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Acoustic Response of Structures to Blasting Analyzed Against Comfort Levels of Residents Near Surface Coal Operations

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FORM FP-1

OFFICE OF SURFACE MINING NATIONAL TECHNOLOGY TRANSFER TEAM FACE PAGE

PROJECT TITLE: Acoustic Response of Structures to BlastAnalyzed Against Comfort Levels of Residents Near Surface Coal Operations

PROJECT DURATION IN MONTHS: 12 **MONTHS**

HAS THIS PROPOSAL BEEN SUBMITTED ELSEWHERE: YES ______ **NO** XX ~~XX~~

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PROPOSERS ORGANIZATION

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CERTIFYING REPRESENTATIVES NAME & TITLE: Deborah K Davis
Assistant Director

[signature] , 2/22/07

SIGNATURE OF PRINCIPAL INVESTIGATOR/DATE

PI Assurance: I agree to accept responsibility for the scientific conduct of the project, to provide the required reports, to acknowledge OSM in any presentations and publications wherein the results of this project are used, and to provide copies of presentation abstracts and publications to OSM. i also agree to allow this proposal to be reviewed by industry and/or academia and that proprietary information which has been properly identified will be used solely for proposal evaluation.

[signature] , 2/22/07

SIGNATURE OF ORGANIZATION'S CERTIFYING REPRESENTATIVE/DATE

Certification & Acceptance: I certify that to the best of my knowledge, the statements contained herein are complete and true and I accept the obligation to comply with OSM terms and conditions provided an award is made as a result of this submission.

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ABSTRACT

Blast vibrations induce sounds within neighboring residences. A house wide vibration and sound monitoring system was installed in a West Virginia home which was subjected to blasts at varied distances and direction. Eighty-five blast events were monitored and analyzed.

Fifteen channels of data were collected including three triaxial geophones, one airblast microphone, one uniaxial geophone mounted to the inside wall of the house (response channel), and four microphones that recorded CD quality sound waves inside the house. Each of these channels was recorded on the same time scale. The response channel signal was easily separated into ground vibration and airblast induced movement due to the differences in their times of arrival. This response channel was then compared to the sounds recorded to determine which component of blast vibration induced the maximum sound response. Blasts at distances less than 762 meters (2,500 feet) had maximum sound responses from both ground vibration and airblast. While for blasts beyond 762 meters (2,500 feet), the maximum sound response was caused by ground vibration without exception. When airblast was identified as the dominant sound generator, the peak amplitude of the sound was directly related to the amplitude of airblast. When ground vibration was identified as the dominant sound generator, the peak amplitude of sound was not related to the amplitude of ground vibration.

In the cases where the ground vibration was the sound generator, sound amplitude was driven by the conditions present in the house such as loose items creating sudden peaks from falling or slamming. Different rooms generated very different sounds based on the contents of the room. Findings from frequency analysis showed that the frequency content of sounds inside the house were not related to frequency content of airblast or ground vibration regardless of source suggesting that residents would have difficulty determining the source of blast induced noise in their homes.

EXECUTIVE SUMMARY

Blast vibrations induce sounds within neighboring residences. A house wide vibration and sound monitoring system was installed in a West Virginia home which was subjected to blasts at varied distances and direction. Eighty-five blast events were monitored and analyzed. Fifteen channels of data were collected including three triaxial geophones, one airblast microphone, one uniaxial geophone mounted to the wall of the house (response channel), and four microphones that recorded CD quality sound waves inside the house. Each of these channels was recorded on the same time scale. The response channel signal was easily separated into ground vibration and airblast induced movement due to the differences in their times of arrival. This response channel was then compared to the sounds recorded to determine which component of blast vibration induced the maximum sound response. Geophones recorded peak particle velocities ranging from 0.008 to 1.181 in/s while the airblast microphone recorded overpressures ranging from $1.81X10^{-4}$ PSI (96 dB) to $1.81X10^{-2}$ PSI (136 dB). Blasts at distances less than 762 meters (2,500 feet) had maximum sound responses from both ground vibration and airblast. While for blasts beyond 762 meters (2,500 feet), the maximum sound response was caused by ground vibration without exception. When airblast was identified as the dominant sound generator, the peak amplitude of the sound was directly related to the amplitude of airblast. When ground vibration was identified as the dominant sound generator, the peak amplitude of sound was not related to the amplitude of ground vibration. In these cases, sound amplitude was driven by the conditions present in the house such as loose items creating sudden peaks from falling or slamming. Different rooms generated very different sounds based on the contents of the room. Findings from frequency analysis showed that the frequency content of sounds inside the house were not related to frequency content of airblast or ground vibration regardless of source suggesting that residents would have difficulty determining the source of blast induced noise in their homes.

For the horizontal vibration components the range of frequencies was between 6 and 16 Hz with the predominant frequencies being from 8 to 10 Hz. The vertical component shows a greater spread (between 3 and 30 Hz) when compared to the horizontal. The frequency calculated in the response channel should be similar to the house's mid-wall natural frequency, in this specific situation; the frequency of the house is between ranges of 6.30 and 22.4 Hz with an average of 12 Hz. This range and average value is typical for mid-walls according to Bureau of Mines for Surface Mining RI 8507 (11Hz-24Hz).

In this study the signals from acoustic sounds inside the house show more energy content in the higher frequency ranges when compared to signals from airblast (69 events are in the audible range in the case of acoustic sounds against zero events in the audible range for airblast signals). This suggests that the noise produced in the house is not the actual airblast. The noise is a product of the response of the structure and objects within the structure.

In addition to the physical data collected in the West Virginia home, a phone survey was conducted by the University of Kentucky Survey Research Center. The survey asked questions about reporting practices and how residents in Boone County and Logan County West Virginia perceived blasting and reporting practices. This survey continued work initiated near quarries in Missouri and Arkansas in 2004. The survey data was then

qualitatively analyzed against the actual acoustic and vibration data collected for the first portion of the study.

Regarding the survey, two important questions which this survey was designed to help answer were: Do people understand the units that blast events are reported in? Are there alternative units that people are more comfortable with?

The units that air overpressure is communicated to the public is currently decibels. This unit was perceived, by the majority of the interviewed who knew or claimed to know what decibels are, to be associated with sound or noise, not pressures. Although decibel is the unit that gained the majority of preference from the interviewed, decibel was not understood to be a unit of pressure. The unit of decibel was preferred by 0.6% over PSI. This preference was marginal at best since 46% chose decibels as their first choice for the reporting unit while 45.4% chose PSI. The unit of PSI was understood to be related to pressure by 58.7% of those who claimed they knew what PSI was.

In addition to being more understood PSI instills more comfort than decibels. When a blast overpressure was communicated in PSI there was a 10.1% less response in the "very uncomfortable" and "uncomfortable" range when compared to decibels. This decrease in uncomfortable was countered by a rise in the comfort level of the interviewed by 8.5% between decibels and PSI. The switch from decibel to PSI for reporting blast over pressure is the type of improvement to be made to foster a better means of communication between members of the blasting community and their neighbors. When it comes to communication between people, both understanding what's being said and feeling comfortable with what's being reported is critical to making them feel more at ease with what is happening around them.

The use of linear units is advisable (as opposed to logarithmic). PSI is the suggested choice of the three units selected in this study for reporting airblast measurements. This suggestion is based upon the data gathered by this survey that suggests that PSI is understood to be related to pressure and also PSI instills more comfort in the individuals interviewed when typical blast data is communicated. It is believed that the higher comfort values for PSI may have been generated by the fact that many people are familiar with the unit, and indeed use it on a regular basis for activities such as tire maintenance on their personal vehicles.

Results for analysis of questions involving units for ground vibration measurement yielded similar conclusions. Currently ground vibrations are communicated to the public in inches per second and Hertz. This unit was not found to be the most preferred unit by the population of this survey, nor did it produce the best comfort levels. Average comfort values were highest for millimeters of displacement as opposed to peak particle velocity and frequency or inches displacement; however, the distribution shift was marginal suggesting that there is perhaps another variable which could instill higher comfort levels.

LIST OF FIGURES

INTRODUCTION

Many research findings to date have focused on structural response of homes from blast vibrations. From these studies, vibration and airblast regulations have been established to prevent damage to private property next to surface coal operations due to blasting activity. Nevertheless, complaints about blasting persist. At this point, the problem transforms from a structural damage issue into one about abating complaints. The limits in place are conservative in nature and have been shown not to cause damage. Therefore, it is apparent that the key or keys to this problem lie somewhere else besides levels of ground vibration alone.

The solution to the problem converges on two paths. The first path encompasses determining how residents experience blast events from within their homes. The second path consists of how the residents affected by blasting receive relevant technical information. This second path affects the public relations between the mine and the people.

In this study to determine how residents experience the blast events within their homes, the acoustic response was measured inside a structure subjected to nearby surface blasting at a surface coal mine operation.

The second path was studied administrating surveys to the residents living in proximity to the surface coal mine, continuing the research initiated by Dr. Lusk in 2004. The original survey work was performed near aggregate quarries in the Midwest. The situation is similar to coal mines in West Virginia, and the two data sets are compared.

ACKNOWLEDGEMENT

The authors acknowledge the assistance of government agencies; OSM, University of Kentucky and the mine operators and homeowner of the instrumented house Raven Crest Minerals LLC. Thanks also go to Harold Aliff who was living in the house during the data acquisition time. Much of the fieldwork and data reduction and analysis was done by graduate students Jhon Silva and Josh Hoffman. Special thanks go to Ken Eltschlager Office of Surface Mining – Appalachian Region by his suggestions through this research and the discussions in order to improve this report.

1 EXPERIMENTAL

1.1 Considerations About Airblast And Noise In Blasting

As a result of rock blasting, undesirable collateral effects such as airblast and ground vibrations are generated. In general terms, airblast is an airborne shock wave generated by the release of explosive energy. Due to the wide variability in the generation and propagation of airblast, frequency content range is wide and sometimes effects are inaudible because the frequency is below the range of human hearing (20 Hz to 20000 Hz). (Virgil J. Stachura, David E. Siskind and Alvin J. Engler 1981). Even at frequencies ranging up to 200 Hz, a large amount of sound energy is not captured in hearing. Humans cannot hear the full range of sound energy until frequencies reach nearly 1000 Hz (ANSI SI.4, 1971).

Conventionally, airblast monitoring is focused to measure the blast wave that is generated by blasting upon arrived at the interest point. Usually the measurement unit is pounds per square inch (psi), decibels (dB), or millibars (mb). The most familiar equation to estimate the sound pressure level in dB is given by equation 1.1:

$$SPL = 20 * \log\left(\frac{P}{P_o}\right) \quad \text{Equation 1.1}$$

Where:

SPL: Sound Pressure Level
P: Shock wave overpressure
Po: Reference pressure.

The result of Equation 1.1 should not be confused with acoustic noise by the fact that the measurement units are the same (dB). Most noise standards have been developed for steady-state noise e.g., engine, plane, equipment sounds, etc. The steady-state noise is related with the time interval of duration of the event. On the other hand airblast is a transient event (short duration) however under some assumptions the steady-stated theory can be applied to transient airblast waves.

In this project, measurement of airblast was accompanied by four microphones that recorded CD quality sound waves inside a house exposed to blasting.

1.2 Objectives

The following two items were the specific objectives of this work:

a) Specific determination and documentation of how residents would experience a blast event from inside their homes by recording the events.
b) Collection of survey information from residents surrounding surface coal mining operations.

In order to fulfill objective (a), a data acquisition system was installed in a single story framed farmhouse in Ashford, WV through Raven Crest Minerals LLC. This house is located on the Boone North No.2 Coal Surface Mine property. Two people live in this house, so the information gathered is representative of a real situation of people perceiving blast events in their homes. Distinct sound differences could be audibly determined due to activities and circumstances such as watching television, talking on the phone, washing dishes, location of keys and other objects on tables and desks.

The location of the house and the surrounding coal mine is illustrated in Figure 1.2. During the time that data was collected the locations of mining areas ranged in distance from the house to the blasting site from 812 to 4376 ft. The mining operation also conducted blasting in almost 360 degrees surrounding the house.

A telephone survey with 27 questions was administered in the counties close to the Boone North No.2 Coal Surface Mine (Boone and Logan Counties) in order to fulfill the objective (b). The questions were raised to study how the people perceive the technical information from blasting and to examine the public relations between mining operations and nearby neighborhoods.

1.3 Acoustic Data Collection Methodology

The activities required for this research project were as follows:

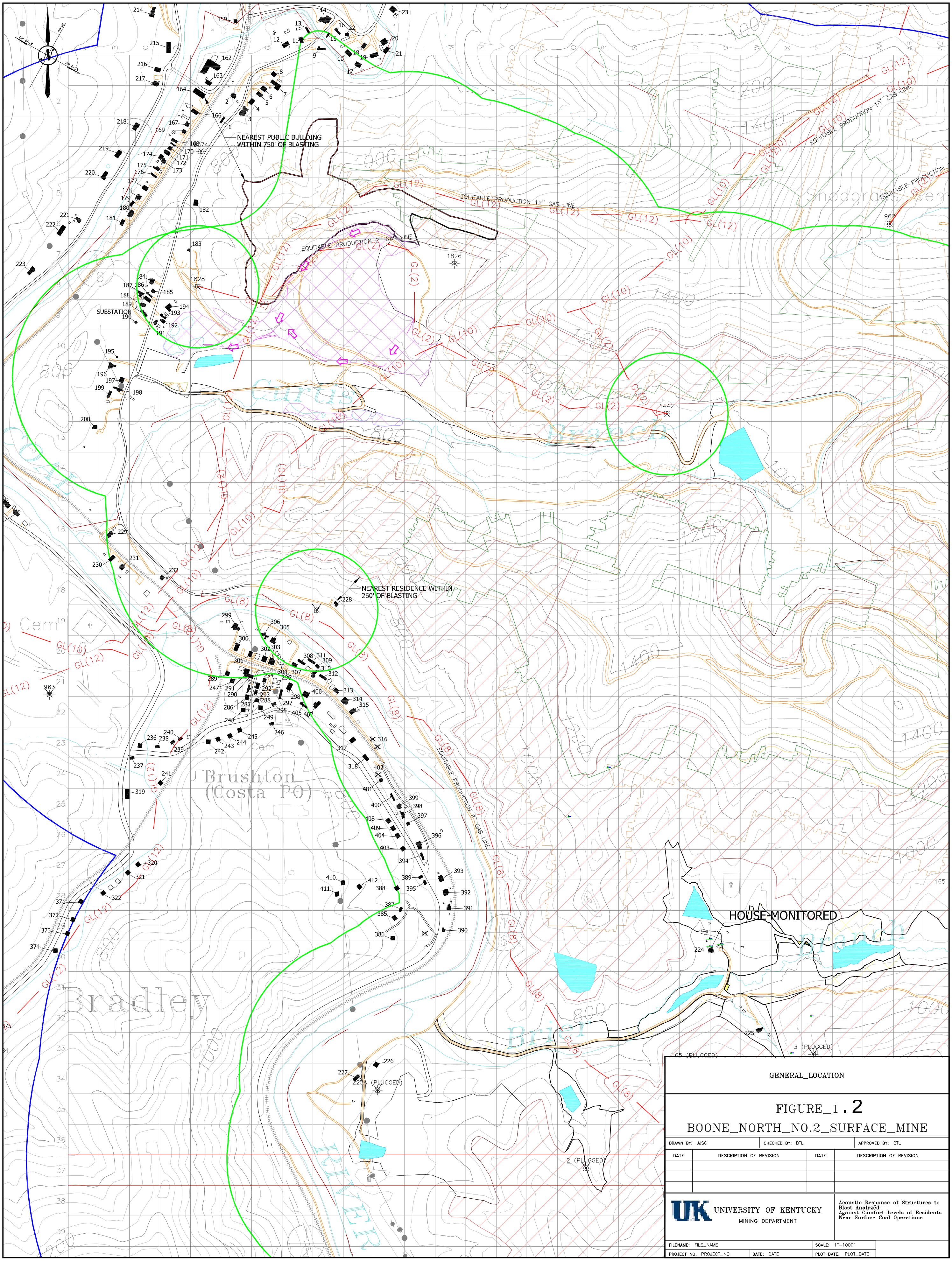
a) Data acquisition system installation
b) Gathering of information concerning ground and structure vibrations, acoustic sound, and airblast.
c) Gathering of information concerning blasting patterns, location of blast event, quantity of explosives employed and rock removed.
d) Development of a procedure and methodology for analyzing the data.

The following sections describe each activity in detail.

1.3.1 Data acquisition System

The system was installed in a typical house, known as Aliff's residence, within the coal exploitation area. Figure 1.1 shows the instrumented house.

Figure 1.1 Aliff's residence, where monitoring system was installed.


NEAREST PUBLIC BUILDING
WITHIN 750' OF BLASTING
EQUITABLE PRODUCTION 12" GAS LINE
EQUITABLE PRODUCTION 2" GAS LINE
EQUITABLE PRODUCTION 10" GAS LINE
EQUITABLE PRODUCTION 8" GAS LINE
SUBSTATION
NEAREST RESIDENCE WITHIN
260' OF BLASTING
HOUSE-MONITORED
Snodgrass Cem
Brushton
(Costa PO)
Bradley
Cem
1442 (PLUGGED)
225A (PLUGGED)
2 (PLUGGED)
3 (PLUGGED)
165 (PLUGGED)
GENERAL_LOCATION
FIGURE_1.2
BOONE_NORTH_NO.2_SURFACE_MINE
DRAWN BY: JUSC
CHECKED BY: BTL
APPROVED BY: BTL
DATE
DESCRIPTION OF REVISION
DATE
DESCRIPTION OF REVISION
UK UNIVERSITY OF KENTUCKY
MINING DEPARTMENT
Acoustic Response of Structures to Blast Analyzed Against Comfort Levels of Residents Near Surface Coal Operations
FILENAME: FILE_NAME
SCALE: 1"=1000'
PROJECT NO. PROJECT_NO
DATE: DATE
PLOT DATE: PLOT_DATE

This house is a wood framed one story structure with a crawl space. Figure 1.3 shows a sketch of the foundation system and house plan.

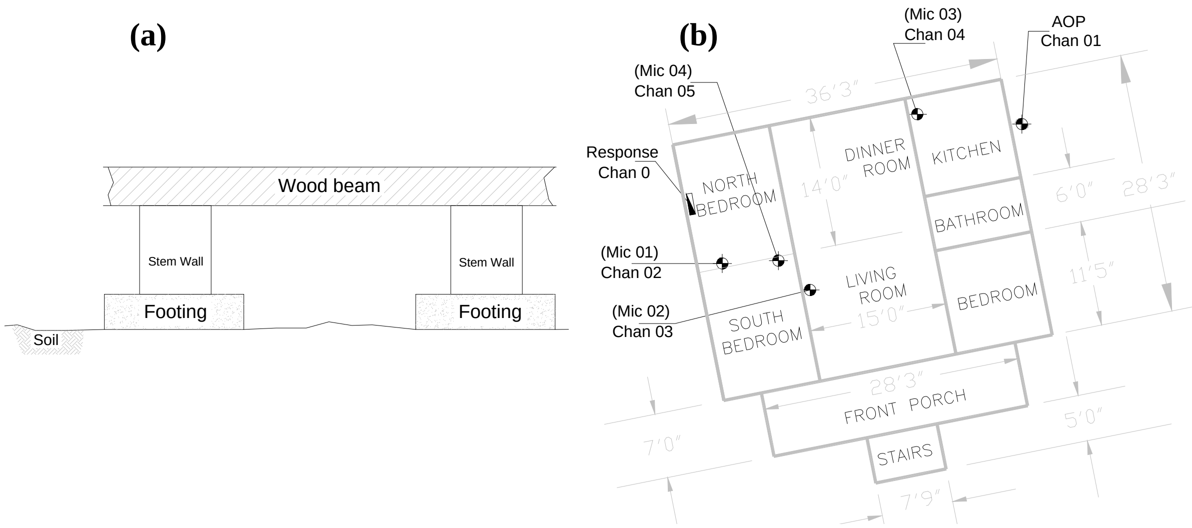


Figure 1.3 a) Foundation system sketch. b) House plan

The monitoring system installed in the house is composed of the following:

- One (1) sensor Structure Mid –Wall Response.
- Four (4) acoustic microphones located inside the house.
- One (1) airblast microphone located outside the house.
- PC and software monitoring system inside the house.
- Three (3) triaxial geophones placed outside the residence to record ground vibration information.

Figure 1.3b shows the location of each component installed inside the house. The triaxial geophones were placed away from the house and buried.

In Figures 1.4-1.6, it is possible to see each of the components in detail as installed in the house monitored for this project.

Figure 1.4 One (1) of 4 acoustic microphones located inside the House.

Figure 1.5 Airblast microphone located outside the House.

Figure 1.6 PC and peripheral components of the monitoring system – Midwall Response.

The technical details of the major components are shown in Table 1.1. The table shows the description of each component and the vendor for the component.

Table 1.1 PC and others components of the monitoring system.

Item	Vendor
AKG C1000S Condenser Microphone	Turnkey
Behringer Ultragain Pro-8 Digital ADA8000 amplifier	Turnkey
Brenell XLR to XLR 20M Audio Cable	Turnkey
Brenell Male XLR Coupler Adaptor	Turnkey
XLR amplifier to passive board cable	GDRS
Vivanco 'Sound & Image' (12348) 0.5m Toslink Cable	Go-electric
Airblast Microphone	Datum
Datashuttle 3000 series	Adept Scientific
AOP Mircophone adaptor & power supply	GDRS
SM-6/U-B 4.5Hz ohm vertical geophone	Input/Output
SM-6/U-B 4.5Hz ohm horizontal geophone	Input/Output
PE-6/B Insert (90 degrees)	Input/Output
Blk diecast alu box,120.5x79.5x55mm	RS
Beldon 3 pair cable - 153m 1182093	Farnell
Beldon 3 pair cable - 305m 1182094	Farnell
Amphenol 6 Way plug - MS3106A-14S6P	Farnell
Amphenol 6 Way socket - MS3106A-14S6S	Farnell
Single Axis Active Transmitter (for trigger) SATX01	GDRS
Passive RX Board w/ Active Trigger Receiver PRXATR01	GDRS
24V PSU To power active trigger and datashuttle 24VPSU	GDRS
Hewlett Packard Server for System Control	HP

To collect the ground vibrations, three (3) blasting geophones compliant with the ISEE performance specifications for blasting seismographs were used. The geophones were installed according to the ISEE field practice guidelines for blasting seismographs. Full wave form events were captured to analyze the time histories for particle velocity and frequency content. The geophone locations with respect to the house are included in Figure 1.7.

