 2

Both these components are critical in determining scaled distance compliance or evaluating the vibration attenuation characteristics in an area to see if unusual site conditions exist.

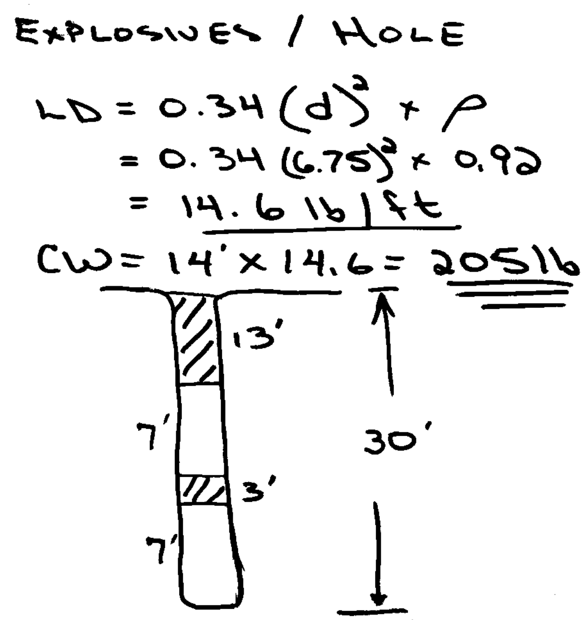

Figure 3 Blast hole cross section.

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: From a regulatory stand point, the blast log for each data point that falls outside the expected envelopes must be rechecked prior to any violations. To illustrate the BLEP utility, the following series of graphs represent 50 blasts at a mine in Kentucky.

Figure 2, 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. Points that touch the reference line are acceptable. The size of the plotted blocks allow for about 10% spread in the data. Figure 3 illustrates the calculation performed by the BLEP for the calculated explosives per hole for comparison with the reported value. 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').

In Figure 4, the reported is plotted against the calculated explosives per delay. This takes the data in Figure 2 one step further by taking into consideration the number of decks in the hole and the actual number of charges detonating on the same delay (overlaps). The reported and calculated values should match or be "close"(10 %). Again the point size approximates 10% deviation and points touching the line are acceptable.

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 for that blast needs to be checked more closely. If more explosive are being detonated than reported, this may be the cause of the complaint. The point above the line indicates that less explosive were detonated than reported.

The other important element for evaluating vibrations is the distance to the nearest house or compliance structure. In Figure 5, the distance reported is plotted against the distance measured. If the measured distances cannot be determined because of an inadequate location, compliance with the scaled distance equation cannot be established and the data will plot errantly with the vibration data (discussed later). In this figure, five of the blasts were conducted closer to the compliance structure than reported.