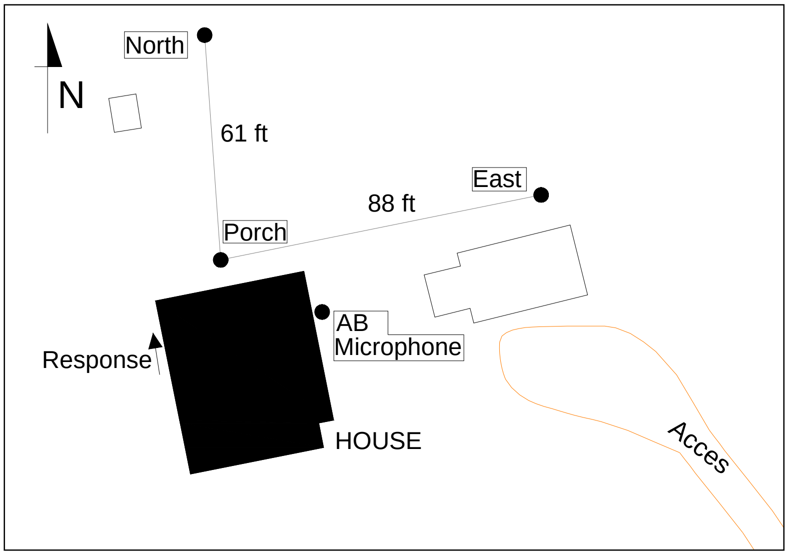
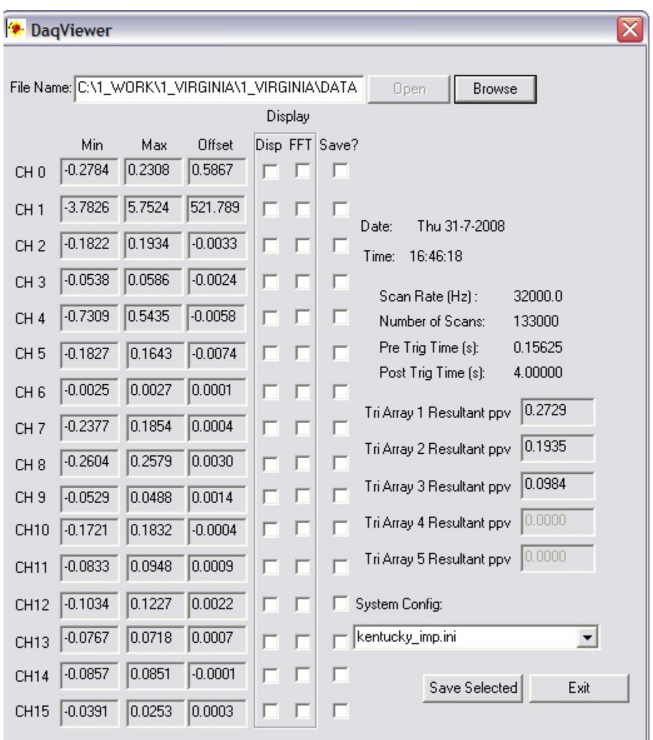


Figure 1.7 Geophone locations and microphone with respect to the house monitored.

1.3.2 Information collected concerning vibrations, acoustic sound, and airblast.

The monitoring system that was used, has a total of 16 channels, to collect the information a program called DaqViewer was used. The information was recorded using the English Unit System. The next figure shows both the typical screen when one event was recorded (Figure 1.8a), and the units used in each channel (Figure 1.8b).



Channels	Device		Units
0	Response		in/s
1	AOP		Pa
2	Mic 1 North BR		V
3	Mic 2 Living Room		V
4	Mic 3 Kitchen		V
5	Mic 4 South BR		V
6	NONE		
7	Longitudinal 1	Porch Geophone	in/s
8	Transverse 1		in/s
9	Vertical 1		in/s
10	Longitudinal 2	North Geophone	in/s
11	Transverse 2		in/s
12	Vertical 2		in/s
13	Longitudinal 3	East Geophone	in/s
14	Transverse 3		in/s
15	Vertical 3		in/s

(a) **(b)**

Figure 1.8 (a) Screen DaqViewer software. (b) Units used in each channel.

The acoustic microphones were not calibrated instruments. The microphones used recorded CD quality sound but were not calibrated to pressure. Voltage was used as a proxy for amplitude during analysis since the amplifier gains were not adjusted between events. In some records TV sound amplitude was used as a reference. This allowed for a qualitative calibration of the sound microphones. Future studies should include a channel for sound pressure level monitoring inside the structure because the microphones are designed to generate high quality sound, and it is expected that calibrations would not show linearity.

The entire system was initiated to monitor by the response channel which was composed of a horizontal uniaxial sensor mounted approximately at midwall in the house. The whole system had a scan rate of 32,000 Hz with a total number of scans of 133,000 in a total time length of 4.15625 seconds. A detail of the response channel device is shown in Figure 1.9.

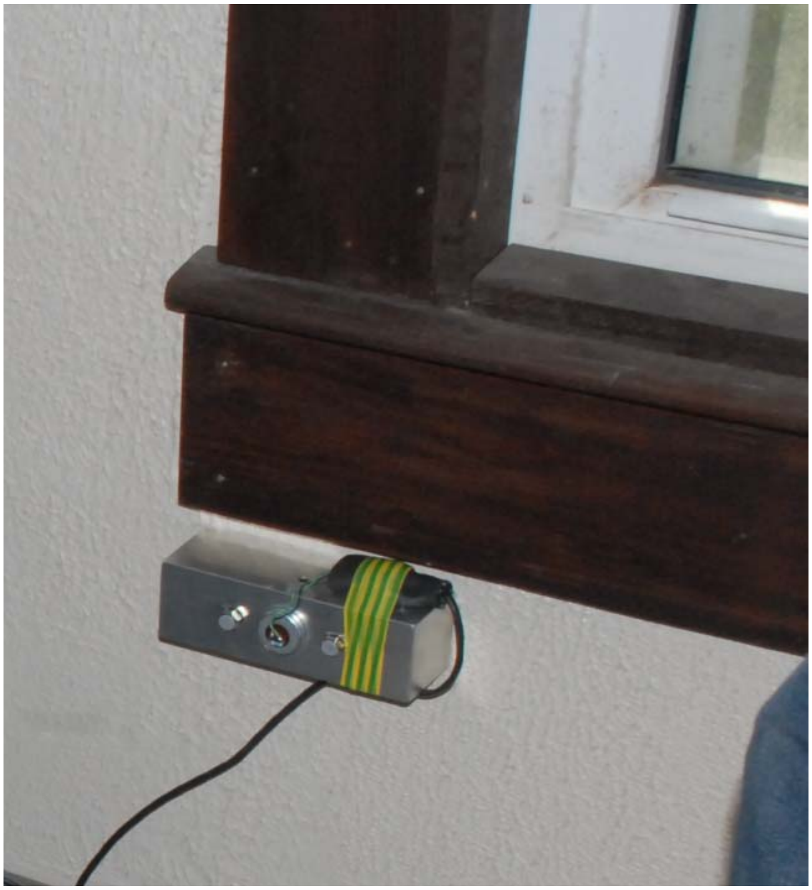


Figure 1.9 Response channel

The recording time of each event was 4.15625 seconds including 0.15625 pre-trigger time and the other 4 sec post-trigger time. The response channel would initiate (trigger) recording an event with a response velocity greater than 0.5 mm/s (0.02 in/s). At this trigger level, 10 to 12 false triggers were collected each day. The false triggers may have been initiated by any number of events. For example, the system was easily triggered by slamming a door in the house or jumping on the floor. While several false triggers recorded unnecessary data, all blasts conducted while the monitoring system was operational were recorded. Furthermore, future studies could use this data to determine how non blast occurrences might produce sound response within the home. Next is presented a typical example of each type of signal recorded.

1.3.2.1 Response Channel

The response channel measures the particle velocity (PV) over time. This device was attached to one of the walls of the house (see Figure 1.9). Figure 1.10 shows the typical wave form of the response recorded. The response channel represents the mid-wall response of the structure and will allow some comparisons with earlier structure response studies. The response channel was used as a triggering mechanism for the acoustic monitoring system.

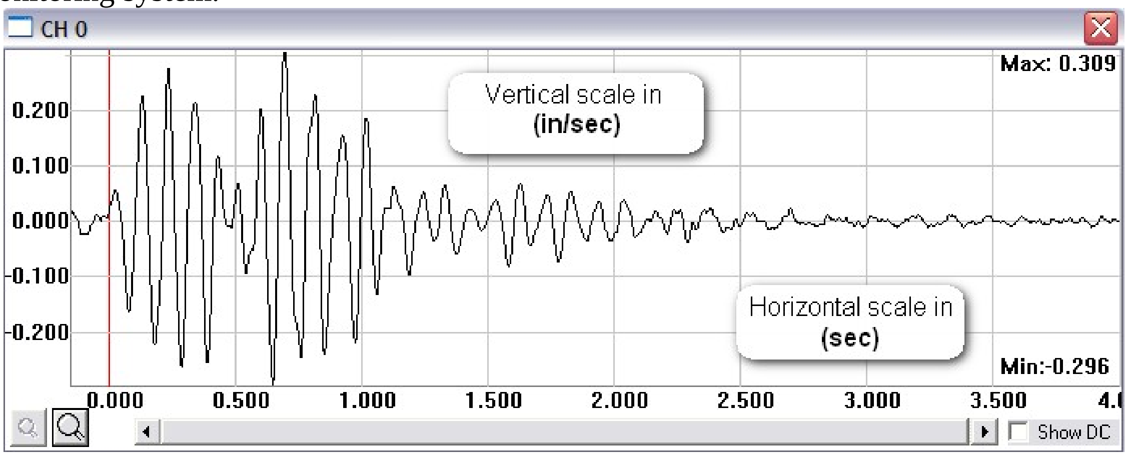


Figure 1.10. Wave form response recorded for blast event 07/28/08.

1.3.2.2 Sound Microphones

The acoustic microphones correspond to channels 2 to 5 in the data acquisition system. They collect the sounds inside the house in the North and South bedrooms, the living room, and the kitchen. The purpose of these microphones was to establish dominant trends in sound response with time relation to airblast and ground vibration arrivals. In short, they determine what causes sound in the house when compared to airblast and ground vibration arrival times on the same time domain.

Using the DaqViewer program, it is possible see the wave form for this signal. This is shown in the Figure 1.11.

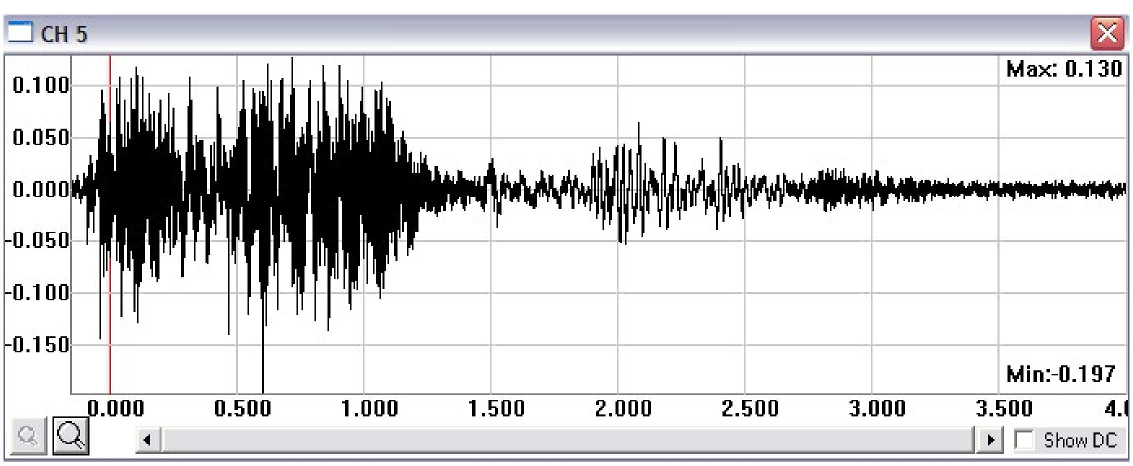


Figure 1.11 Typical waveform recorded with acoustic microphone.

1.3.2.3 Airblast Microphone

The airblast microphone was one of the most important devices in the system. With this device it was possible to measure the arrival of the airblast wave generated by the blast event experienced by the house. An airblast example can be seen in Figure 1.12.

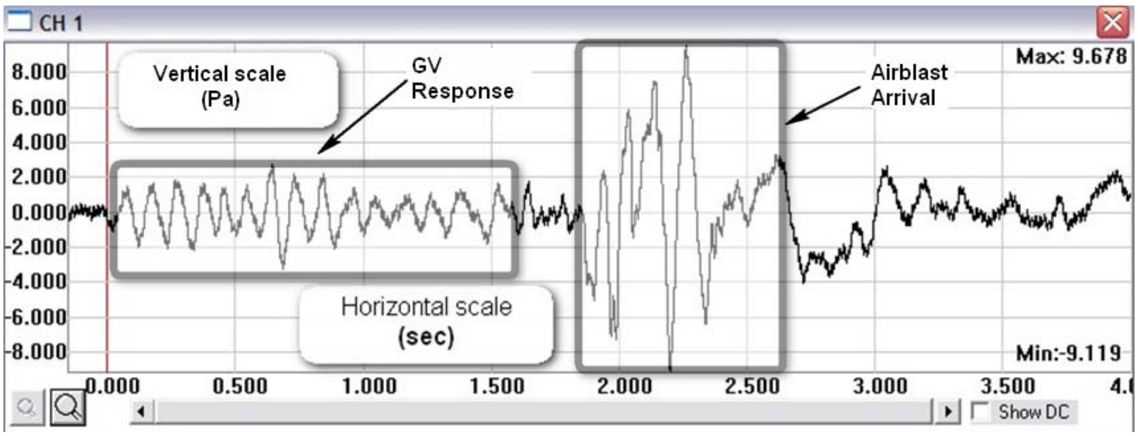


Figure 1.12 Airblast record.

The airblast microphone typically recorded structure response before the arrival of the airblast at approximately 2 seconds in this case. This is due to mounting the airblast microphone on the house. The ground vibration would generally cause response in the house and thus in the siding on which the airblast microphone was attached. Ideally, the airblast microphone would have been mounted away from the house; however, due to the long period of installation and power requirements, it was determined that the airblast microphone would continue to perform best mounted directly to the home and thus not exposing any of the power system to weather.

1.3.2.4 Geophones

Three geophones monitored each blast event. Each one had triaxial sensors that measured the longitudinal, transverse and vertical components of the ground vibration. Because the geophones were stationary and blast events varied nearly 360 degrees surrounding the house and geophones, the radial and transverse components of the triaxial geophones varied in orthogonal direction from the blast. Figure 1.13 shows the permanent orientation of each transverse and radial/long component of the geophones. Figure 1.13 also shows the orientation of the response channel inside the house, the uniaxial geophone was mounted such that it measured the movement of the wall into and away from the interior of the house. Due to the similar orientation to the response channel, the transverse component was analyzed first and foremost in the geophone data.

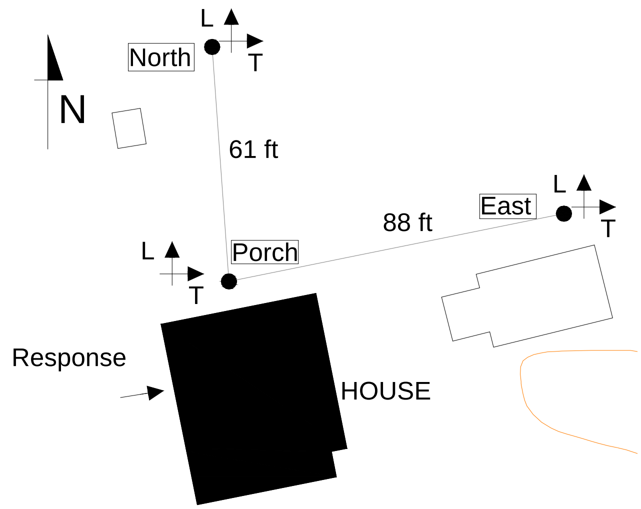


Figure 1.13 Orientation of Transverse and Longitudinal components of geophones with reference to response channel orientation.

In further discussions all vibration analysis were made using the Porch geophone. This is because it was the closest geophone to the house and is the best element to represent the energy arriving to the house in form of vibrations.

Figure 1.14 shows a typical record of the transverse component in each geophone.

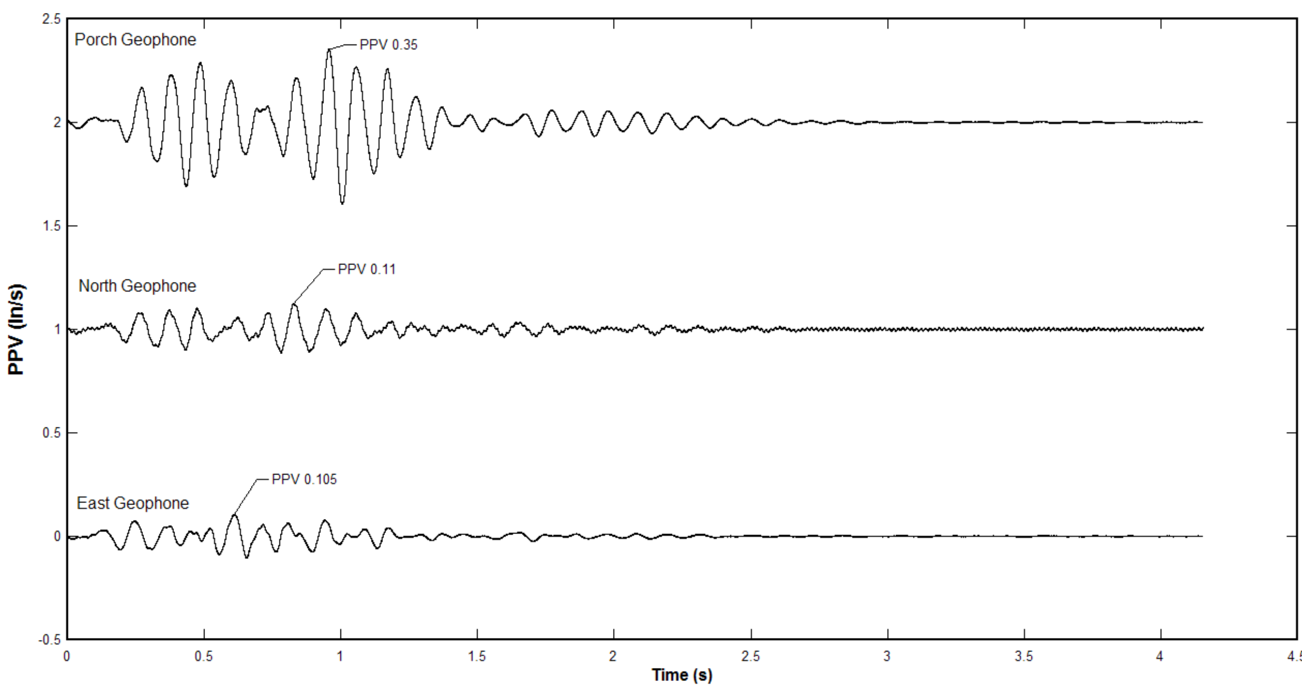


Figure 1.14 Record of Typical Transverse components.

1.3.3 Type of information concerning blasting patterns, location of blast event, quantity of explosives employed and rock removed.

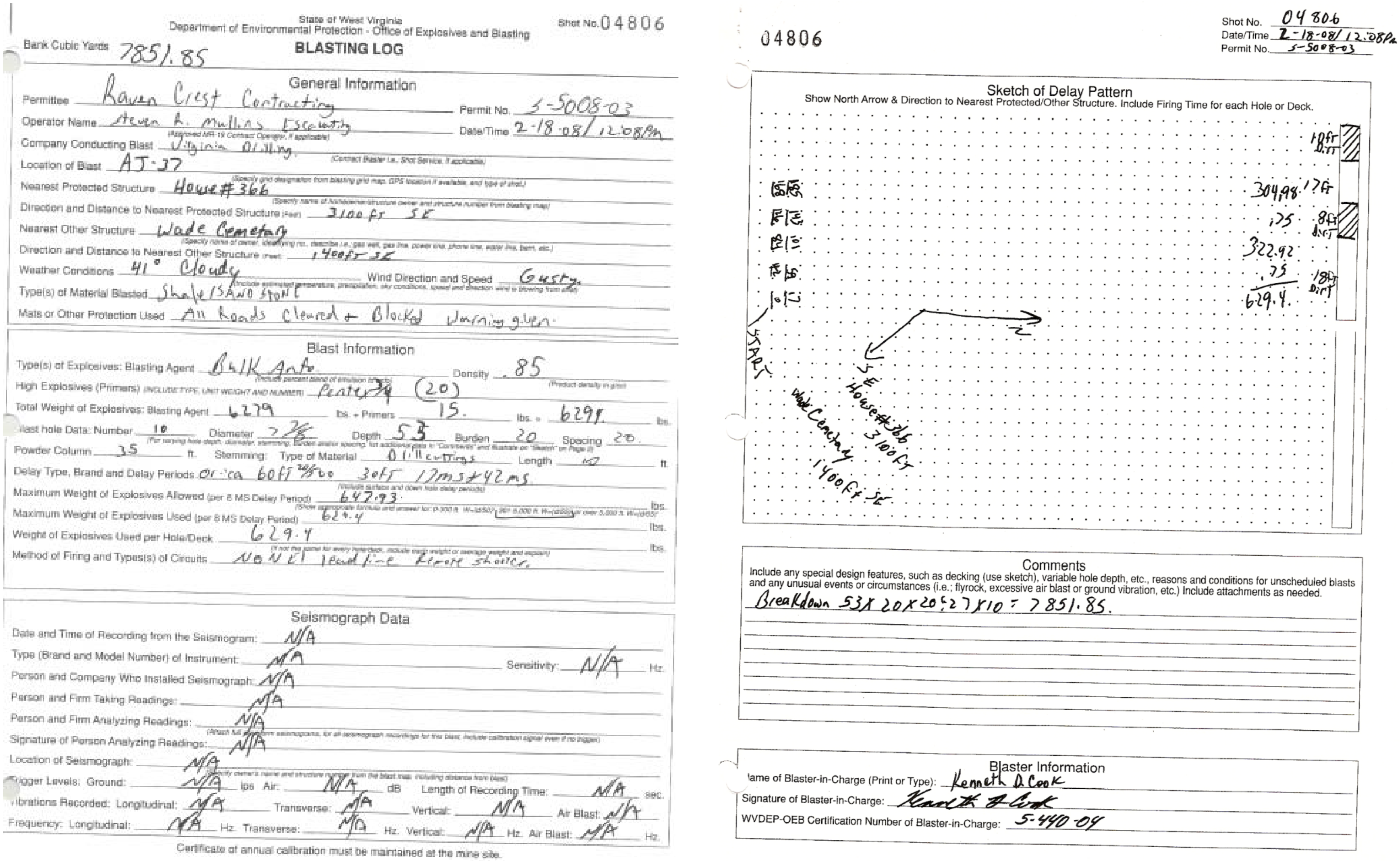
With the information of the blasting logs, it was possible to create the database in an Excel spreadsheet. This database can be found complete in Appendix A. The data transcribed from the official blast log includes:

- Number of Shot
- Date, Location, Approximate distance to the house.
- Total explosive (lb)
  - -Type of blasting agent
    - -Density (g/cc)
    - -Type of high explosive (Primers)
    - -Weight of blasting agent (lb)
    - -Weight of primers (lb)
- Number of Holes
    - -Diameter (inches)
    - -Depth (ft)
  - -Burden (ft)
  - -Spacing (ft)
  - -Powder Column (ft)
  - -Stemming (ft)

- Maximum values permitted of charge
  - -Maximum Weight of Explosive Allowed/Delay **MWEA (lb)**
  - -Maximum Weight of Explosive Used/Delay **MWEU (lb)**
  - -Weight of Explosive Used per Hole **WEUH (lb)**
  - -Weight of Explosive Used per Deck **WEUD (lb)**
- Bank Cubic Yards of rock blasted and Comments.

For this study date and time of blast events were correlated with structure response date and time. Blast locations were used to measure distances to the house. Also the WEUD coupled with the distance were used to calculate cubed root scaled distances to plot with airblast levels. The other information in the data base was not used at this time.

Figure 1.15 shows a typical blasting log.



State of West Virginia
Department of Environmental Protection - Office of Explosives and Blasting
Shot No. 04806

BLASTING LOG

Bank Cubic Yards 7851.85

General Information

Permittee Raven Crest Contracting
Permit No. S-5008-03
Operator Name Steven L. Mullins Excavating (Approved MR-19 Contract Operator, if applicable)
Date/Time 2-18-08/ 12:08PM
Company Conducting Blast Virginia Drilling (Contract Blaster i.e., Shot Service, if applicable)
Location of Blast AJ-37 (Specify grid designation from blasting grid map, GPS location if available, and type of shot.)
Nearest Protected Structure House #366 (Specify name of homeowner/structure owner and structure number from blasting map)
Direction and Distance to Nearest Protected Structure (Feet) 3100 ft SE
Nearest Other Structure Wade Cemetary (Specify name of owner, identifying no., describe i.e.; gas well, gas line, power line, phone line, water line, barn, etc.)
Direction and Distance to Nearest Other Structure (Feet) 1400ft SE
Weather Conditions 41° Cloudy (Include estimated temperature, precipitation, sky conditions, speed and direction wind is blowing from (mph))
Wind Direction and Speed Gusty
Type(s) of Material Blasted Shale/SAND STONE
Mats or Other Protection Used All Roads Cleared + Blocked Warning given

Blast Information

Type(s) of Explosives: Blasting Agent Bulk Anfo (Include percent blend of emulsion to anfo)
Density .85 (Product density in g/cc)
High Explosives (Primers) (INCLUDE TYPE, UNIT WEIGHT AND NUMBER) Pentex ¾ (20)
Total Weight of Explosives: Blasting Agent 6279 lbs. + Primers 15. lbs. = 6294 lbs.
Blast hole Data: Number 10 Diameter 7 7/8 Depth 53 Burden 20 Spacing 20 (For varying hole depth, diameter, stemming, burden and/or spacing, list additional data in "Comments" and illustrate on "Sketch" on Page 2)
Powder Column 35 ft. Stemming: Type of Material Drill cuttings Length 17 ft.
Delay Type, Brand and Delay Periods Orica 60ft 25/500 30ft 17ms+42ms (Include surface and down hole delay periods)
Maximum Weight of Explosives Allowed (per 8 MS Delay Period) 647.93 lbs. (Show appropriate formula and answer for: 0-300 ft. W=(d/50)², 301-5,000 ft. W=(d/55)², over 5,000 ft. W=(d/65)²)
Maximum Weight of Explosives Used (per 8 MS Delay Period) 629.4 lbs.
Weight of Explosives Used per Hole/Deck 629.4 lbs. (If not the same for every hole/deck, include each weight or average weight and explain)
Method of Firing and Types(s) of Circuits NONEl lead line Remote shooter

Seismograph Data

Date and Time of Recording from the Seismogram: N/A
Type (Brand and Model Number) of Instrument: N/A Sensitivity: N/A Hz.
Person and Company Who Installed Seismograph: N/A
Person and Firm Taking Readings: N/A
Person and Firm Analyzing Readings: N/A (Attach full waveform seismograms, for all seismograph recordings for this blast. Include calibration signal even if no trigger)
Signature of Person Analyzing Readings: N/A
Location of Seismograph: N/A (Specify owner's name and structure number from the blast map, including distance from blast)
Trigger Levels: Ground: N/A ips Air: N/A dB Length of Recording Time: N/A sec.
Vibrations Recorded: Longitudinal: N/A Transverse: N/A Vertical: N/A Air Blast: N/A
Frequency: Longitudinal: N/A Hz. Transverse: N/A Hz. Vertical: N/A Hz. Air Blast: N/A Hz.

Certificate of annual calibration must be maintained at the mine site.

04806

Shot No. 04806
Date/Time 2-18-08/ 12:08PM
Permit No. S-5008-03

Sketch of Delay Pattern

Show North Arrow & Direction to Nearest Protected/Other Structure. Include Firing Time for each Hole or Deck.

Comments

Include any special design features, such as decking (use sketch), variable hole depth, etc., reasons and conditions for unscheduled blasts and any unusual events or circumstances (i.e.; flyrock, excessive air blast or ground vibration, etc.) Include attachments as needed.

Breakdown 53X20X20÷27X10 = 7851.85.

Blaster Information

Name of Blaster-in-Charge (Print or Type): Kenneth D Cook
Signature of Blaster-in-Charge: Kenneth D Cook
WVDEP-OEB Certification Number of Blaster-in-Charge: S-440-04

Figure 1.15 Typical Blasting Log.

1.4 Development of a procedure and methodology to analyze the data

To process the signals, DaqViewer software was used for pre-visualization of the collected data. With this, it was possible to export the recorded files to ***txt*** format and use excel and Dplot software to graph and calculate the Fast Fourier Transform (FFT) for each signal. Figure 1.16 shows a flow chart of the process adopted to create the database.

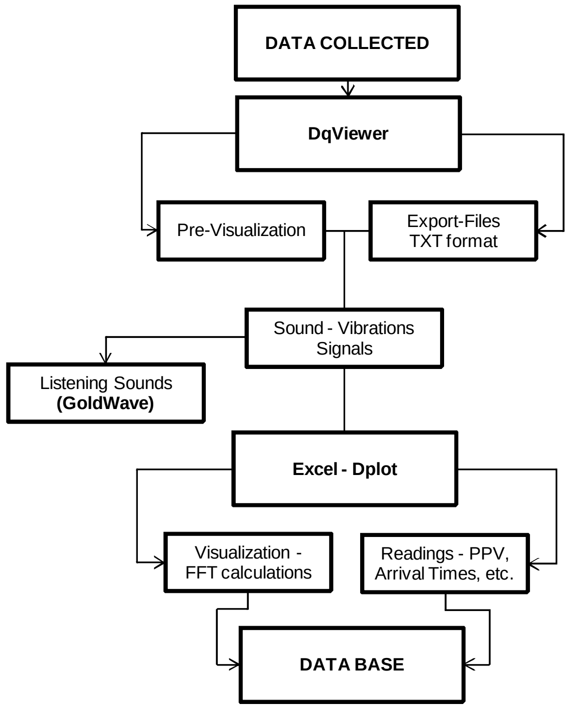


Figure 1.16 Flow chart for analyzing the data

To read both the PV values and the time, a Dplot function was used which gave the peaks of the signal. Figure 1.17 shows one of the readings for the response channel.

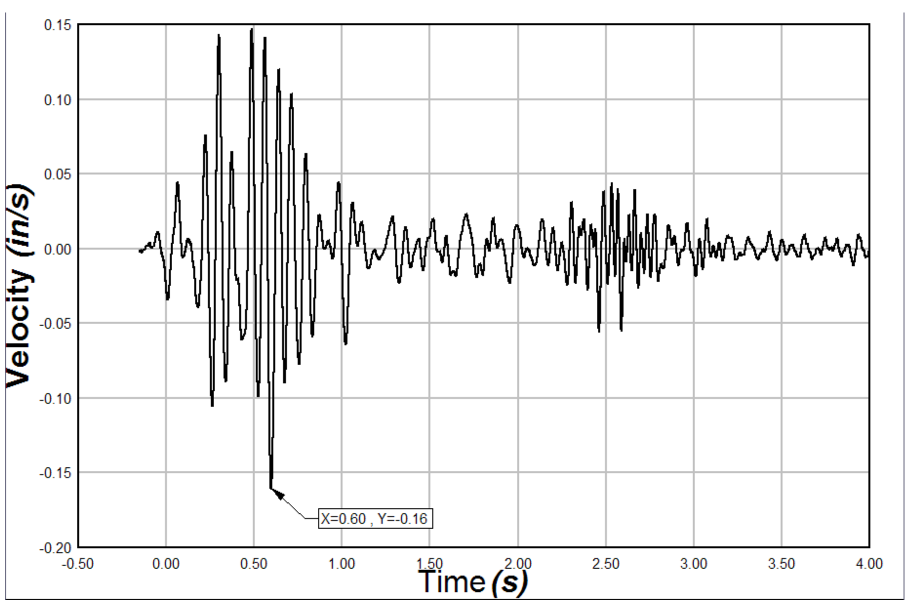


Figure 1.17 Typical record for response channel

From the signal in time domain (Figure 1.17), the Fast Fourier Transform (FFT) in frequency domain was calculated (Figure 1.18). Using the same function in Dplot, the dominant frequency of the signal was established. Figure 1.18 shows one of the frequency readings.

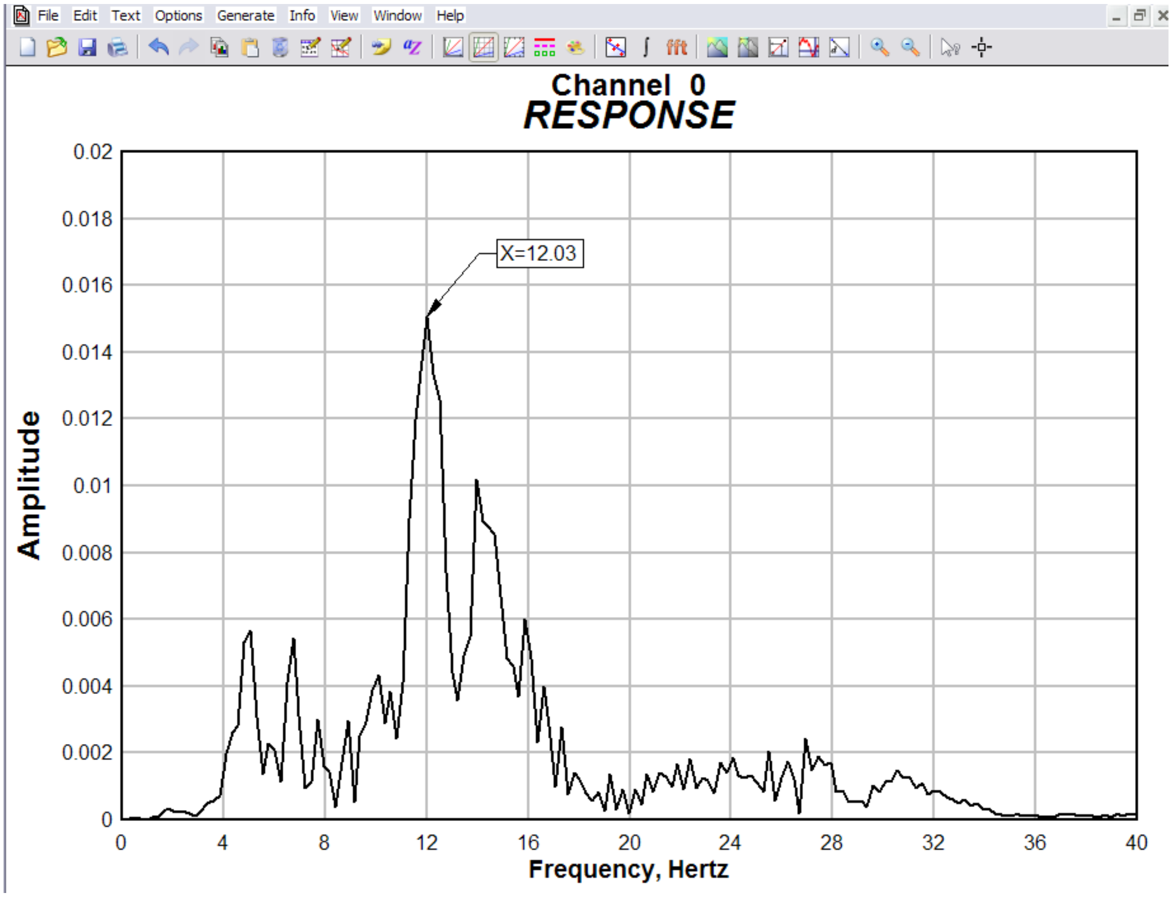


Figure 1.18 Typical record and its frequency domain.

This procedure was repeated for the 16 channels (16 signals) in each blast event. The database collected has 85 events. There were some electrical power problems in the area; such problems influenced the gathering of information between the months of March and May of 2008. However, a database of 85 records was enough to draw interesting conclusions about the objectives studied. Figure 1.19 includes a sample of 7 first records in the database. In figure 1.19 for a record there are two values, the upper value (green row -Frequency-) is related with the maximum frequency for the analyzed channel. On the other hand, the lower row (white row -Value-) relates the maximum peak in the signal. Appendix B contains the entire database of 85 records.

		CHANNEL NUMBER [Read Values]														
		0	1	2	3	4	5	7	8	9	10	11	12	13	14	15
Shot No.		Trigger (in/s)	AOP (Pa) (dB)	Mic 1 (Volt)	Mic 2 (Volt)	Mic 3 (Volt)	Mic 4 (Volt)	L1 (in/s)	T1 (in/s)	V1 (in/s)	L2 (in/s)	T2 (in/s)	V2 (in/s)	L3 (in/s)	T3 (in/s)	V3 (in/s)
4590	Frequency	12.85	12.27	37.79	121.59	13.84	12.15	11.64	8.91	13.12	11.59	13.38	13.53	13.32	13.03	13.31
	Value	-0.40	115.76	-0.48	-1.35	0.34	-0.15	-0.32	-0.31	0.10	-0.15	-0.17	0.06	-0.21	0.23	-0.05
4591	Frequency	11.90	15.70	38.47	122.72	58.76	11.84	11.64	10.13	13.13	12.12	12.99	12.33	13.06	13.08	8.68
	Value	0.21	117.90	-0.16	0.61	0.18	0.09	-0.22	-0.14	0.05	0.09	0.10	-0.03	-0.11	0.11	-0.02
4592	Frequency	15.55	71.79	39.59	55.12	60.96	39.54	9.65	9.64	9.72	9.40	10.39	2.67	10.13	4.60	2.67
	Value	-0.20	131.10	-1.39	1.10	1.79	0.48	-0.07	0.05	-0.02	-0.03	-0.03	0.02	-0.03	0.03	0.01
4593	Frequency	13.11	21.95	38.16	58.64	58.58	11.80	11.12	10.67	13.11	10.67	10.13	6.03	10.42	11.16	6.07
	Value	-0.19	120.81	0.17	-0.21	-0.16	0.06	-0.06	0.04	0.02	0.04	0.04	-0.01	-0.02	-0.02	-0.01
4594	Frequency	15.56	24.13	34.39	48.92	30.66	28.44	9.23	9.43	3.90	10.17	10.20	3.86	5.29	3.14	3.89
	Value	-0.12	121.63	-0.28	0.22	0.48	-0.18	-0.04	-0.06	0.02	-0.02	0.04	-0.01	-0.02	0.02	-0.01
4596	Frequency	13.61	18.77	37.46	122.40	20.02	26.99	6.81	6.55	13.35	6.79	13.55	13.31	6.74	13.61	6.75
	Value	-0.14	119.45	0.17	-0.26	-0.13	-0.11	0.10	-0.08	-0.04	-0.05	-0.07	0.03	-0.06	-0.08	0.02
4597	Frequency	13.12	54.24	36.33	35.23	43.99	45.90	8.90	9.23	10.13	10.22	9.97	9.95	5.10	15.75	4.58
	Value	-0.13	128.67	-0.65	0.19	0.45	-0.15	0.09	0.05	-0.02	0.05	0.03	-0.02	0.03	0.04	-0.02

Figure 1.19 First seven samples of the database

1.5 Analysis Of Vibration And Acoustic Data

1.5.1 Amplitudes Vibration and Airblast Analysis

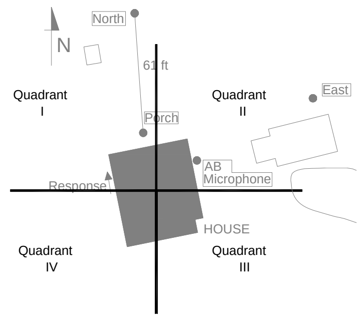
It is possible to construct different attenuation curves in order to estimate the peak particle velocity as a function of scaled distance with the type of information collected. In practice many blasters will use a simple equation to predict PPV prior to firing the first blast. This approximation can be found using equation 1.2. The method is somewhat effective for predicting PPV without a database of information to create an attenuation curve that would be more precise and tailored to the site conditions. For this reason, the 160 in Equation 1.2 can be variable and is often referred to as the ground response factor (Blaster's Handbook, 17th Edition, pg 603.). The ground response factor of 160 is considered an average value for typical data. A value of 242 is considered an upper bound for normal blasting conditions. Without a large database of samples on a particular site, equation 1.2 must be used as a predictive tool for PPV prior to blasting activity.

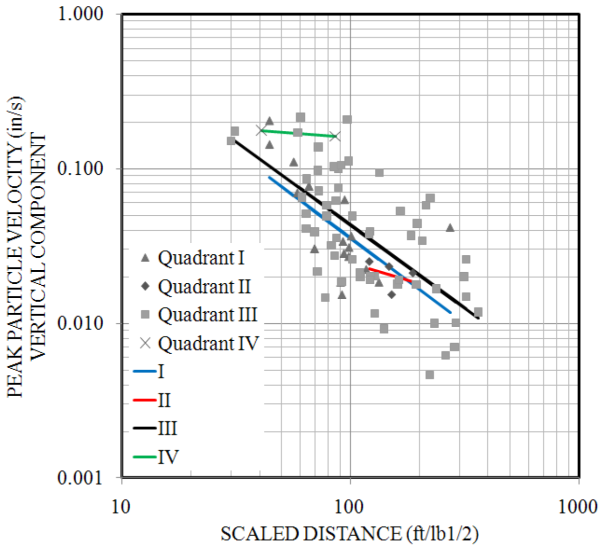
$$PPV = 160 * \left(\frac{D}{W^{0.5}}\right)^{1.6}$$

Equation 1.2

For the data collected for this report, the possibility of correlations using the cube and the square root relationship was studied. In this case it was determined that the most appropriate relationship was the square root because higher correlation coefficients were obtained for square relationships. The correlation factors obtained when the decay slope was solved were low (the range was between 0.43 and 0.46), suggesting that a larger range of scaled distance would be needed to perform a proper regression. Other important factor affecting the regressions coefficients is related with the accuracy in the measurement of the distances between the house and the blast event site. In a few records the distance between the house and the blast site was obtained using GPS but in the majority of events it was calculated using the approximate location recorded in the blasting logs. Variability in the direction to the blasts and the geological and topographic effects definitely affect the data set. Other factors are related with the varying direction to the blast and stationary geophones creating a condition which resulted in lower correlation coefficients. This was to be expected; however, quantifying this relationship has merit because most blasting operations must consider attenuations in all directions and not a single direction. This conventional vibration analysis is not relevant to the study and only the results for the Porch geophone is presented next.

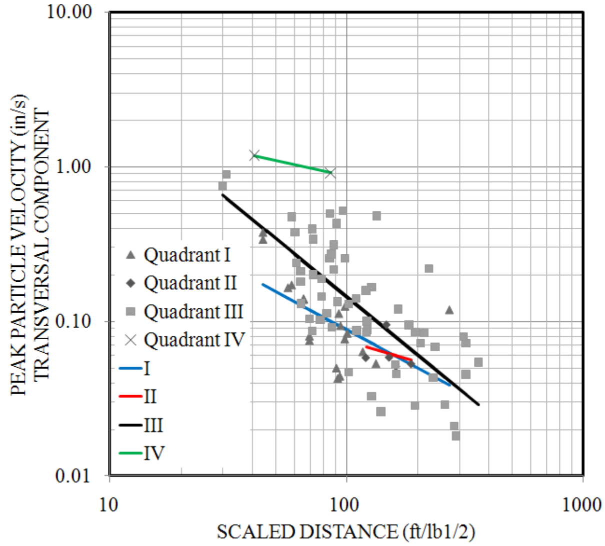
Figure 1.20 shows attenuation correlations for each axis of the porch geophone, the overall PPV for the porch geophone, and color coded attenuation curves related to the azimuth direction of the blast with respect to the house. Figure 1.20 separates the vibration data for PPV of the porch geophone into quadrants surrounding the house. Quadrants I to IV were chosen to study the azimuth incidence in the PPV. The figure shows that there are directional to the blast effects the attenuations. This is an expected result due to the range of topography and geology in the nearby area.





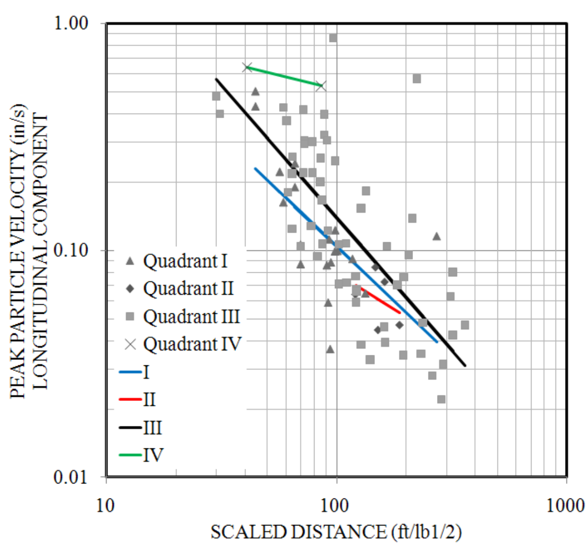
$$V_V = 6.20\left(\frac{D}{W^{0.5}}\right)^{-1.08}$$

(a) Vertical component



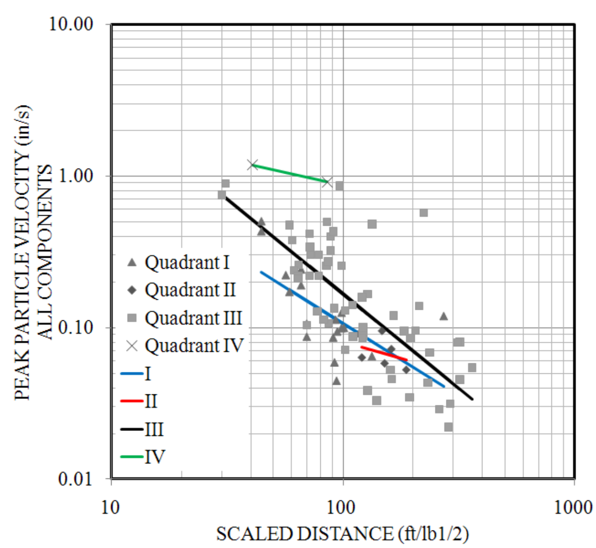
$$V_T = 26.69\left(\frac{D}{W^{0.5}}\right)^{-1.18}$$

(b) Transverse component



$$V_L = 23.07\left(\frac{D}{W^{0.5}}\right)^{-1.12}$$

(c) Longitudinal component



$$PPV = 34.54\left(\frac{D}{W^{0.5}}\right)^{-1.18}$$

(d) Group PPV

Figure 1.20 Peak Particle Velocity vs. Scaled Distance

The equations reported match with the regression correlation including all data. As was named; there is incidence in the attenuation curves according to the location of the blast.