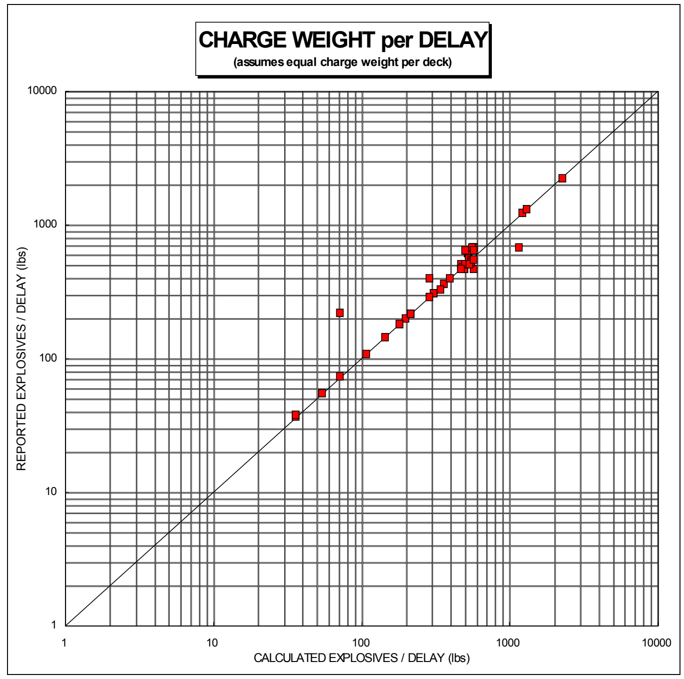

Figure 4

Figure 6 is a log-normal plot of reported and calculated scaled distance against distance to the nearest structure. If the logs are accurate, the calculated points (squares) should plot on top of the reported values circles). The reference line is the allowable scaled distance at distances from 0-300', 301- 5000' and >5000' (30 CFR 816.67). Points below the line fail the scaled distance compliance test. In this instance all points (both reported and calculated) are above the line the graph clearly and conservatively shows compliance. However since all the calcualted points do not obscure all the reported points some discrepancies in the data exist.

Figure 7 is a log-normal plot of reported and measured distance versus reported peak particle velocity (PPV). Again if the logs are accurate, the measured points (squares) should plot on top of the reported values circles). The reference line is the allowable PPV at distances from 0-300', 301- 5000' and >5000' (30 CFR 816.67). Points below the line fail the peak particle velocity compliance test. As expected all the vibration levels are low because the blaster has shown compliance with scaled. However one blast does stand out and may warrant closer scrutiny.

Figure 8 is a log-log graph of reported and calculated scaled distance versus reported peak particle velocity at the nearest house. 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 line is two standard deviations from the mean (worst-case). The worst-case line has the equation:

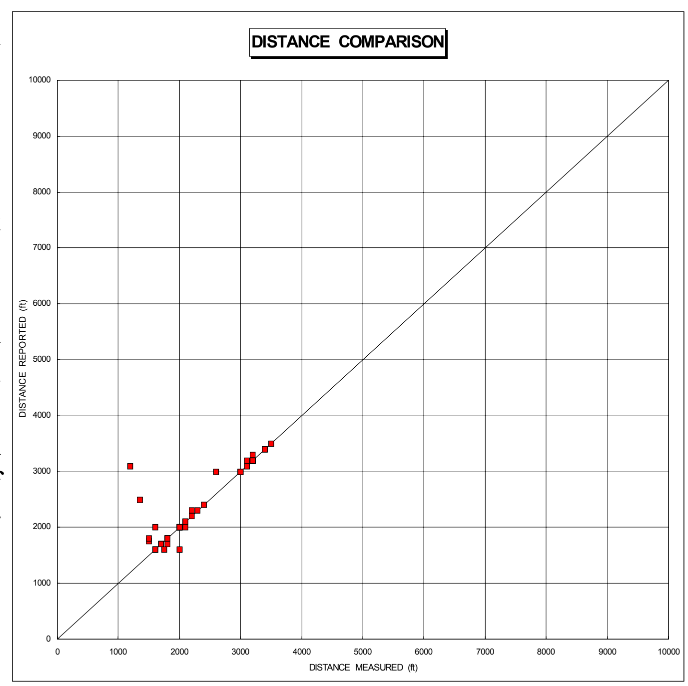

Figure 5

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

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 8 should raise suspicion of the log accuracy. Upon further review it was found that the seismograph was place at the wrong house and thus paired with the wrong scaled distance. If many of the points are above the line and the data is good, the vibrations in the area may be unusually focused and require modifications to the blast plan.