Figure 1.21 separates the PPV data into both distance ranges and azimuth directions.

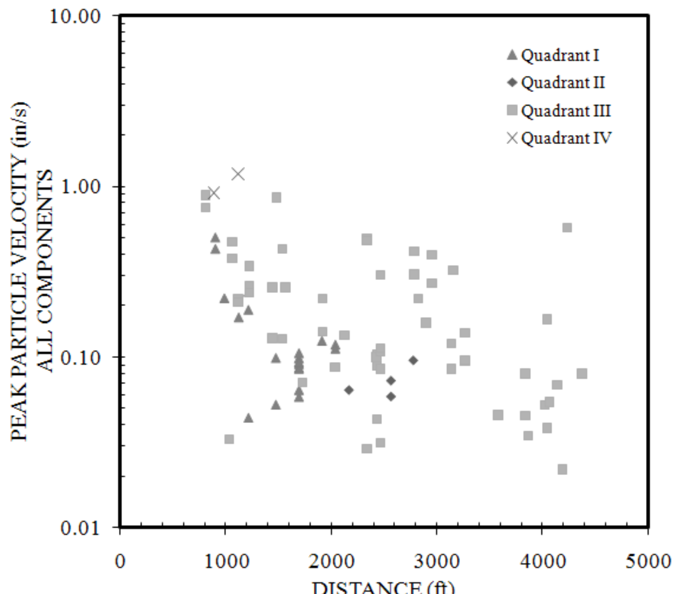


Figure 1.21 PPV separated by distance and azimuth direction

A comparison with the typical limits from downhole blasting, (Oriard, 1970, 1991) is included in Figure 1.22. The graph demonstrates that the values are in the range for down-hole bench blasting. The upper and lower limits were published by Oriard based on typical data collected from bench blasts.

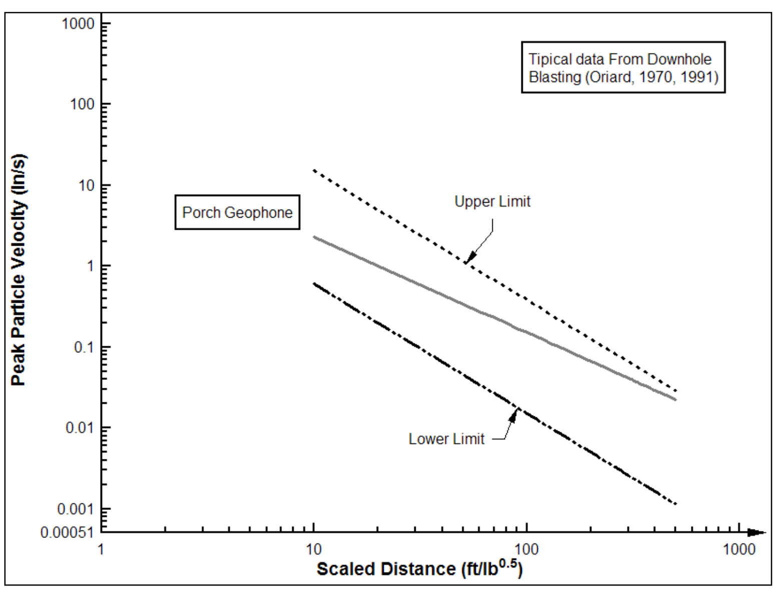


Figure 1.22 PPV and typical range.

As expected, the ground response factor values in the regression equations for vibrations in the horizontal plane (longitudinal and transverse components) are similar, while the vertical plane is almost quartered with respect to horizontal values. The regression was made also using the peak values in each event (Figure 1.21 (d)). Because peak values were used the ground response factor calculated was approximately 34.5; which is between the limits in Figure 1.22.

The data were compared to the OSM blasting level chart, using the peak values (PPV) and the frequency contents (FFT) from the porch geophone. The results are included in Figure 1.23. The samples with PPV exceeding the OSM limit prove that the database produced sounds expected from blasts within the limits. The wide range of PPV means that the database is filled with quality data.

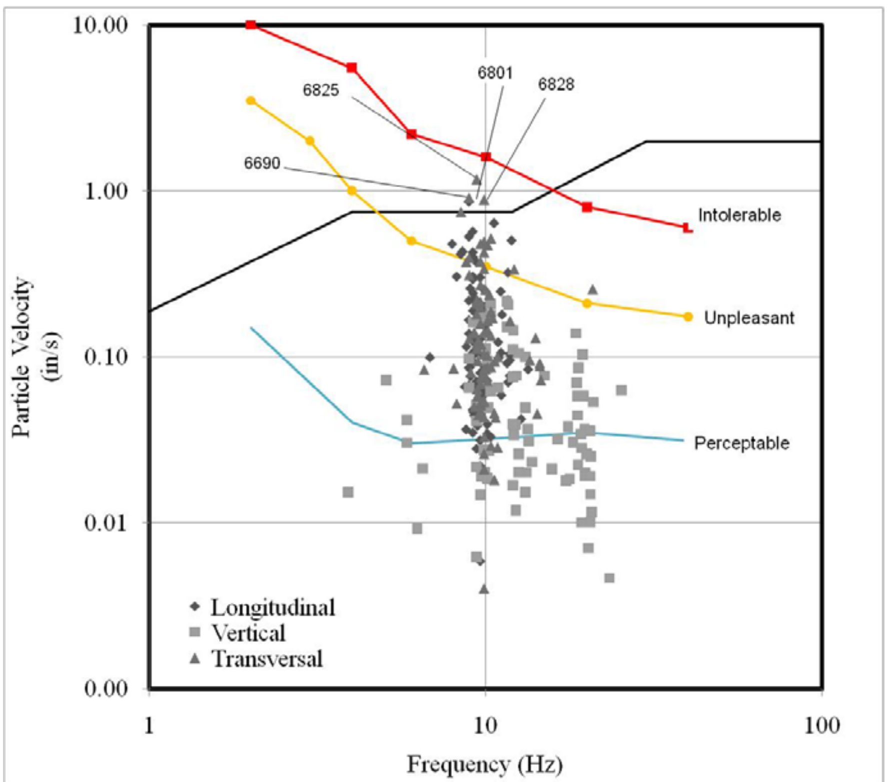


Figure 1.23 OSM regulation chart, Porch geophone.

Also the airblast over pressure peak was plotted in the OSM regulation sound level to see if the over passing vibrations events match with the over passing airblast events. The airblast results are included in the Figure 1.24.

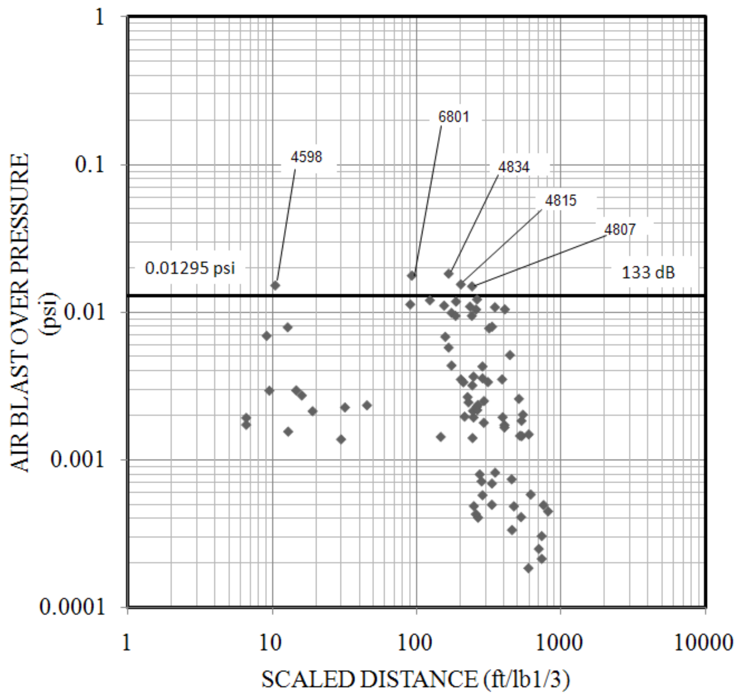


Figure 1.24 OSM regulation Airblast levels

Figure 1.23 also shows the contours for subjective response of human body to vibratory motion. These levels were extracted from the Army Corps of Engineers Manual EM 1110-2-3800. Eighteen (18) records in the horizontal plane (nine longitudinal and nine transversal) classify between unpleasant and intolerable vibrations for the human body none of the records was beyond intolerable levels. It is also notable that all the particle velocity records in the vertical component are below the unpleasant level, this is in agreement with the higher particle velocities in the horizontal plane. The combination of these contours and the collected data begin to show that vibration levels could be unpleasant while not exceeding regulatory limits. Understanding this type of information and analyzing survey data also collected in this project allows for improvements in relationships with neighbors of surface coal mines.

As Figures 1.23 and 1.24 shows, only one event (6801) exceeds both regulations. Since this is not a damage study the analysis of these events are not relevant for this report. Furthermore, the house was owned by the mining company and thus was allowed a ground vibration and airblast waiver. The values shown in figures 1.23 and 1.24 do show that the recording system was subjected to blast events that covered a wide range of ground vibration and airblast levels, confirming that the data collected is useful for determining sound levels that could be generated from typical surface coal mine blasting within the regulatory limits because it is often assumed that higher ground vibration and airblast levels correlate to higher noise.

1.5.2 Frequency Analysis

Using conventional math software (Dplot), the frequency spectrum for each digital signal; structure response, ground vibrations, airblast and acoustic sounds, were obtained. The results are presented in the next section.

1.5.2.1 Response Channel

In the case of the sensor attached to the wall of the house, the frequency found can be used as the reference for the response of the house, meaning that the frequency calculated in the response channel should be similar to the house's mid-wall natural frequency. Figure 1.25 shows that in this specific situation, the frequency of the house is between ranges of 6.30 and 22.4 Hz with an average of 12 Hz. This range and average value based in Bureau of Mines for Surface Mining RI 8507 (11Hz-24Hz) is typical for midwalls.

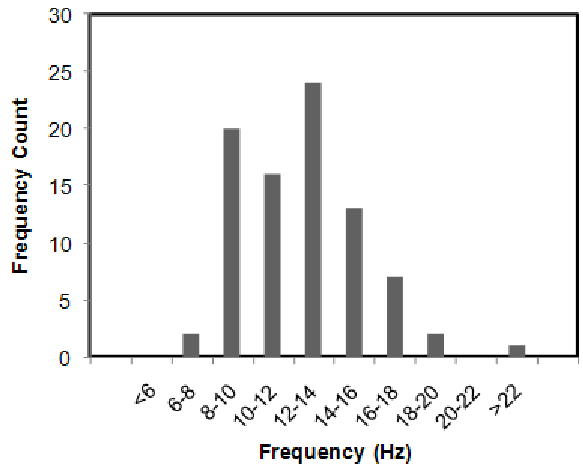


Figure 1.25 Predominant Frequency content response channel (house)

This result was expected because the values are in the range of response frequencies for this kind of structure, one story floor, wood framed, etc.

All structures have a natural frequency at which excitation is amplified. The natural frequency of the whole structure can be simplistically estimated by using equation 1.3 from classical earthquake engineering (Newmark and Hall, 1982).

$$F = \frac{1}{0.1\, N}$$

Equation 1.3

Where:
N = Number of stories of the structure
F = Frequency (Hz)

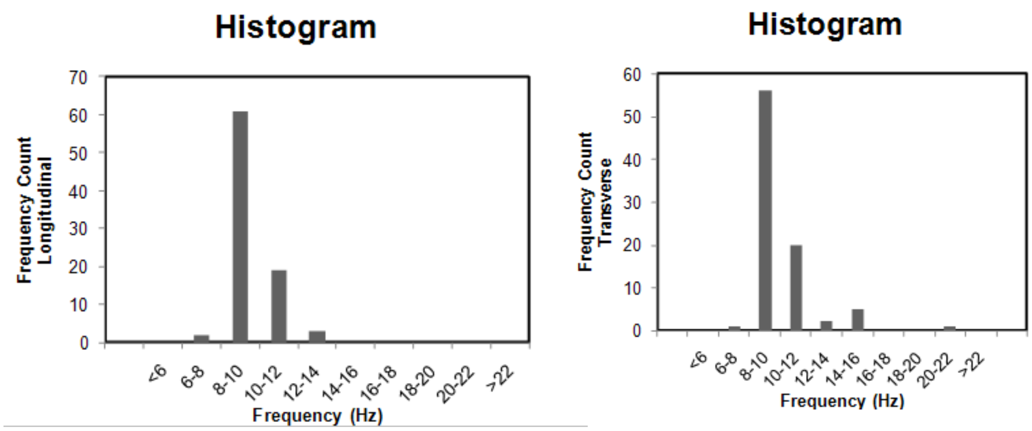
Utilizing equation 1.3, most residential structures with 1 or 2 stories would have a predominant natural frequency between 5 and 10 Hz. The natural frequency of the structure will determine the response to ground vibration meaning that ground vibrations and airblast producing frequencies near the natural frequency will create more response in the structure. This is why frequencies in the range of 5 to 10 Hz are particularly problematic. Higher frequencies tend to produce less response in residential structures.

1.5.2.2 Geophone Channels

Initially, the frequencies for the three components of ground vibrations were pooled in only one graph. During this process, the records of vibrations located in the horizontal plane (longitudinal and transverse directions) showed similar values while vertical direction produced somewhat different results. Due to this, the three components for the porch geophone are shown separately in figures 1.26 and 1.27.

For the horizontal components the spread of the information presented frequencies between 6 and 16 Hz (Figure 1.26). The vertical component (Figure 1.27) shows a greater spread compared with the horizontal (the values for vertical frequencies were between 3 and 30 Hz).

Figure 1.28 shows a comparative histogram between the values reported in this study for the longitudinal signal in the Porch geophone and typical values reported from a coal mine (Siskind, et al., 1980, p.6).



a) Longitudinal b) Transverse

Figure 1.26 Predominant Frequency content for Longitudinal and Transverse Ground Vibration

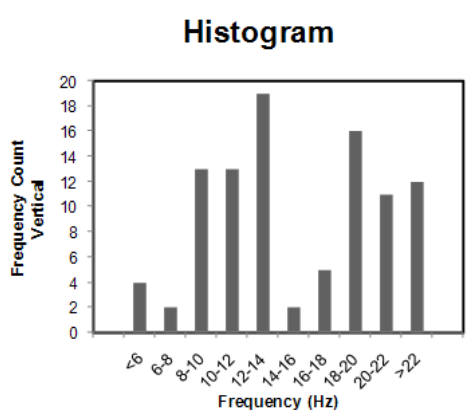


Figure 1.27 Predominant Frequency content for vertical Ground Vibration.

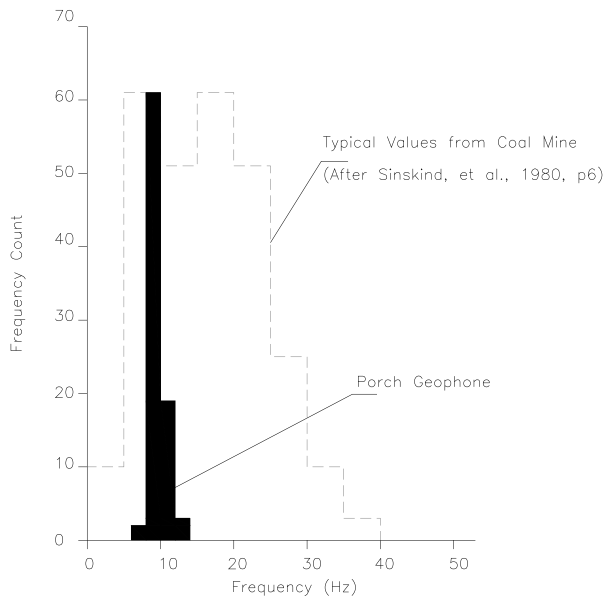


Figure 1.28 Comparative Histogram Frequency content.

1.5.2.3 Acoustic Sound

In order to see the behavior of the sound inside the house, the histogram for microphone three (Channel four) was created, see Figure 1.29. The average value is 29.1 Hz and the dominant frequency is in the range of 30 to 35 Hz.

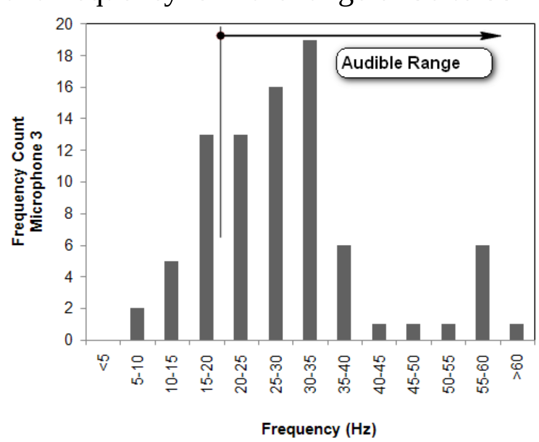
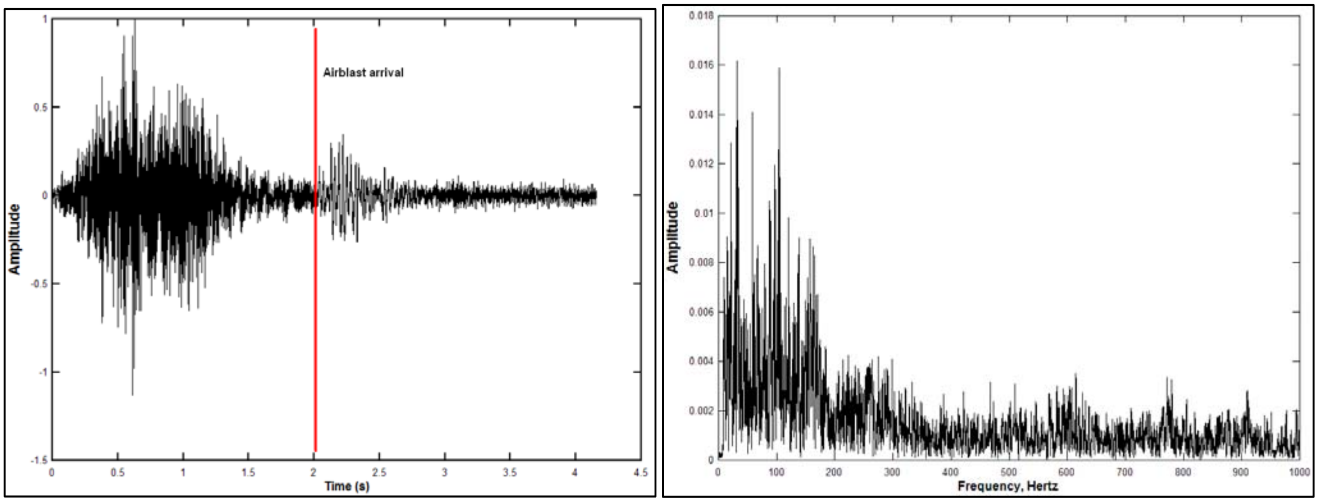


Figure 1.29 Predominant Frequency content for Sounds (Microphone 3)

As presented at the beginning of this document, the audible range for humans are greater than 20 Hz. Lower frequencies are not perceptible. Also, a large amount of energy content is not captured in human hearing at lower frequency ranges below 200 Hz. Humans cannot hear the full range of sound energy until frequencies reach nearly 1000 Hz (ANSI SI.4, 1971).

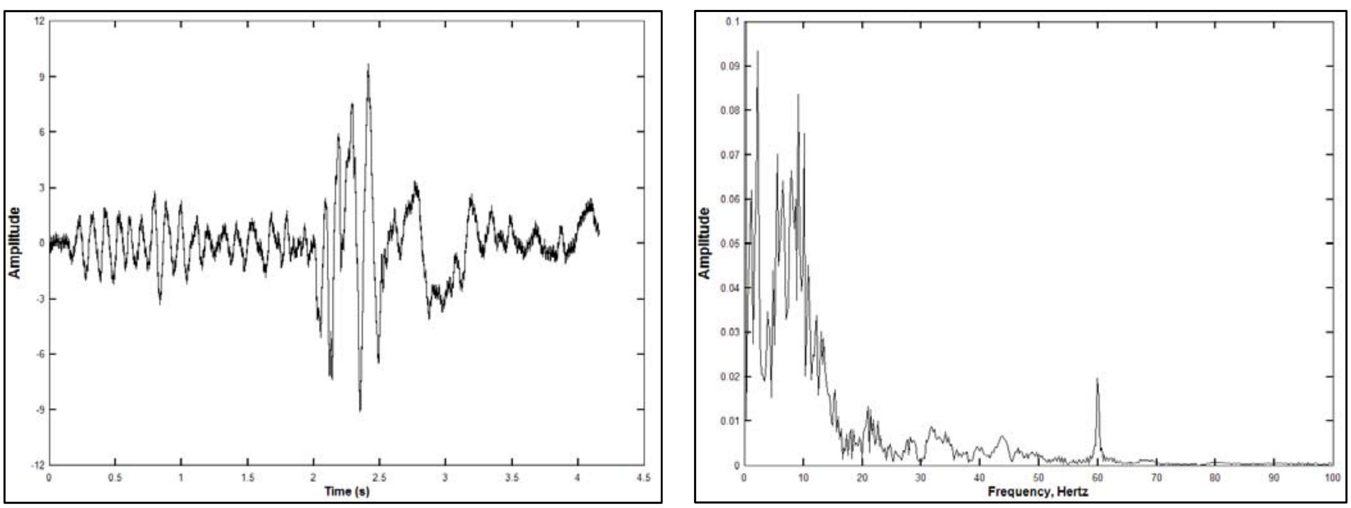
Figure 1.30 (a) shows a typical waveform from microphone 3 (Channel 4 – Kitchen) and the corresponding frequency content FFT Figure 1.30 (b). It is noteworthy that there is energy content in the higher frequency ranges. This suggests that the noises produced in the house are not the actual airblast, but the response of the structure and objects within the structure.



(a) Sound wave form (b) Sound FFT

Figure 1.30 Sound wave form and corresponding FFT

On the other hand Figure 1.31 is a typical waveform from the airblast trace and its corresponding frequency content FFT.

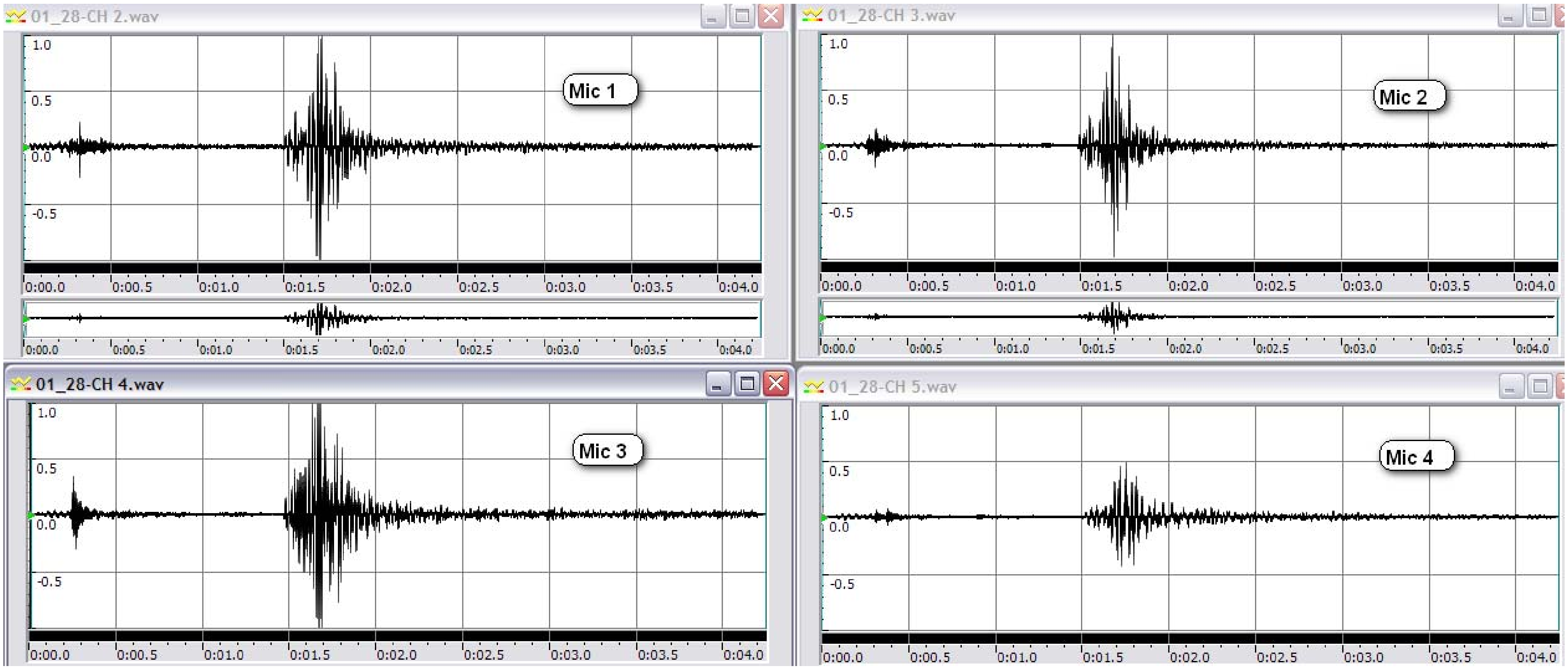


(a) Airblast wave form (b) Airblast FFT

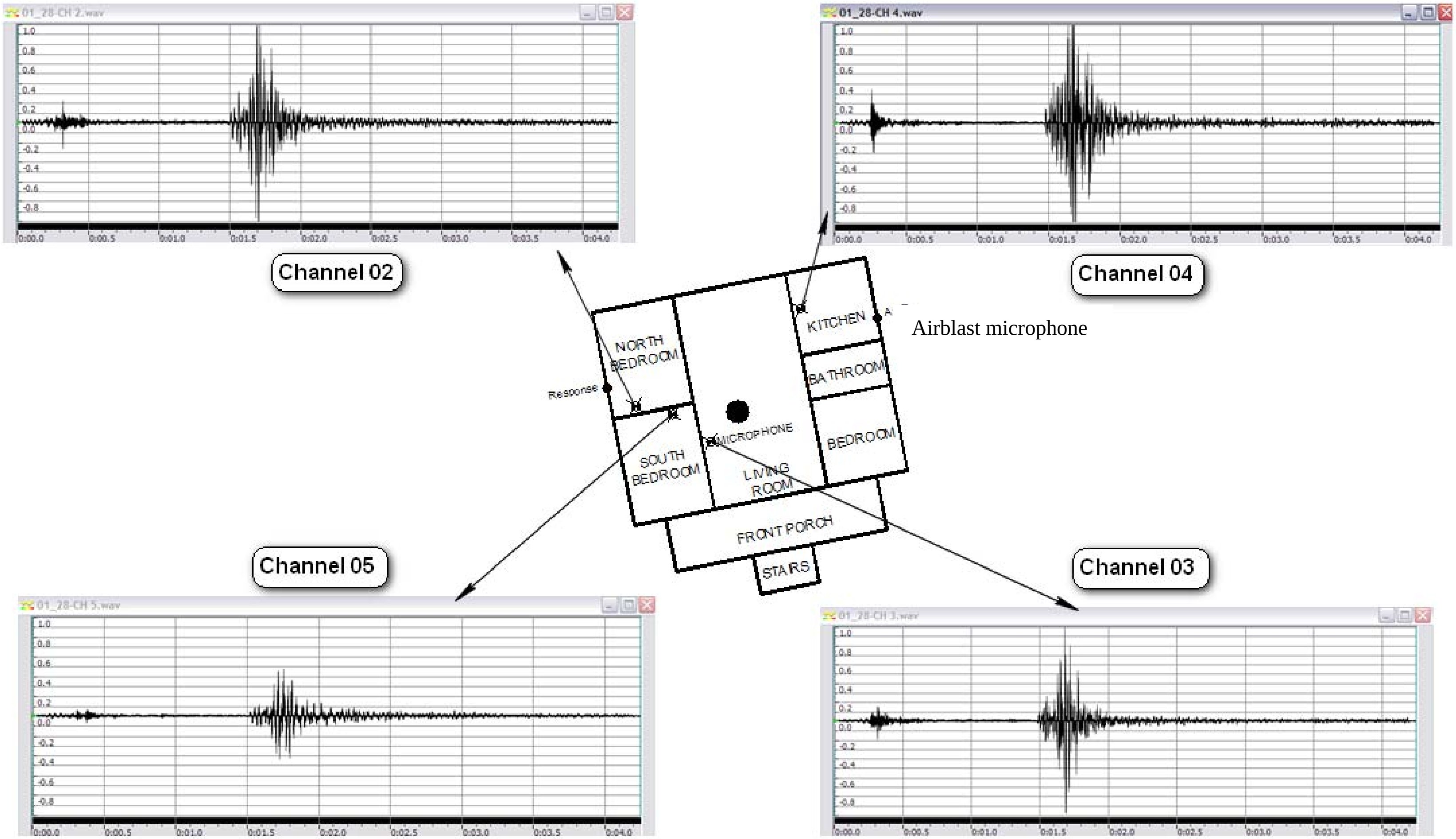
Figure 1.31 Airblast wave form and corresponding FFT

The comparison shows that the airblast trace does not have energy content in the higher frequency ranges; the energy content of the signal beyond 20 Hz is very low against energy content lower than 20 Hz (Figure 1.31b). On the other hand in the FFT of the audible sound wave shown in Figure 1.30b the major energy content of the signal is in the range from 0 up to 400 Hz. This behavior suggests that the audible sound has frequency contents independent of the excitation source (airblast or ground vibration).

This suggests that residents would have difficulty determining whether the sounds in the house were produced from airblast or from ground vibration. In order to do these analysis, the microphone 3 (Channel 4 - kitchen) was chosen because it is the microphone that presents higher amplitudes comparatively with others microphones in others locations Figure 1.32 (**a)** and (**b)**.



(a) Microphone amplitude comparison



(b) Typical sound recorded and his locations

Figure 1.32 Sound Microphones, (a) Amplitude comparison. (b) Location

1.5.2.4 Airblast

The histogram for the Airblast microphone is included in the Figure 1.33.

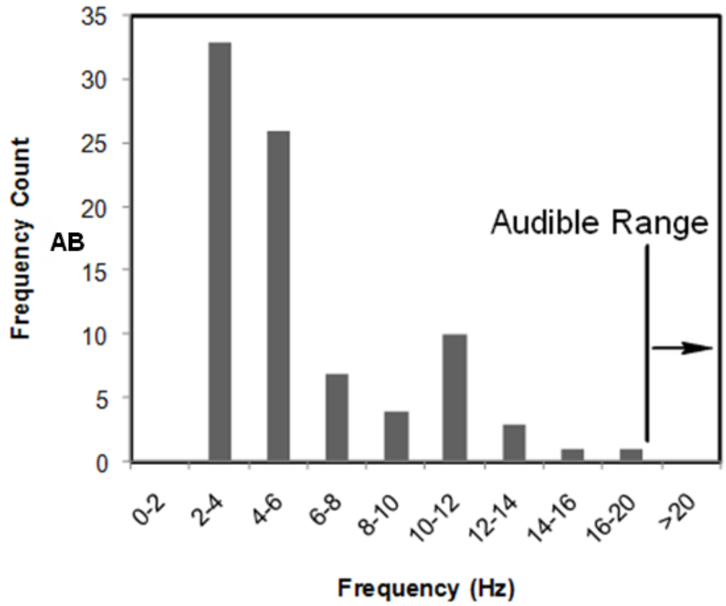


Figure 1.33 Predominant Frequency content for Airblast signal.

As we can see, all the collected information in this channel has frequency content below 20 Hz. That means that all the airblast signals were in the inaudible interval.

The major statistical parameters for frequency content information are showed in Table 1.2. As expected, the frequency content of the sound microphone is significantly higher than the ground vibration frequencies.

Table 1.2 Statistical parameters frequency content

Channel	Frequency Average (Hz)	Standard Deviation	
Response	12.59	2.9	**House**
Airblast	3.8	3.5	
Sound Mic 3	29.1	12.2	
Longitudinal	9.7	1.1	**Ground Porch Geophone**
Transversal	10.2	1.8	
Vertical	14.3	5.8	

1.5.3 Arrival Times and wave form analysis

When all the signals are plotted in the time domain, in some cases it is possible see the delay between the time of Acoustic Sound and Airblast waves. For the specific case shown in Figure 1.34, it is apparent that the sound recorded inside the home is related directly with response signal and the ground vibration more than the Airblast wave. Many blasting complaints are automatically accredited to airblast (Lusk, 2004). While this may be true in some cases, it is unreasonable to assume that airblast is the dominant factor with noise within a house subjected to blast vibrations.

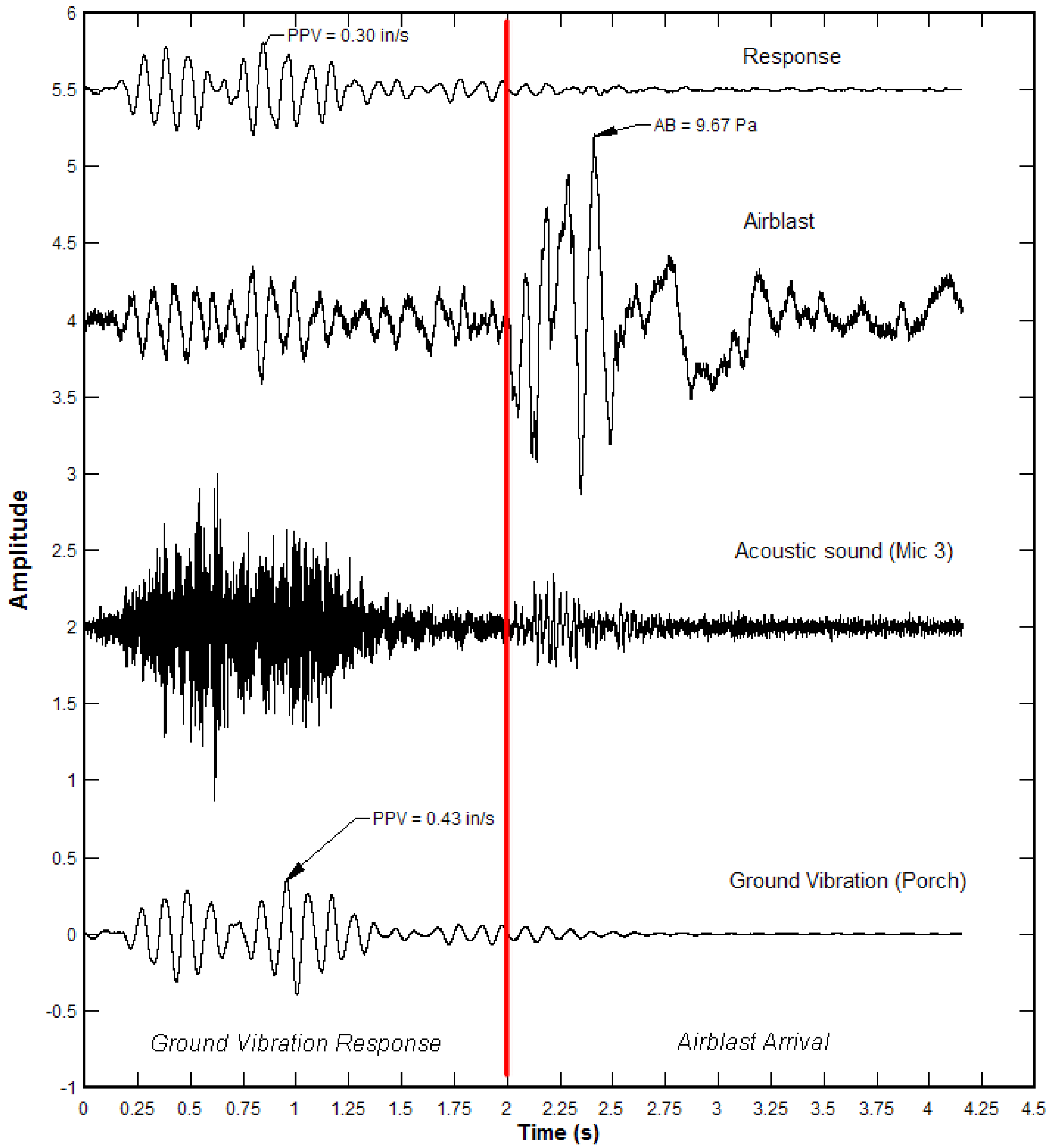


Figure 1.34 Time domain signals greater distances.

Visual inspection of the time of arrival plots for several blast events prompted an investigation into how distance affected the sounds within the monitored house. Several blast events did seem to create sound or noise within the house by way of airblast; however, several cases showed that ground vibration was the dominant factor in creating sound. Trends became evident that blasts at greater distances created sound that was generated by ground vibration more than airblast, as shown in Figure 1.34.

With the unique characteristic of the monitoring system used in this project, time of arrival can be used to determine the source of sound in the home in relation to ground vibration and or airblast. The monitoring system records all channels on the same time domain so that they can be compared directly for the same event. In the following analysis, the response channel was used as a proxy for sound due to the proportional nature of their relationship.

In order to quantify the relationship between the sources of acoustic sound (maximum response) inside the home and distance to the blast, a new factor (Airblast Response Factor) was established (ABRF). This is defined as the ratio between the Time of Peak for Response ($t_{Response}$) / Time of Peak for the Airblast (t_{PAB}) see Figure 1.35. The figure shows that the response cannot be generated by airblast because the response occurs prior to the arrival of airblast. The ratio helps to quantify this relationship.

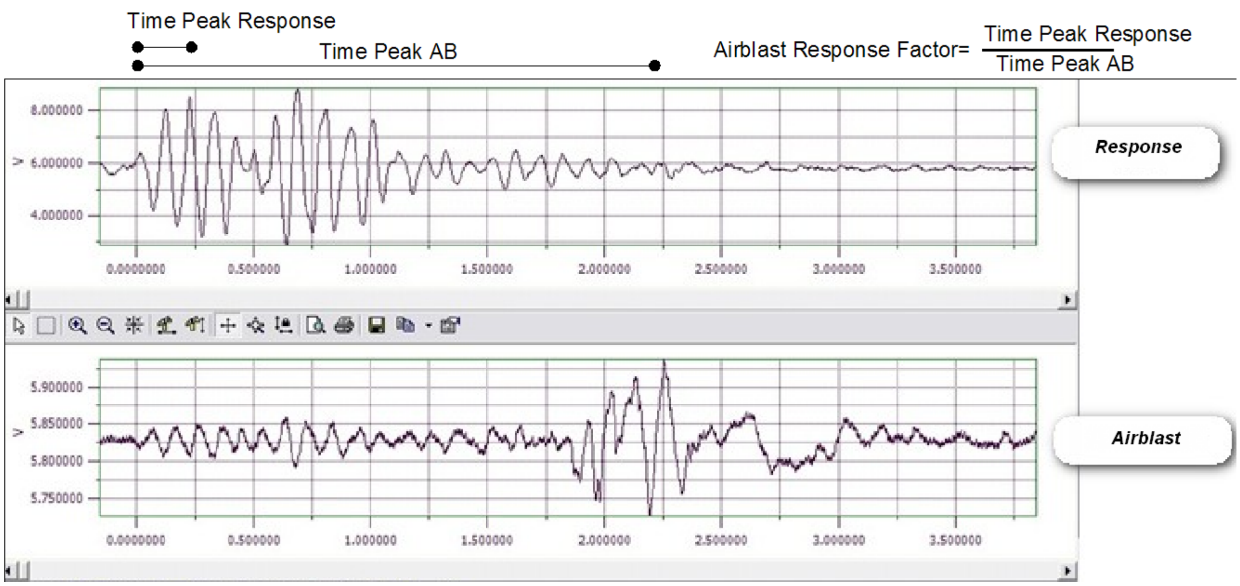


Figure 1.35 Wave arrival time relationship definitions

As evident in the graph, with this ratio, if the value is one or close to one, the peak of both waves occurs at similar times means that airblast induces the acoustic sound inside the house. Conversely, values less or much less that one indicate that the acoustic sound is related to ground vibration. This ratio was plotted against the distance from source to the house and is shown in Figure 1.36. This graph is based on distances reported on mine records so the relationship may not be totally accurate but it is a good trend between the time relationship and the distance source-monitored point. Some blasts reported GPS location, but the majority were listed as grid numbers which were likely not as accurate.

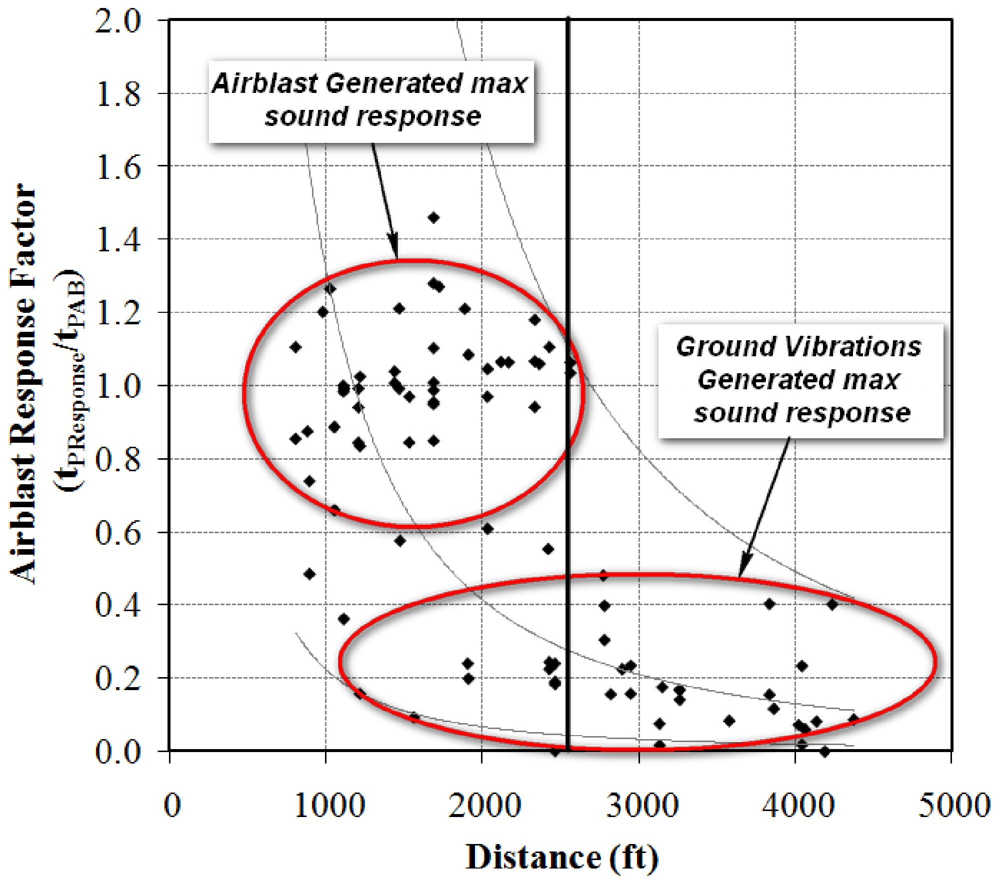


Figure 1.36 Airblast Response Factor (ABRF) vs Distance

Figure 1.36 shows that after a distance of approximately 2500-3000 ft, the influence of the acoustic sound is principally related with ground vibration. It is noteworthy that even at closer ranges, some of the peak acoustic sounds were caused by ground vibration as opposed to airblast; however, ground vibration induces the peak sound in all cases beyond 2500 ft. This behavior is also visible from the histogram in Figure 1.37.

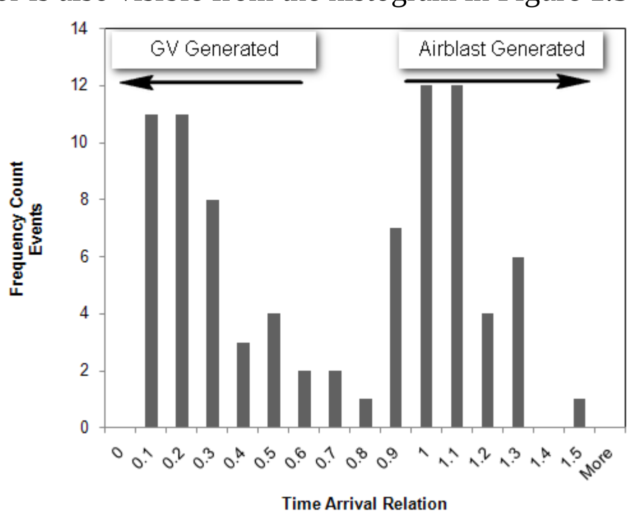


Figure 1.37 Wave arrival time relationship Histogram

This phenomenon lends some insight into blast complaint issues. In many cases, blast complaints will come from locations well beyond residents that are much closer to the mining activity. Perhaps the distance allows for a more unexpected response (perception of the resident) since airblast is generally negligible at such distances. This could be attributed to the square law decay for ground vibration in rock and a cube law decay for airblast as well. There must be a crossover at some point, since the waves would be decaying at different rates. This value is almost certainly site specific.

On the other hand, acoustic sound signal has a general envelop shape similar to the response signal. This suggests that sound response is proportional to the mid-wall response of the house. Figure 1.38 shows how this similarity is presented in the events that are close to the house.

Similar behavior is observed in the events that are more than 2500 ft from the house, Figure 1.39 shows the agreement between the wave form of both signals (Sound - Mid wall response).

To compare the wave form for a far and near event signals 07/24 (6704) and 03/11 (5401) were chosen. Figure 1.40 shows the response, airblast, acoustic sound and longitudinal vibration wave forms.