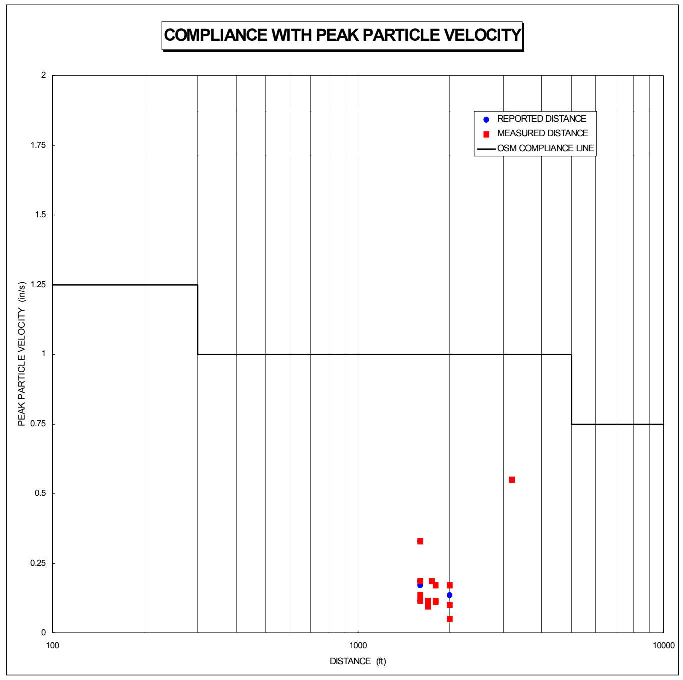

Figure 6

Figure 9 is a log-log graph of particle velocity versus frequency. This data is reported only if blasting seismographs were used. The reference line is from the Federal rules at 30 CFR 816.67 and provides the best gauge for evaluating damage claims. Points above the line represent vibrations with a potential to create damage to residential structures. 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. Here the virtations recorded have no potential to cause damage to the house where the seismograph is located.

Figure 10 is the reported and calculated 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 highwall line are unusual for that scaled distance and may be the cause of the complaint. The one point above the line on Figure 10 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.

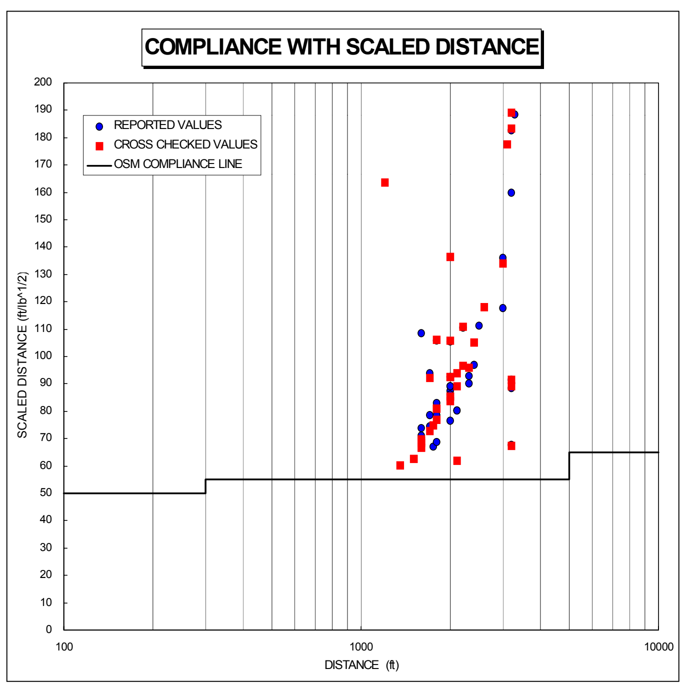

Figure 7

After reviewing Figures 2 through 10, it is concluded the records are reasonably good and can be used to evaluate the complaint.

Spatial Relationships

Now that the blast log have been deemed adequate, the data can be extrapolated to the house of concern. To address the citizen's complaint, 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 1). THE BLAST LOCATION IS ESSENTIAL! If it cannot be determined, any subsequent analysis is worthless. With the end of selective availability, all blasts should be located with GPS and recorded on the blast log.