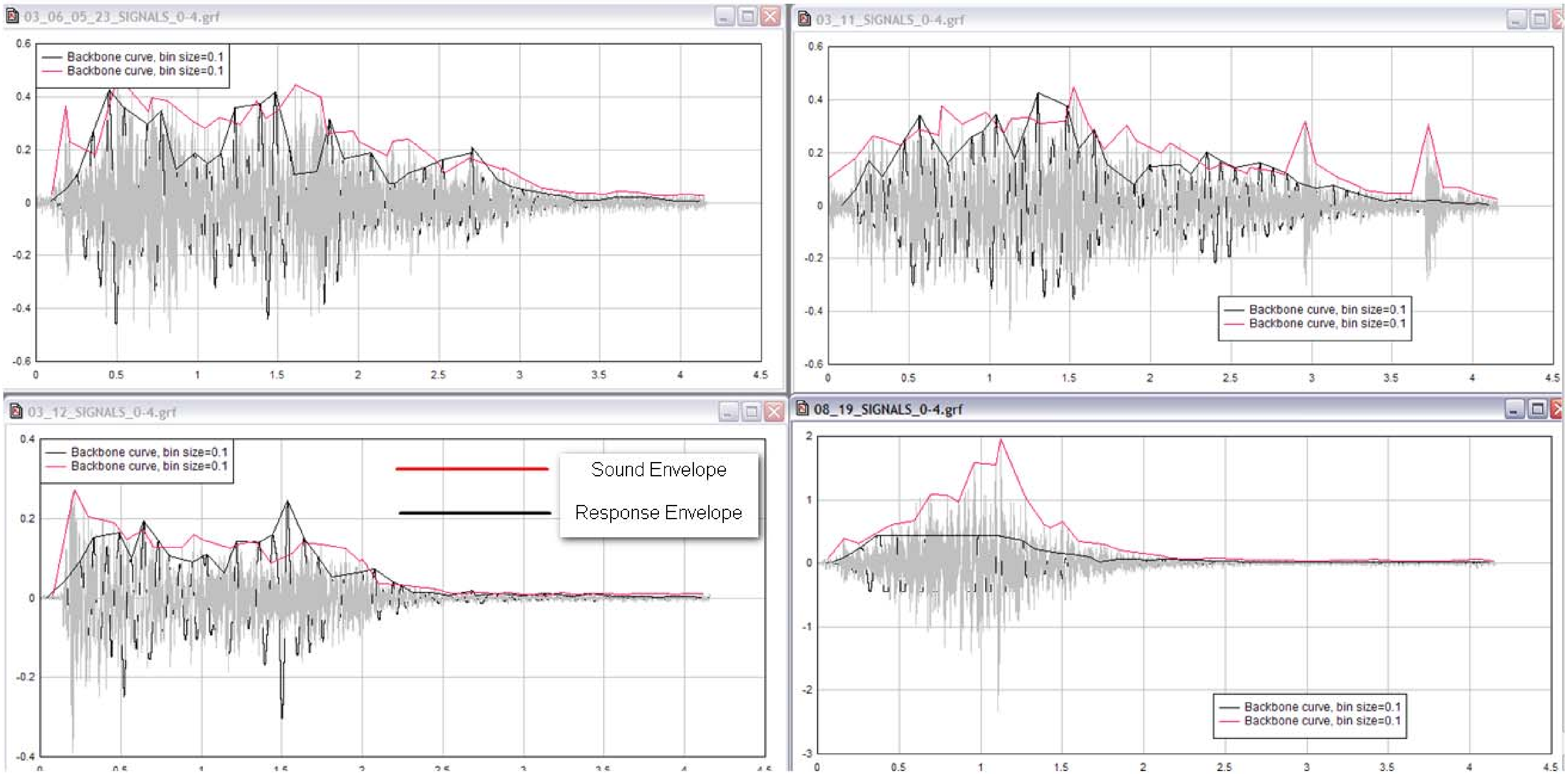


Figure 1.38 Response and Acoustic sound Wave forms four (4) near events.

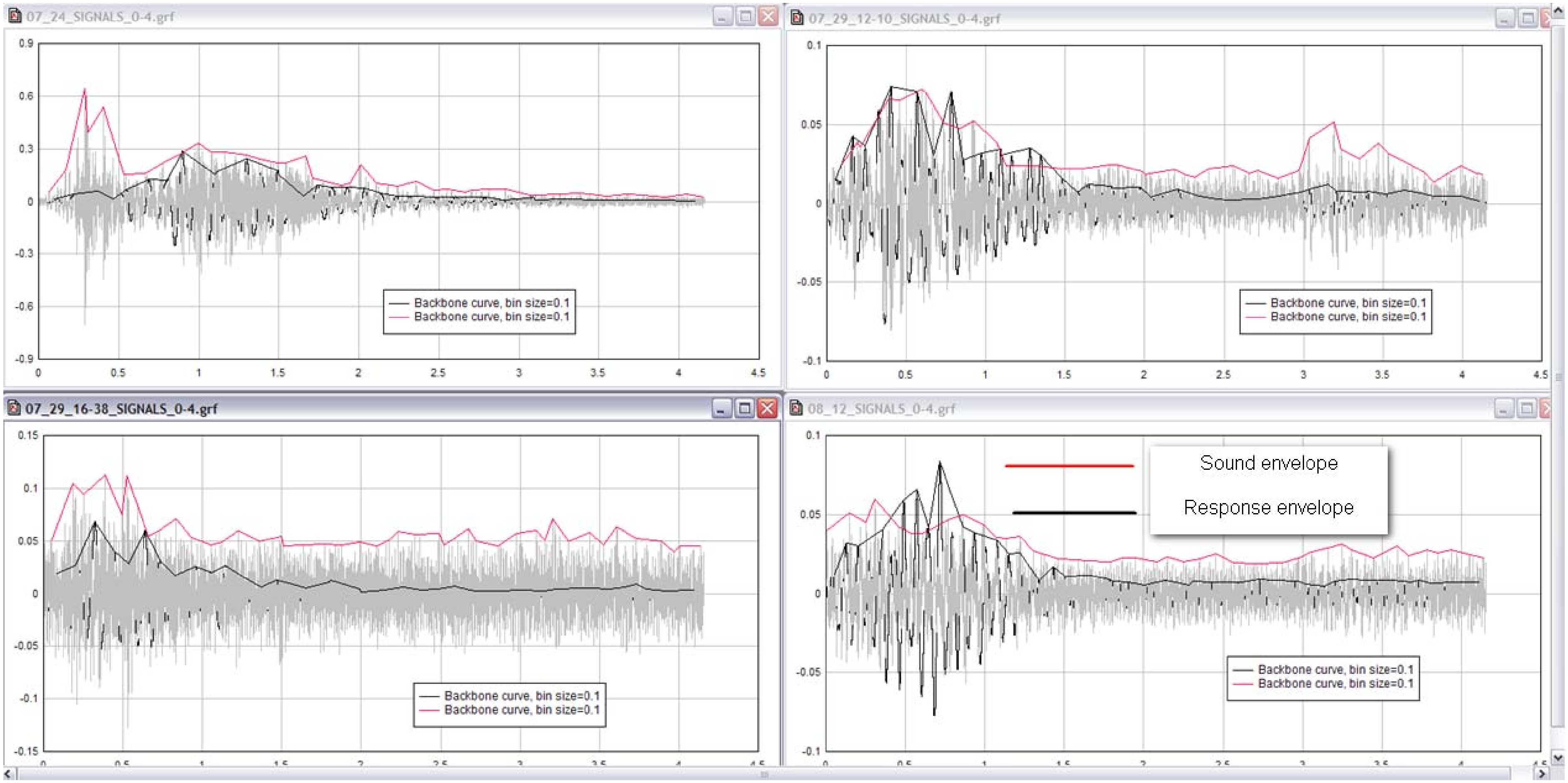


Figure 1.39 Response and Acoustic sound Wave forms four (4) far events

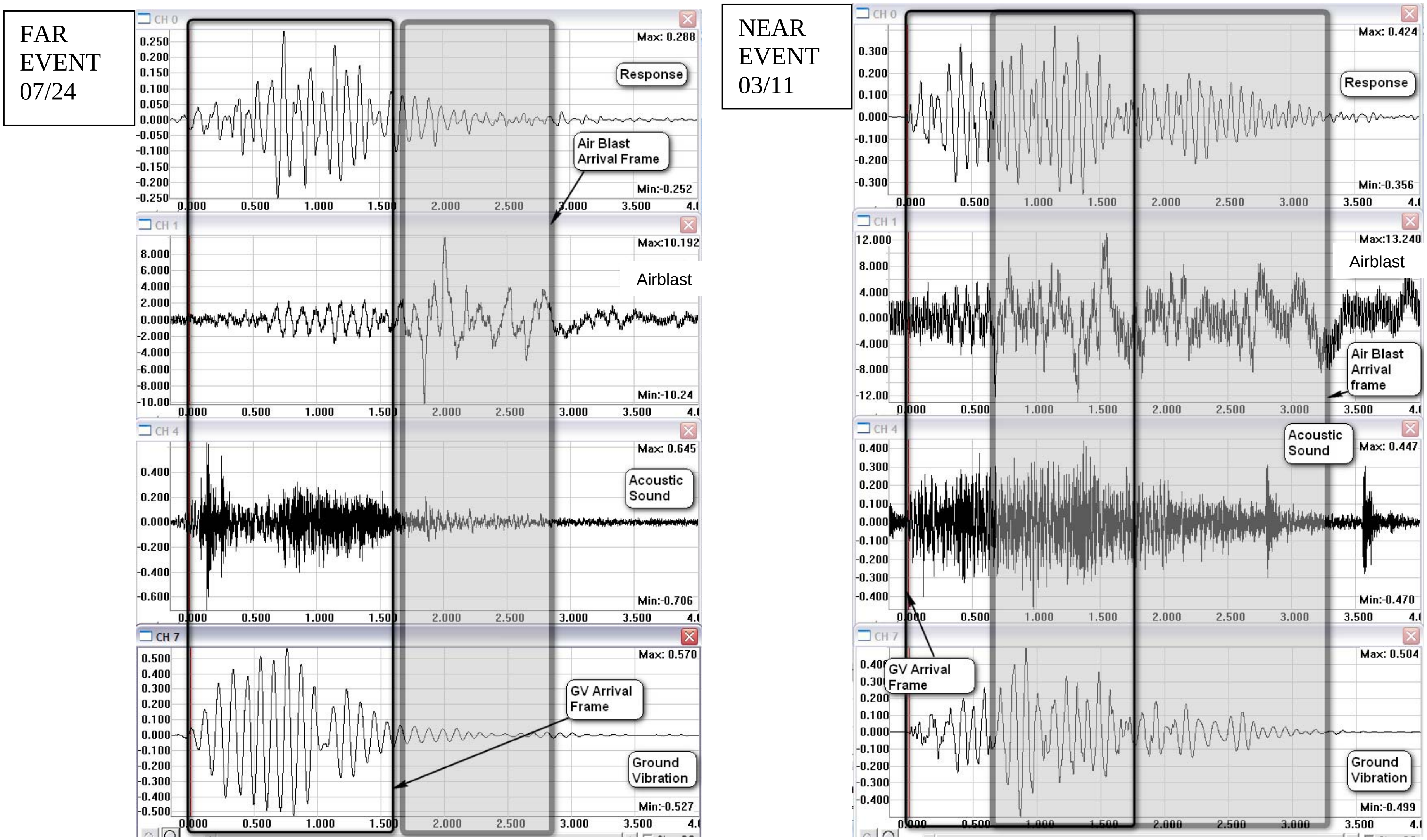


Figure 1.40 Wave forms far and near events

Figure 1.41 shows the detail in the acoustic sound signals for both events.

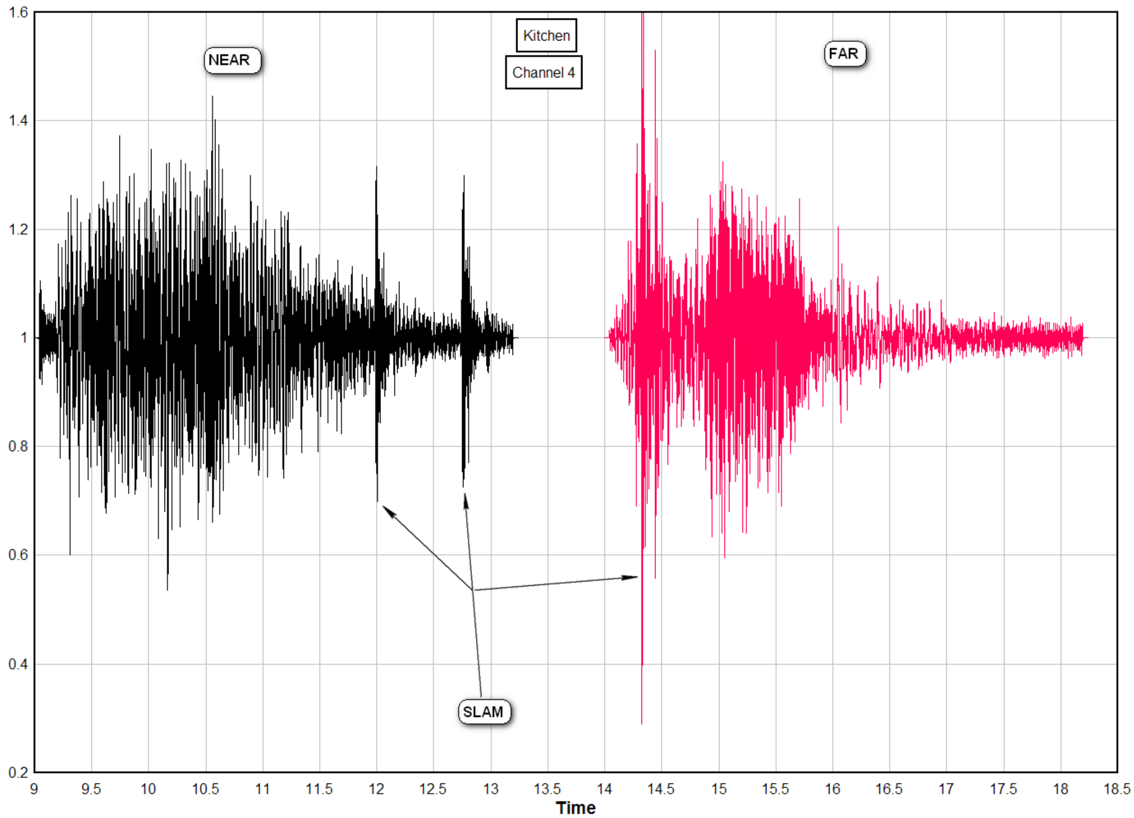


Figure 1.41 Detail acoustic sound wave form both events 6704 and 5401

The objective of this project is to study how residents would experience a blast event from inside their homes; thus discussion about the sound signals in far and near events were compared and discussed here.

Only two events were chosen Event 6704-Date 7/24/08 Far Event and Event 5401-Date 3/11/08 for near event for comparison between far and near events; however, the comparison is similar for all the others events recorded.

Figure 1.41 shows that while the sound in the kitchen was recorded during a blast event, the acoustic microphones recorded some slams. For the far event, the amplitude of the slam is even greater than the amplitudes recorded in the close event. The explanation to this random behavior is related to elements like doors or windows that are loose at the moment of the blasting.

The previous statement means that even though the acoustic sound is related more to ground vibration than airblast in the far events, according to the conditions of the elements in the house like doors, windows, dishes, etc., a slam can change the human perception of the sound.

The perception of the sound amplitude during a blast event is also related with the location inside the house. Figure 1.42 shows the sound according to location in the house for both types of events (near and far).

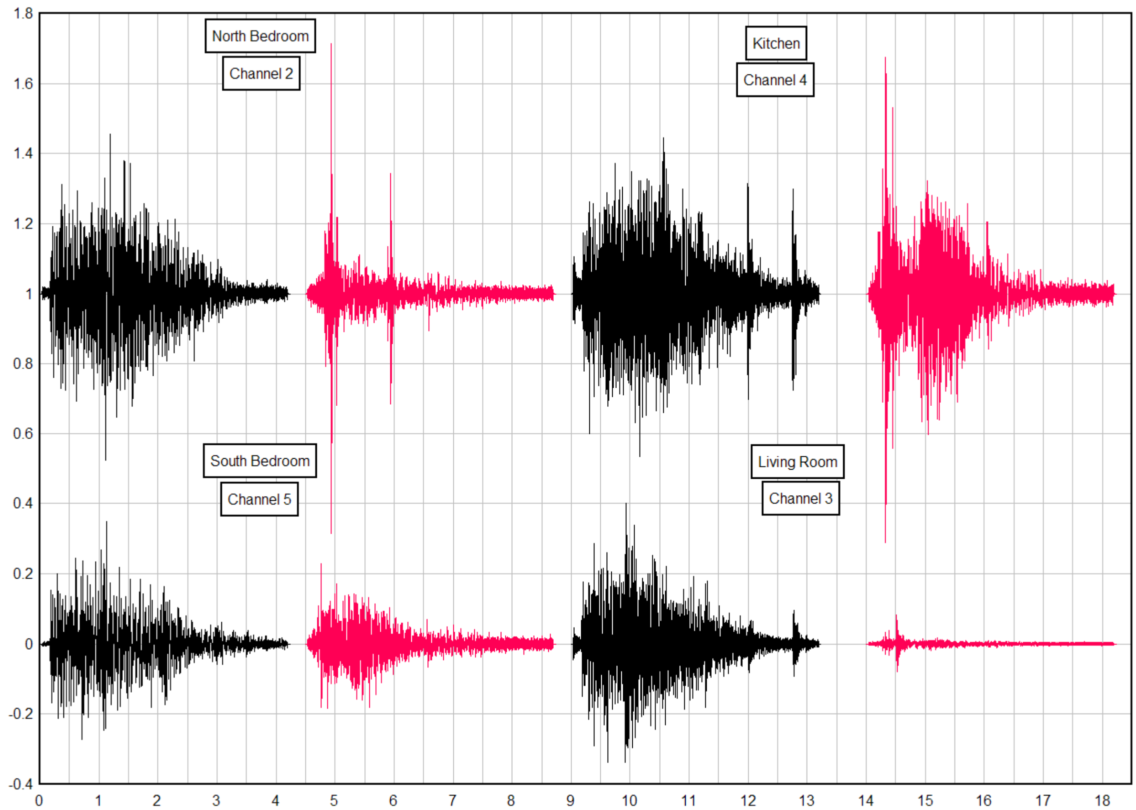


Figure 1.42 Acoustic sound and location into the house far event 6704 (red) and near event 5401 (black).

In figure 1.42, for the near event, the south bed room is the place where less sound amplitude is recorded (see the amplitude in the south bedroom against the others) while the microphone in the living room for the far event recorded a sound (amplitude and duration) almost imperceptible.

Referring to the duration, Figure 1.43 shows a comparison between both signals in the kitchen.

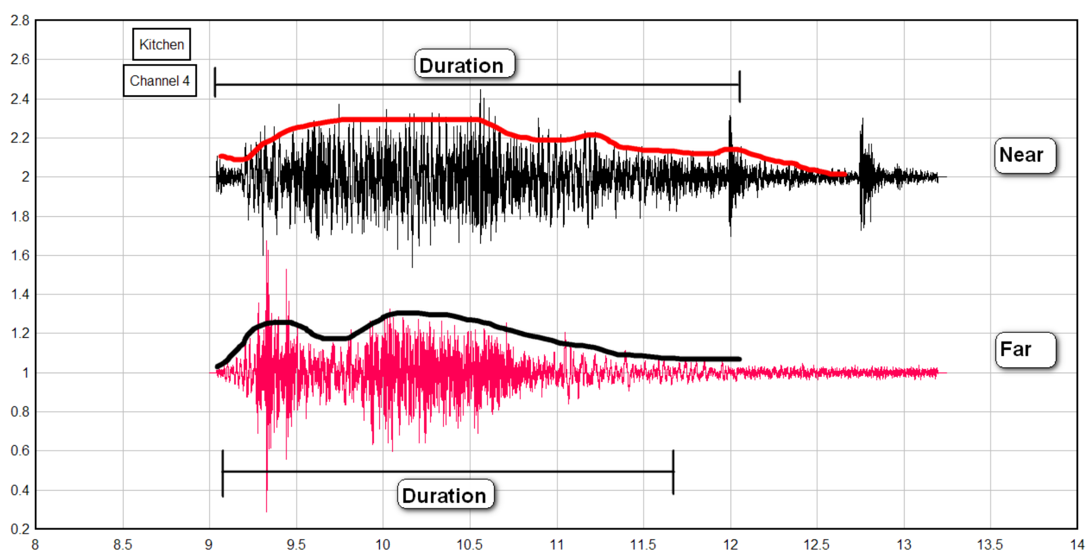


Figure 1.43 Detailed Wave form signal channel 4 for far (6704) and near (5401) events.

For the events chosen, Figure 1.43 shows that in this particular event close to the house, the duration of the sound signal is greater than in the far events given the perception of "long rattling noise" in the near events. This is possibly due to near joint arrival times of ground vibration and airblast, in this case the ABRF is close to one. The parameters of the individual blasts are in table 1.3.

Table 1.3: Blasting characteristics events near (5401) and far (6704)

Shot No.	Type of event	Distance to Target (ft)	Scaled Distance	Total explosive (lb)	Number of Holes	MWEU (lb)
5401	Near	902.02	48.40	26176.64	114	347.31
6704	Far	4238.59	211.55	13313.04	19	401.45
4826	Far (With TV sound)	3264.79	213.55	10284.35	44	233.72

Since the microphones were not calibrated, a signal including TV sound was used to give a perspective about the sound amplitude in a far event. Unfortunately the event 6704 didn't have any background TV sound. Due to this another event 4826-Date 03/06/08 was selected to compare the sounds inside the house in different locations against the channel with background TV sound. In the event 4826 the signal with TV corresponds to the channel 3. The sound recorded in the far event 4826 is shown in figure 1.44.

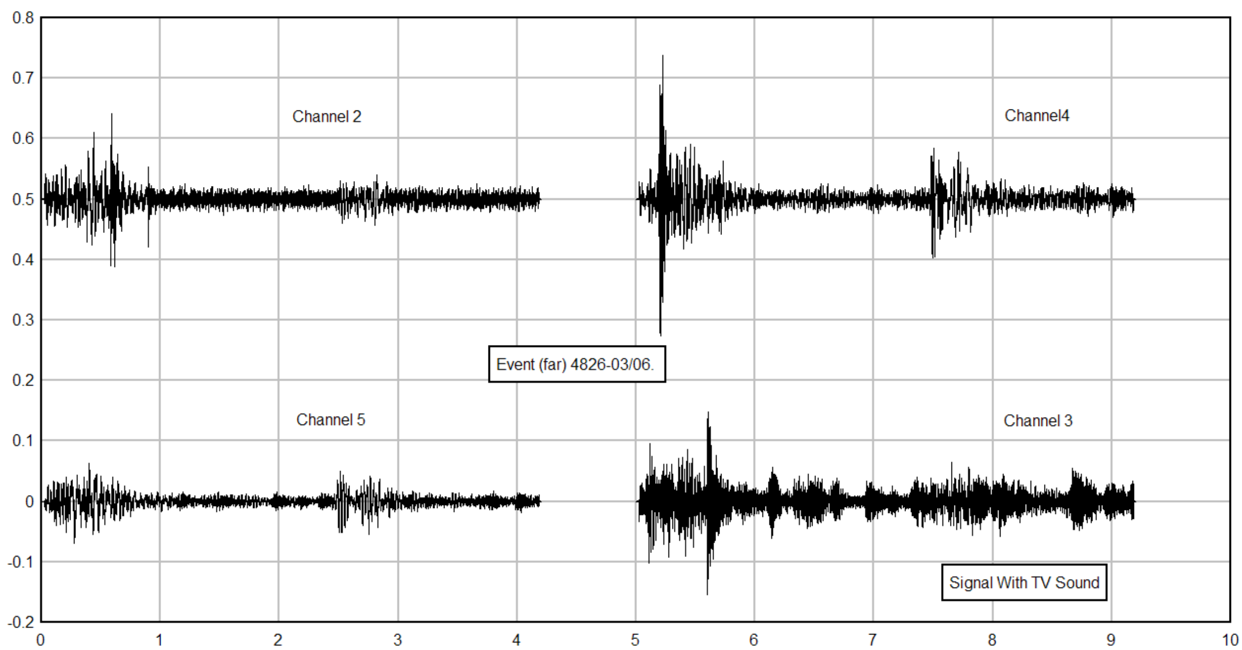


Figure 1.44 Event 4826 (03/06) Channel 3 with TV sound

Event 4826 occurred at 12:28 pm and on this particular day the TV in the living room was turned on (microphone with channel 3 is in the living room) so a TV sound signal was recorded during the blast event. This signal was plotted against the near and far signals in figure 1.43, the results including, near, far and tv signal are included in figure 1.45.

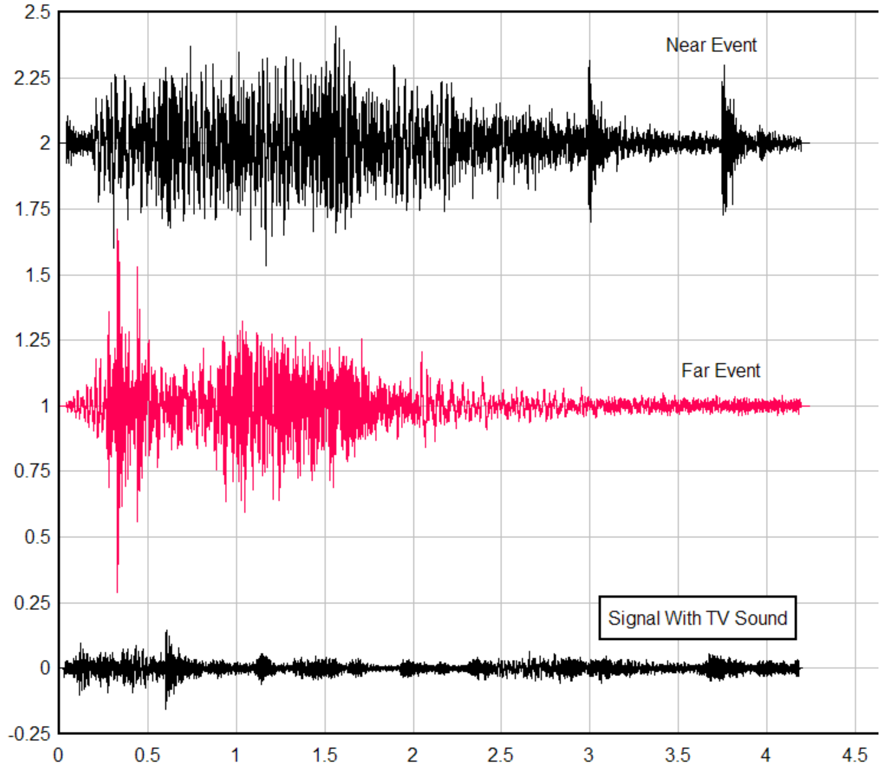


Figure 1.45 Sound Amplitude comparison (channel 4 near and far), TV sound channel 3.

According to the current comparison, the acoustic response amplitude in a blast event inside a typical house is almost 8 to 10 times the regular TV sound.

1.5.4 Comparison of Acoustic Data to Blast Parameters

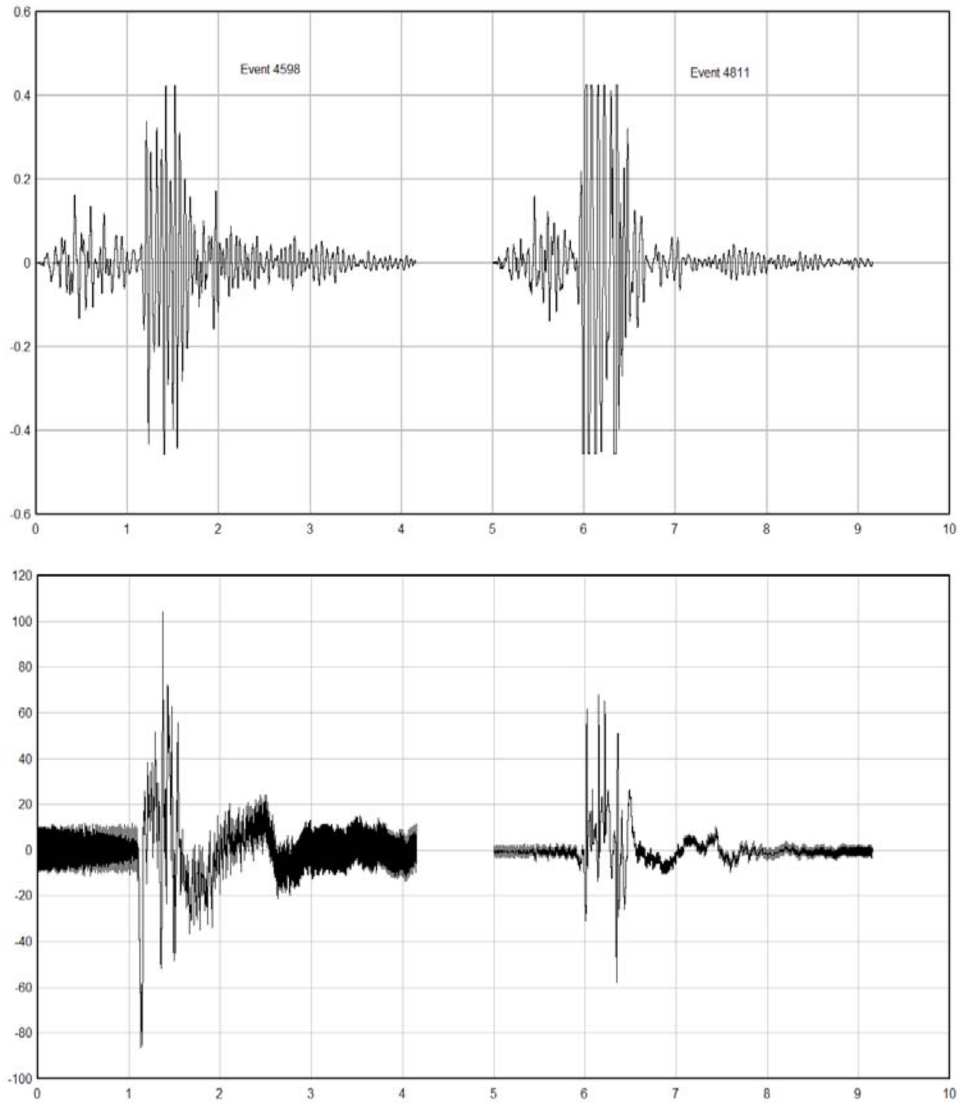
From the 85 records, 4 records were chosen for detailed comparisons. The principal blasting characteristics of these records are in table 1.4:

Table 1.4: Blasting characteristics events for detailed analysis

Shot No.	Distance to Target (ft)	Scaled Distance	Total explosive (lb)	Number of Holes	MWEU (lb)
4598	983.36	64.32	26176.64	112	233.72
4811	1213.54	65.68	13313.04	39	341.36
4809	3790.99	119.56	85458.15	85	1005.39
4826	2807.53	183.64	10284.18	44	233.72

MWEU: Corresponds with the maximum weight of explosive used (8ms delay).

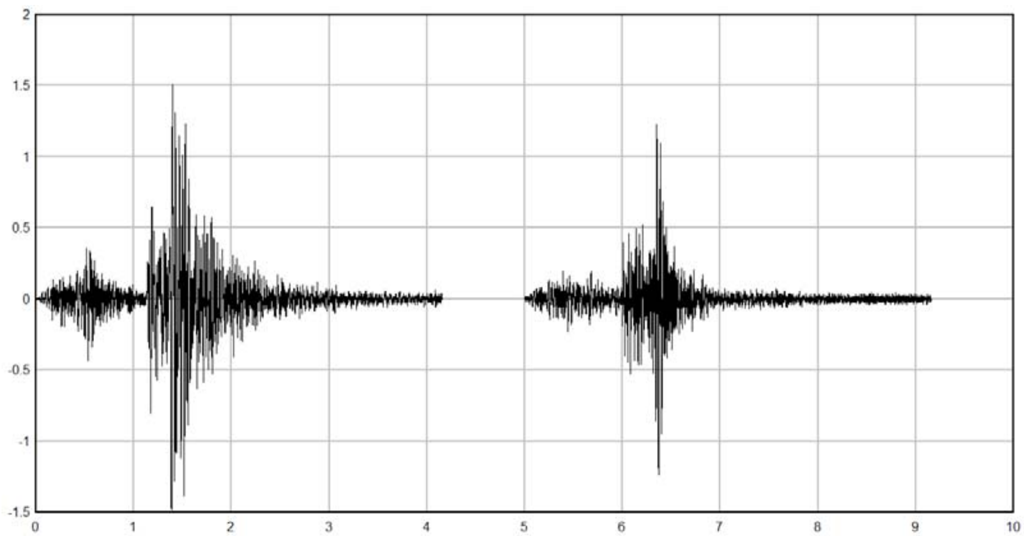
Shots 4598 and 4811 are similar because they have similar distance source to site and weight of explosive resulting in a scaled distance approximately of 65 ft/lb$^{0.5}$. This similitude is also represented in the general behavior of the different waves recorded in the house. For instance, in Figure 1.46, we can see the ratio between the response (mid wall sensor) signal and the airblast for both events.



Event 4598 Event 4811

Figure 1.46 Response and airblast wave forms for near events.

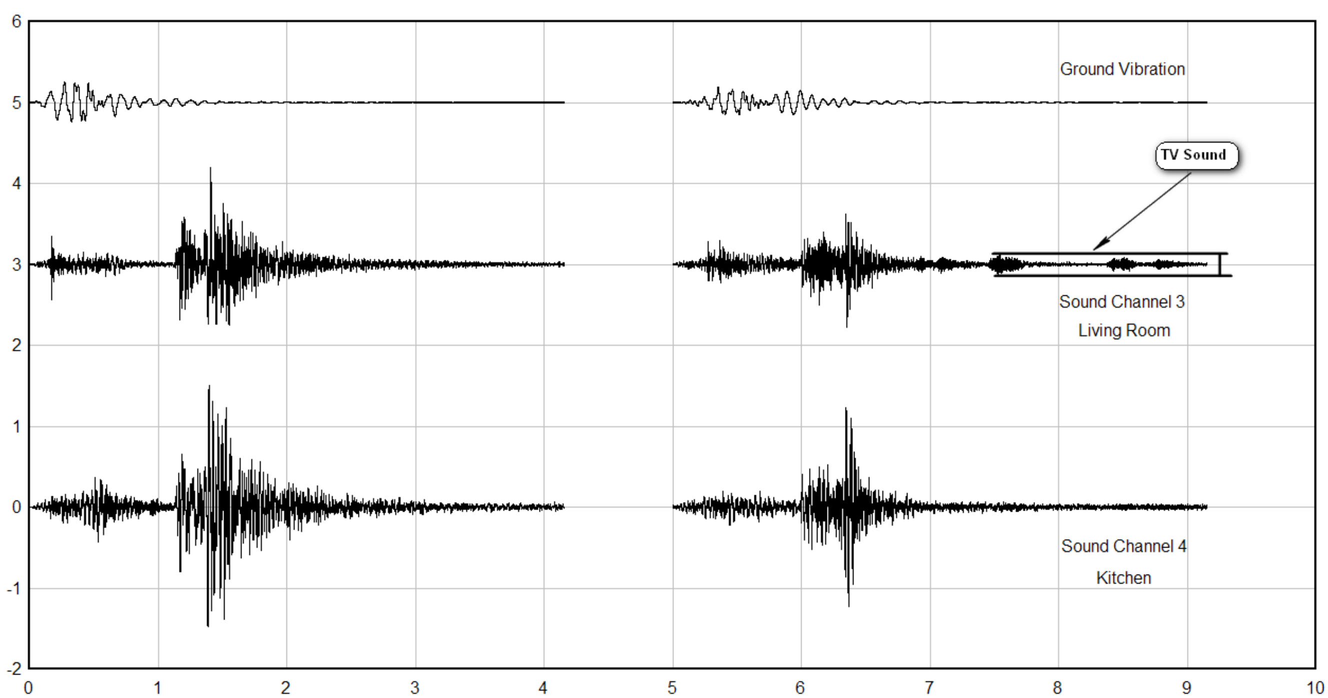
The *ABRF* in this case is close to one, meaning the source of acoustic sound is produced by airblast. Event 4598 had much higher airblast, while event 4811 created a lower amplitude airblast, this fact is reflected in the sound amplitudes for both events as figure 1.47 shows.



Event 4598 Event 4811

Figure 1.47 Acoustic sounds Channel 4 (Kitchen)

In this case despite the direct relation between Airblast and acoustic sound, both events also generated in the house a vibration response and acoustic sound due to ground vibration. It is possible to see this fact in figure 1.48. The initial part of the acoustic sound signal (first second) match very well with the ground vibration.



Event 4598 Event 4811

Figure 1.48 Acoustic sound and ground vibration.

In the event 4811, the living room microphone recorded TV sound (Figure 1.48). The TV acoustic sound amplitude can be used to have an idea about sound amplitude related with ground vibration. Figure 1.48 and 1.49 shows that sounds generated from ground vibration are close to 1.5 to 2 times the normal TV sounds in the near field.

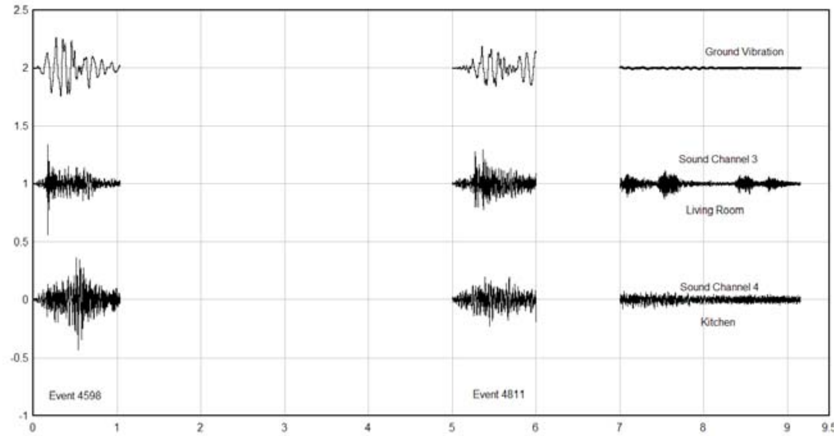


Figure 1.49 Acoustic sound related with ground vibration and TV sound (Detail).

In this specific case, the maximum sound amplitude is related with the amplitude of airblast (figure 1.46). Previous statement means that greater airblast amplitude causes greater acoustic sound inside the house, where the airblast is the major source of energy arriving to the house and generating acoustic response.

Events 4809 and 4826 are events at distances greater than 2500 ft. In these events, ground vibration induced the greatest sound in the home. Figure 1.50 shows response and airblast traces from events 4809 and 4826 (see Table 1.4) the *ABRF* in this case is 0.24 and 0.14 respectively.

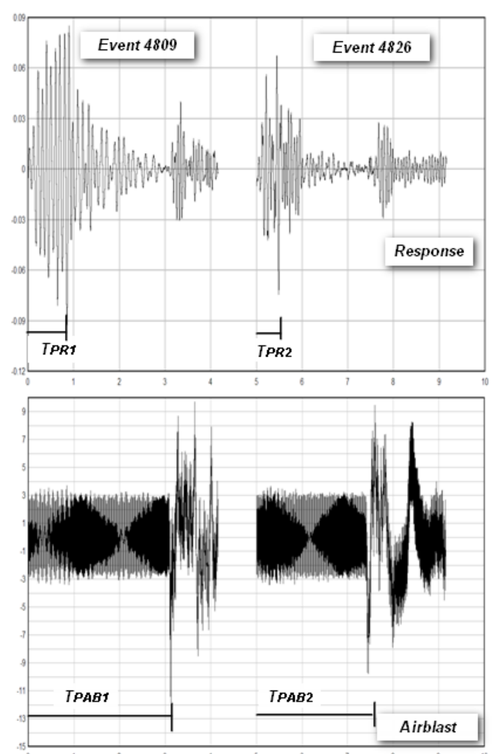


Figure 1.50 Response and airblast wave forms far events.

As expected, the amplitudes for ground vibration and airblast are considerably lower than those shown in Figure 1.46 approximately five times (5) in response and ten (10) times in airblast.

With regard to the sounds, channel 3 and 4 were used for comparison. Additionally in figure 1.51 the sound for near events were plotted.

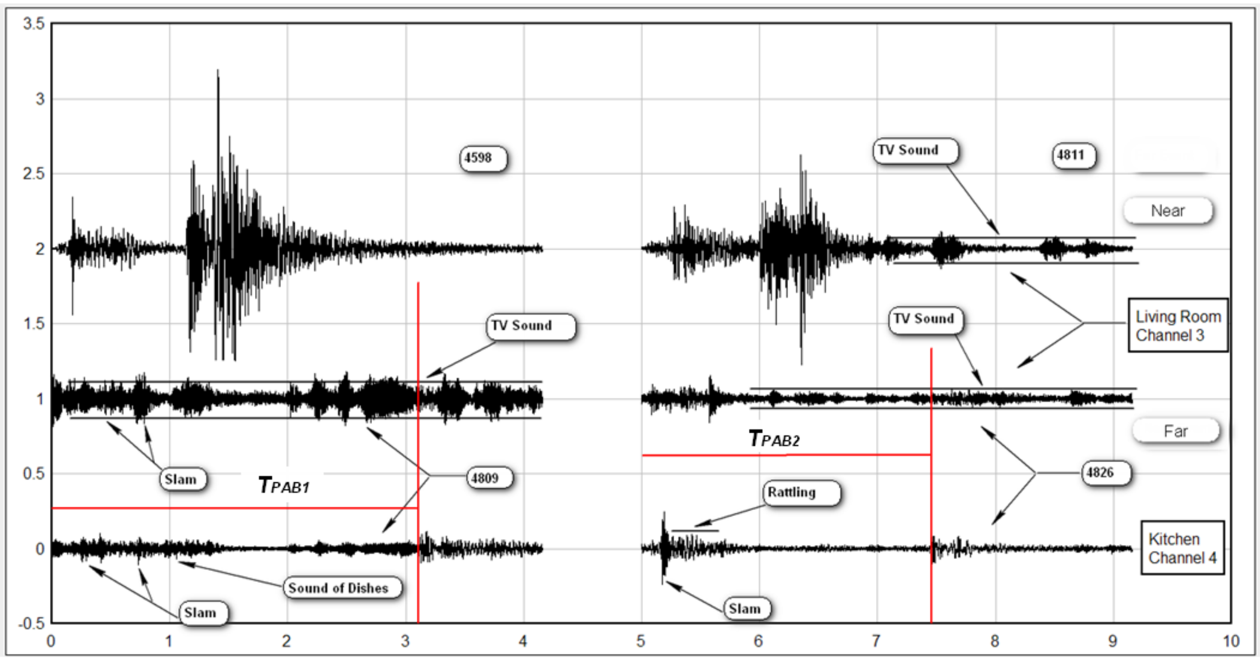


Figure 1.51 Acoustic sounds far and near events. (TPAB. Time Peak Airblast)

Acoustic sound shapes for far events (4809-4826) are more irregular when compared to the near events (4598-4811).

In the far events, the environment sound (TV sound in this case) is an important factor to take into account. Places within the house where TV sound is not affecting the record (channel 4, event 4826), slams and rattling sounds are more “clear” in the record. Moreover in places like the living room the slams and rattling sounds are “mixed” with TV sounds. The previous observation means that for far events (distances greater than 2500 ft in this case) in noisy environments, the sounds due to vibrations are less noticeable.

Another aspect about the sounds during a blast event is the fact that each place in the house has a characteristic sound. This is related to the type of elements found in each place. For example in the case of channel 4 for event 4809, it is possible to hear dishes rattling while in other places of the house these sounds are inaudible.

Regarding the acoustic sound amplitudes, the peaks in far events are related with slams of loose door or windows or objects falling. Figure 1.51 shows for the same event different times for the occurrence of slams according to different locations. Again, the occurrence of the slams is related to the items in place in each room.

The airblast should not affect the magnitude of sound in this case because these sounds are related to ground vibrations and the airblast has not arrived yet. Figure 1.52 shows the ground vibration and the sounds in the far event.

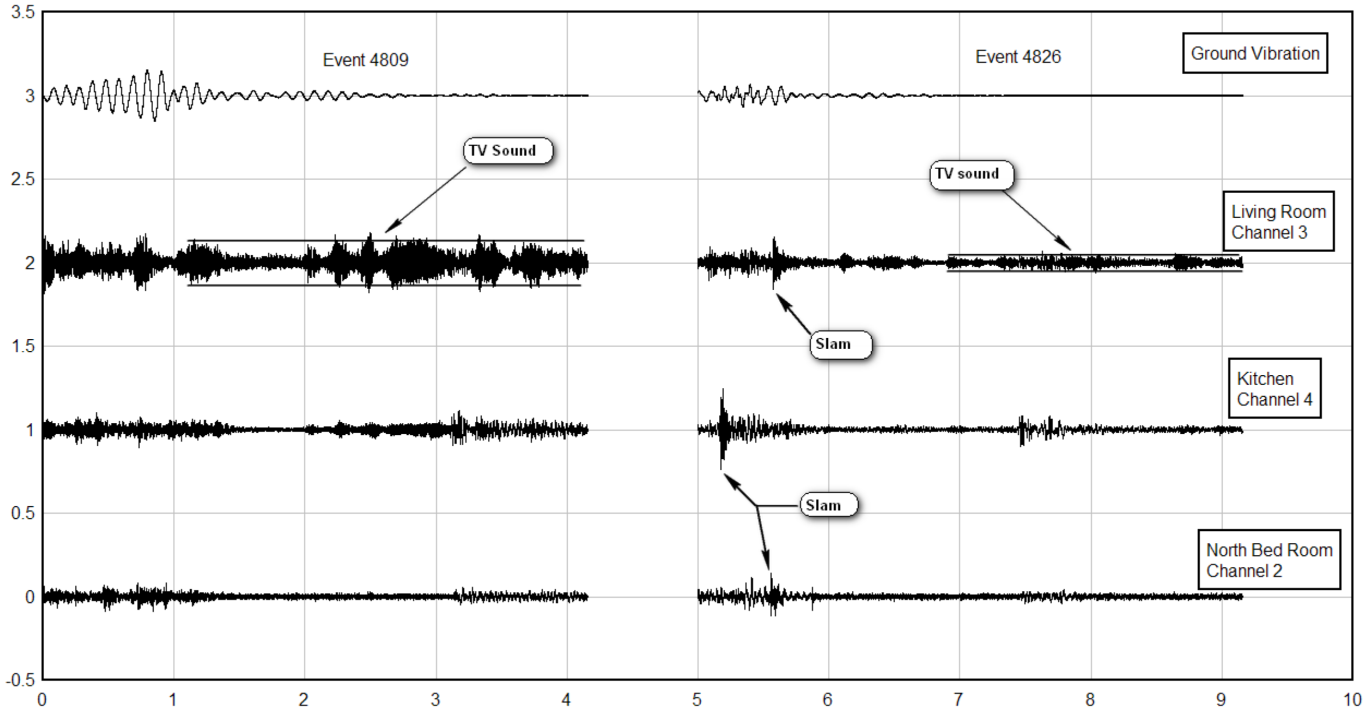


Figure 1.52 Ground vibration signals and acoustic sounds far event.