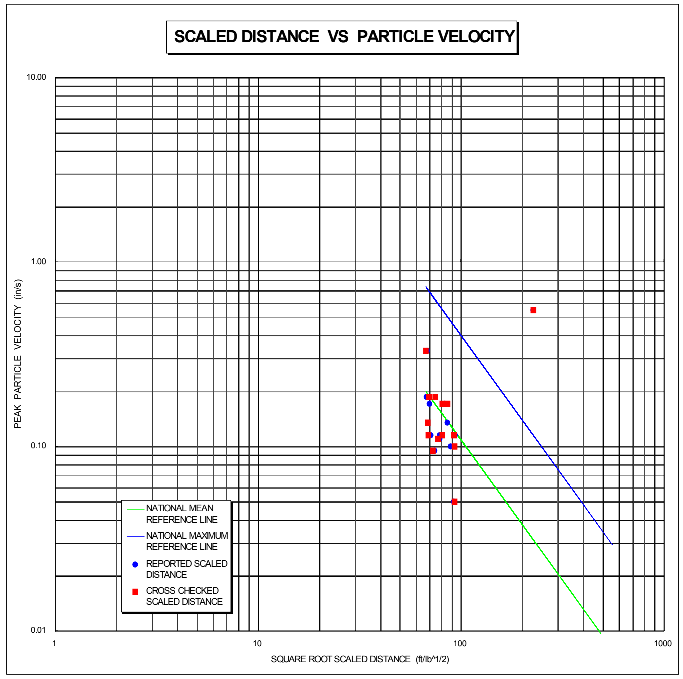

Figure 8

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 must be obtained using a USGS topographic map, surveying or GPS. Keep in mind the relative accuracy of the selected method.

If the complainant is on the same side of the mine and beyond the compliance house then it is fair to say the vibrations at the more distance house were less. Or as often stated, "the mine is in compliance" is also fair. But when the complaint comes from the other side of the mine as shown in Figure 1, the resolution in not as simple. Vibrations, both air and ground, vary depending on the direction and soil/rock type or atmospheric weather conditions (i.e. propagating medium). In this instance, the open pit is between the blast and compliance house. This will effectively dampen vibrations in this direction. The strongest vibrations are likely towards Complainant 1 even though it is further away by 100 feet. In this case the an annoyance complaint may be substantiated and a change in the blasting plan and/or monitoring scheme is necessary.

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

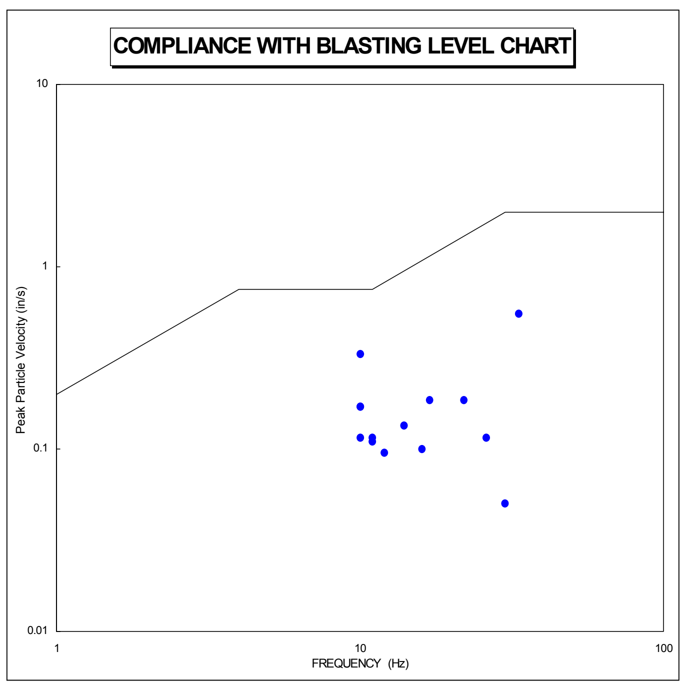

Figure 9

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).

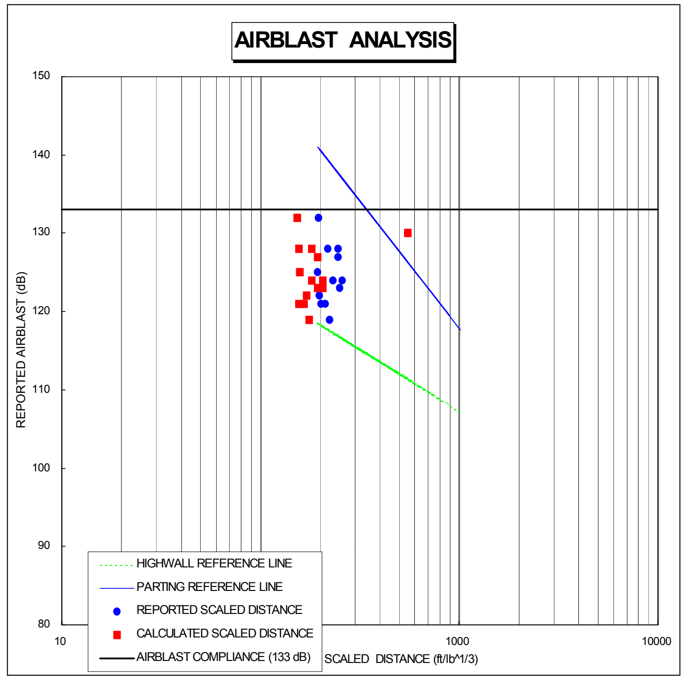

Figure 10

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 historicalrelationships 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:

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

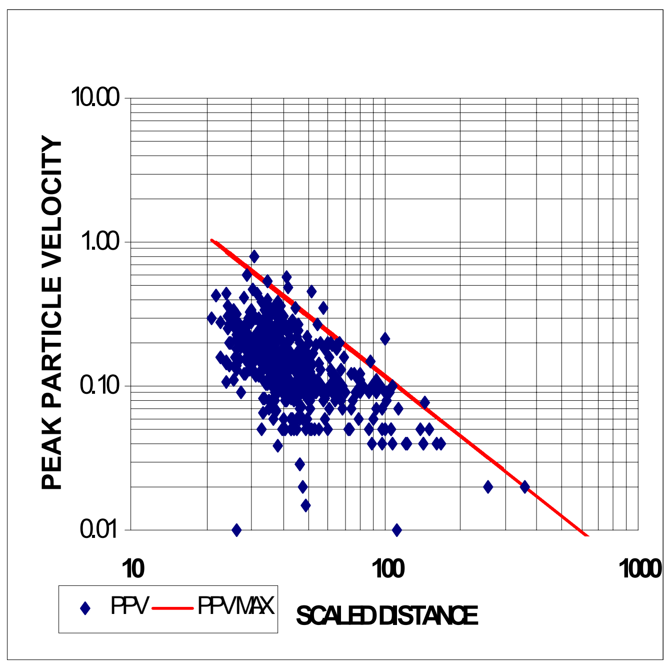

Figure 11 Regression analysis of blasting data.

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, data collection or that vibrations at the site are unpredictable. 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.

Vibration and Damage Assessment

Once the blast logs are verified to be correct and statistical analysis are performed, a sound determination on the damage allegations is possible. For the blast that was monitored in Figure 10, the following findings 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.
- Airblast does not exert a force on basement walls and thus the alleged damage is not airblast related.

The conclusion is that the alleged damage at the complainant's homes was not due to blasting. The last thing to do is a report that clearly shows the facts and conclusions that resolve either the annoyance or damage complaint.

Conclusion

Citizen complaints need to be addressed in a timely and sound manner. Of foremost importance is record keeping, the location of the blast and the location of the complainant relative to the blast. If the blasting data is verified and adequately complied, a conclusive defensible decision on the disposition of the complaint can be made. New electronic tools and computer programs are available to help evaluate the large quantities of data from the blast logs and blasting seismograph records. 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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