Event 4809 presents a peak particle velocity almost two times that of event 4826; however the acoustic sound with greater amplitude corresponds with the event with lower peak particle velocity (4826). In the 4826 event, figure 1.52 shows how the occurrence time for the slam is different, according to the location of the microphone. Also in this case, the amplitude of the acoustic sound related with ground vibration is between 1.5 to 2.0 times the TV sound amplitude.

Analysis of data shows that during a blast event, there are two types of acoustic sound response inside the house. The sounds are related to the source of generation. The first type of acoustic sound as traditionally expected is generated by the airblast, while the second source of acoustic sound is the ground vibration. In a blast event the two types of acoustic sound responses are presents.

In this research, for events (blasts) with distances to the monitored house less than 2500 ft, acoustic sounds where recorded with the characteristic that the occurrence time of the maximum amplitude of the acoustic sound matches the maximum airblast arrival time (Time Peak Airblast). In such cases, the amplitude of the acoustic sounds inside the house during a blast event is related with the amplitude of airblast. Also in such cases, the *ABRF* is close to one.

When the major source of acoustic sound is the airblast, comparisons with TV sound shows that the maximum amplitudes are between 8 and 10 times the TV sound while the acoustic sound related with ground vibrations have amplitudes between 1.5 and 2 times the TV sound.

For events with distances greater than 2500 ft, acoustic sounds generated by ground vibrations are predominant over sounds generated by airblast.

In these events, the *ABRF* is much lower than one. The analysis shows that when the source of acoustic sound is the ground vibrations it is more difficult to correlate the sound amplitude with ground vibration amplitude or frequency content, however the comparison with TV sound as reference shows that acoustic sounds amplitudes are between 1 and 1.5 times the TV sound.

Figure 1.53 shows the acoustic sounds for near and far events isolated according with the ground vibrations.

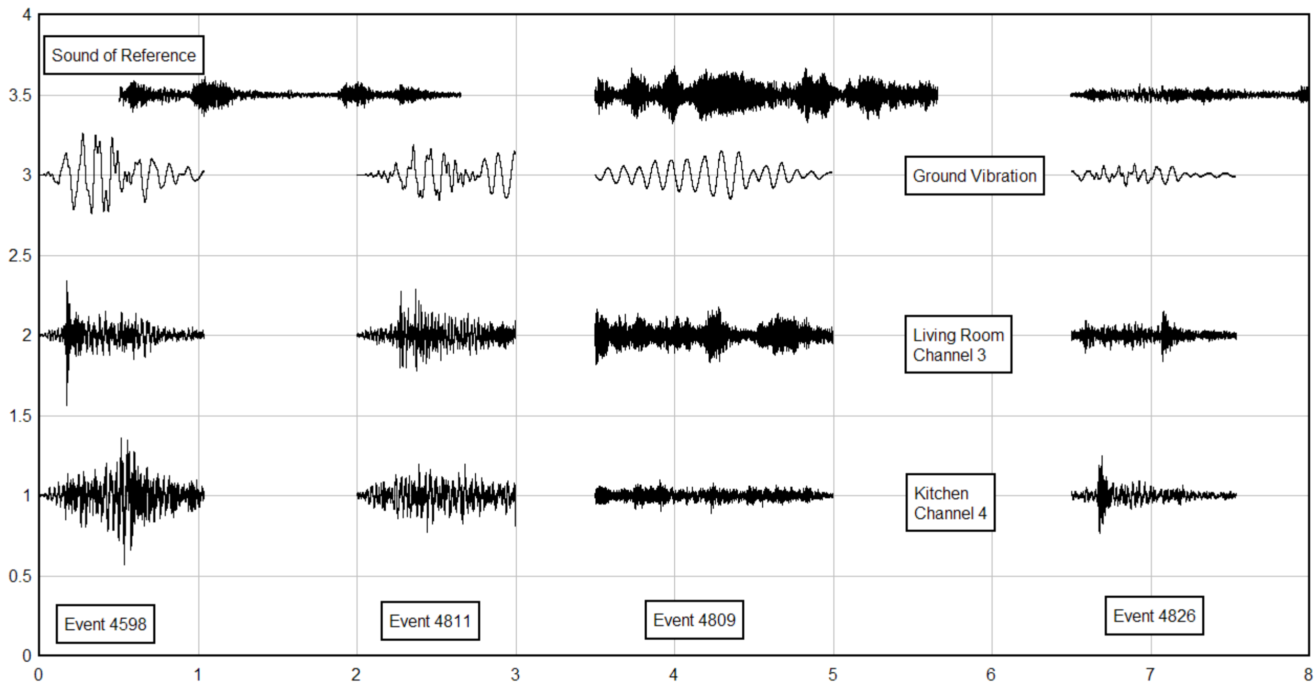


Figure 1.53 Acoustic Sounds isolated by ground vibration

Figure 1.53 shows that sounds related with ground vibrations have 1 to 2 times amplitudes greater than a “normal” TV sound, this fact suggests that complaints from homes located at greater distances from the blast are, most likely, due to ground vibration, rather than to airblast. The lack of correlation between ground vibration amplitude and acoustic amplitude also suggests that reducing ground vibration may do little to abate complaints due to sounds because the sound generation is more related to the conditions of the house. The majority of far events generated peak acoustic sounds in the form of slams or abnormal events rather than a rattling response. This suggests that some level of house preparation could significantly reduce noises produced in far events. Securing loose items would likely reduce sound amplitudes generated by ground vibration in far events.

Table 1.4 summarizes table include a comparison between the different characteristics studied for the two types of events, far and near.

Table 1.4 Summary of general observations

Parameter		**Near Field**	**Far field**
Distance		< 2500 ft	> 2500 ft
Records		58	27
Airblast Response Factor (ABRF)		Often near one Range (0.1-1.4)	Always much lower than one Range (0.0-0.4)
Maximum Amplitudes	**Response Channel (Midwall)**	0.46 in/s	0.40 in/s
	Ground Vibration (Maximum PPV)	0.86 in/s	0.57 in/s
	Airblast	$1.81X10^{-2}$ PSI (136 dB)	$1.04X10^{-2}$ PSI (131 dB)
FFT Dominant Frequencies	**Response Channel (Midwall)**	22.39 Hz	16.3 Hz
	Ground Vibration Porch	12.12 Hz	13.37 Hz
	Airblast	16 Hz	14 Hz
General Acoustic Response Characteristics			
Typical Acoustic Response Associated with Airblast and Ground Vibration		8 to 10 times TV background associated with Airblast (ABRF ~ 1)	1.5 to 2.0 times TV background associated with Ground Vibration (ABRF < 1)
House Location Generally Reporting Highest Sound Response		Kitchen	Kitchen
House Location Generally Reporting Lowest Sound Response		North or South Bedroom	North or South Bedroom

1.6 Development And Analysis Of Phone Survey

Coal Mines and other long term mining operations utilizing blasting are coming under increasing public and legislative pressure in the United States. The question being posed for the blasting industry is, “Has our past haste in adopting complex scientific scales and units been detrimental to us?” In other words, are the most palatable things being reported? This section discusses whether current blast reporting units create an atmosphere of discomfort among neighbors to mines; putting the public relations efforts of the company at a disadvantage from the start.

A Likert scaled survey, developed by Rensis Likert (1932) in social sciences, was distributed and analyzed across the targeted constituency of West Virginians. The scale requires the subjects to make a decision on their level of agreement with the asked statement. Generally the scale is composed of five levels (ie. Strongly Agree, Agree, Neither, Disagree, Strongly Disagree).

The surveys also evaluate the decibel (dB) scale against millibar and pounds per square inch (PSI) as units for measurement of airblast pressure. The industry is already starting the process of rethinking how it handles the vibration issue. The past practice of treading softly as an industry has been proven to be a poor choice, and education of the public as well as lawmakers on all levels is necessary.

The Likert scaled survey was contracted out to University of Kentucky Survey Research Center to be conducted via phone interviews. The survey was intended to evaluate people’s perception of the decibel (dB) scale against millibar and pounds per square inch (PSI) with respect to using them for airblast pressure measurements. Peak Particle Velocity (PPV) and frequency (Hz) were also compared to displacement in both inches (in) and millimeters (mm) for vibration measurement. The phone interviews were conducted on 348 residents of Boone and Logan counties located in West Virginia. The survey pool was selected in order to obtain the opinions regarding blasting of persons near and not near coal mining operations in counties that contain an appreciable number of surface coal mines. Analysis of the survey data will enable the understanding of people’s perception of reporting units used in blasting. This data will be added to a growing database of similar surveys used for a public relations toolset.

There are four main goals for the research, and they are described in this section. The major contributions are listed below.

- Survey data analysis will enable the selection of better reporting units for the airblast and ground vibrations produced in industrial blasting.
- The survey data will be shown to be an important part of the toolset for an effective public relations tool for mining companies.
- Recommendations for improvements in the public relations programs for the mining/blasting industry, and for that industry’s relationship with regulatory authorities will be made.
- The determination of future research for the continuation of work in this area.

Absent from this list is the goal of changing or addressing the level of limits for airblast and ground vibrations that are based on quality scientific research. This is not one of the goals of this research. In fact, limits in place that are based on USBM RI 8507 and USBM RI 8485, such as those adopted by OSM for the regulation of surface coal mining operations, are based on sound scientific research (Siskind, et. al. A, 1980, Siskind, et. al. B, 1980). Since 1980, these limits have been proven to provide conservative limits for the protection of structures exposed to ground vibrations and airblast from mining blasts. Some limits in place, however, are not based on research of this kind.

1.6.1 Reasons for Surveying

Expanding urban environments are presenting new challenges for the explosives industry. When development of the larger cities in the United States began, mines were strategically located to serve specific cities. By nature these mines were located as close to the cities as possible while not interfering with development of commercial and residential land. Of course mines must operate where there is that which can be mined. As the cities have continued to sprawl into the countryside and suburbs have continued to grow, many established mines are encountering challenging situations. Neighborhoods, shopping centers, and high tech industry are now common neighbors for suburban mines. These mines are now forced into public relations issues that were never a concern before.

In the past, extensive research has been undertaken on blast damage levels; however, this work has done little on perception. While it has been important work since it has provided the industry with certainty about what vibration and airblast levels are harmful to structures, a problem still remains. Although structurally safe levels have been met, complaints about blasting do not cease. This report summarizes an effort to obtain how residents perceive blasting events through surveys.

In order to clarify the problem faced by blasters forced to interface with numerous neighbors, background information is necessary. Disturbances like blasts from nearby quarries instill worry in people. In many cases, residents will start looking for damage following blasts. They may encounter damage or defects in their homes that occurred prior to any blasting activity nearby. Many times, lawsuits are initiated against the mining company or blasting contractor for damage not caused by blasting. The use of confusing units may be the root of many problems associated with neighbors in close proximity to blasting. The simple fact that residents may not understand the units used to report ground vibration and airblast data has been overlooked to date when considering public relations for mining and blasting operations. Warneke (Warneke, 2004) introduces the use of indicators to help in the creation of mining-related public policy. Through discussing the many definitions and characteristics of indicators, Warneke identifies a common thread among effective indicators. He states “characteristics necessary for effective indicators: …Simple to interpret, accessible and publicly appealing.” (Warneke, 2004). In the same way, blast reporting units are indicators of the success of a blasting program; thus, the units should follow the same characteristics.

The use of the decibel scale for airblast reporting can be shown as possibly detrimental when the logarithmic nature of the scale is considered. Figure 1.54 is a bar graph providing a visual comparison of the decibel scale and a linear PSI scale. The figure shows how a resident might be uncomfortable with the decibel scale because the values of a typical blast, the Office of Surface Mining (OSM) limit, and the threshold for damage appear to be very close relative to the scale. In contrast, the PSI scale shows that the actual pressure values of these items are farther apart. The safety margin appears to be much larger when using the PSI scale.

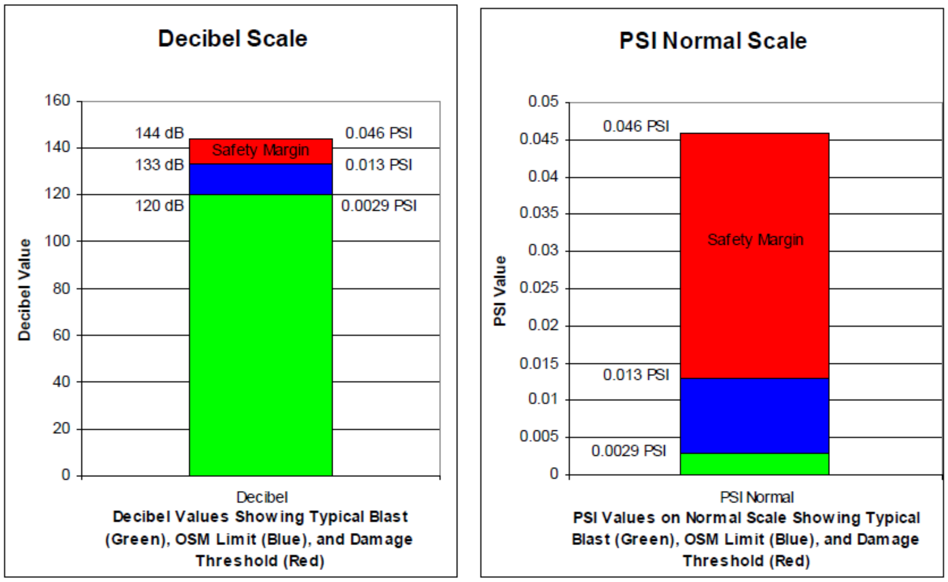


Figure 1.54 Comparison of logarithmic decibel scale and normal PSI scale.

In much the same way, ground vibration is reported using peak particle velocity (PPV) and frequency. This practice may also cause confusion and discomfort in residents close to mines. Since ground vibration reporting is dependent upon two variables, visual representation is more difficult to assess. Nevertheless, through inspection of Siskind's (Siskind, et. al., 1980 A) Z curve, which has been modified by OSM as well, possible alternative reporting units can be determined (ISEE, 1998). A possible alternative to PPV and frequency would be to report data in displacement, which can be derived from PPV and frequency.

The first step in accomplishing the long standing, yet unearthed goal of public comprehension is to determine what is understandable to the public. The survey detailed later in this section was an effort at determining public comfort levels with blasting and current reporting units. The survey asked questions about how comfortable people were with blast vibration and airblast levels and limits. Many more surveys will be required to complete the research that this survey aided in.

1.6.2 The Likert Scale Survey

The survey that was conducted via phone interviews consisted of the following questions:

***** QUESTION #1 *****

Hello, my name is [I]## and I am calling from the University of Kentucky Survey Research Center. I am calling to ask for your participation in an important survey about the best way to provide people information about commercial blasting near their home. This will take about 5 minutes and your telephone number was chosen randomly by a scientific sampling process, so all of the information you give us will be kept strictly anonymous. The data will be used to help determine the best possible methods for communicating blast vibration measurements to the public. My instructions are to speak with an adult age 18 or older who lives in the residence. Would that be you?

***** QUESTION #2 *****

[RECORD RESPONDENT'S GENDER]

***** QUESTION #3 *****

If I have your permission, let me start by asking how long have you lived at your current residence?

***** QUESTION #4 *****

What is your age?

***** QUESTION #5 *****

Is your residence in close proximity to a mining or construction operation that utilizes blasting?

***** QUESTION #6 *****

Do you own or rent your residence?

***** QUESTION #7 *****

Next, I am going to ask questions about a few different ways to measure the amount of airblast pressure a home can be exposed to during blasting. I am going to ask you about how familiar you are with 3 of these measures. The first is decibels. Do you know what decibels are?

***** QUESTION #8 *****

In your own words, please tell me what decibels are.

***** QUESTION #9 *****

Do you know what millibars are?

***** QUESTION #10 *****

In your own words, please tell me what millibars are.

***** QUESTION #11 *****

Do you know what PSI are, or pounds per square inch?

***** QUESTION #12 *****

In your own words, please tell me what PSI are.

***** QUESTION #13 *****

For the following questions, please rate your comfort level from 1 to 5 with 1 being very uncomfortable and 5 being very comfortable.

First, how comfortable would you feel having a blasting operation within 1 mile of your home?

***** QUESTION #14 *****

In decibels, the Federal Safety limit for airblast overpressure is 133 decibels. Using the same 1 to 5 scale with 1 being very uncomfortable and 5 being very comfortable, how comfortable would you be with a blast producing 120 decibels of airblast overpressure?

***** QUESTION #15 *****

In millibars, the Federal Safety limit for airblast overpressure is POINT 89 millibars. How comfortable are you with a blast producing POINT 2 millibars of airblast overpressure?

***** QUESTION #16 *****

In psi, the Federal Safety limit for airblast overpressure is 13 THOUSANDTHS PSI (pounds per square inch). How comfortable are you with a blast producing 2 POINT 9 THOUSANDTHS PSI of airblast overpressure?

***** QUESTION #17 *****

Thinking about these three measures, please tell me what would be your preferred method for receiving airblast measurements that your home is exposed to during blasting.

[INTERVIEWER; ENTER A **'1'** FOR THE PREFERRED METHOD, THEN ASK WHAT THEIR 2ND MOST PREFERRED METHOD WOULD BE AND ENTER A **2** FOR THAT REPOSNSE. ENTER A **3** FOR THE REMAINING RESPONSE; DK=8; REF=9]

GO TO Q. #18 ====> <1> Decibels
-- RANGE IS 1 THRU 3 --
GO TO Q. #18 ====> <2> Millibars
-- RANGE IS 1 THRU 3 --
GO TO Q. #18 ====> <3> PSI
-- RANGE IS 1 THRU 3 --
GO TO Q. #18 ====> <4> DK
-- RANGE IS 8 THRU 8 --
GO TO Q. #18 ====> <5> REF
-- RANGE IS 9 THRU 9 --
-- NUMERIC CLOSED END --
-- SPECIAL FEATURE * SHUFFLING ANSWERS
ALL BUT LAST TWO ANSWERS --

***** QUESTION #18 *****

There are also safety standards for reporting ground vibrations at a home as a result of blasting. These can be reported in inches per second and Hertz, or inches of movement, or millimeters of movement.

The Office of Surface Mining and Reclamation Enforcement, or OSM, has a regulated safety limit for ground vibration of 1 POINT 8 inches per second at 35 Hertz. Using the same 1 to 5 scale with 1 being very uncomfortable and 5 being very comfortable, how comfortable would you be with ground vibrations at your home with velocity in the range of POINT 5 inches per second at 35 Hertz?

***** QUESTION #19 *****

The OSM has a regulated safety limit for ground vibration of 8 POINT 18 THOUSANDTHS inches of movement. How comfortable would you be with ground vibrations of 2 POINT 27 THOUSANDTHS inches at your home?

***** QUESTION #20 *****

The OSM has a regulated safety limit for ground vibration of POINT 21 millimeters of movement. How comfortable would you be with ground vibrations of POINT 06 millimeters at your home?

***** QUESTION #21 *****

Thinking about these three measures, please tell me what would be your preferred method for receiving ground vibration measurements that your home is exposed to during blasting.

[INTERVIEWER; ENTER A '**1**' FOR THE PREFERRED METHOD, THEN ASK WHAT THEIR 2ND MOST PREFERRED METHOD WOULD BE AND ENTER A **2** FOR THAT REPOSNSE. ENTER A **3** FOR THE REMAINING RESPONSE; DK=8; REF=9]

***** QUESTION #22 *****

Using a 1 to 5 scale with 1 being strongly disagree and 5 being strongly agree, please tell me how much you agree or disagree with the following statement: Federal safety limits are reasonable for public safety.

***** QUESTION #23 *****

Okay, just a couple more questions. Have you ever lodged a complaint against a blasting operation?

***** QUESTION #24 *****

Are you currently employed for wages outside your home?

***** QUESTION #25 *****

What shift do you work?

***** QUESTION #26 *****

Those are all the questions I have for you. Thank you for your time and help!
Respondents understanding of the questions was:
GO TO Q. #27 ====> <1> Excellent
GO TO Q. #27 ====> <2> Good
GO TO Q. #27 ====> <3> Fair
GO TO Q. #27 ====> <4> Poor

1.6.3 Survey Results

The survey detailed in the previous section was administered by the University of Kentucky Survey Research Center. A total of 330 surveys were completed and analyzed. An additional 18 surveys were incomplete, but provided answers for a limited number of questions. The following figures and analysis were generated directly from the survey data which can be seen in its entirety in Appendix D.

The results of each question are presented using histograms and can been seen in Figures 1.55 - 1.xx. Each response histogram has been analyzed for clues to the perception of blast vibration data where applicable. Questions 1 through 4 asked simple demographic questions for future separation of the data set.

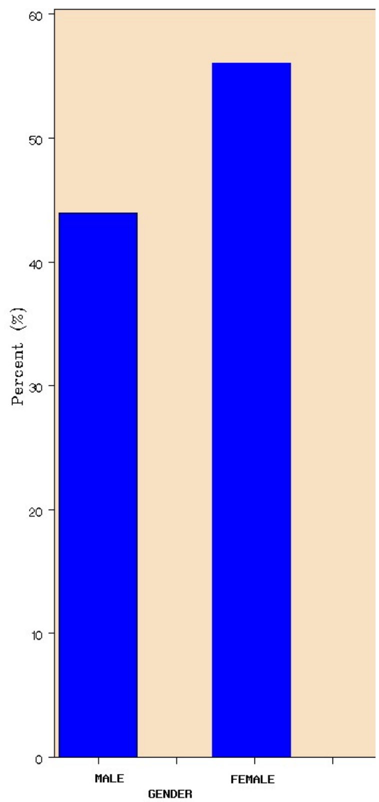


Figure 1.55 Question 2: What is your gender?

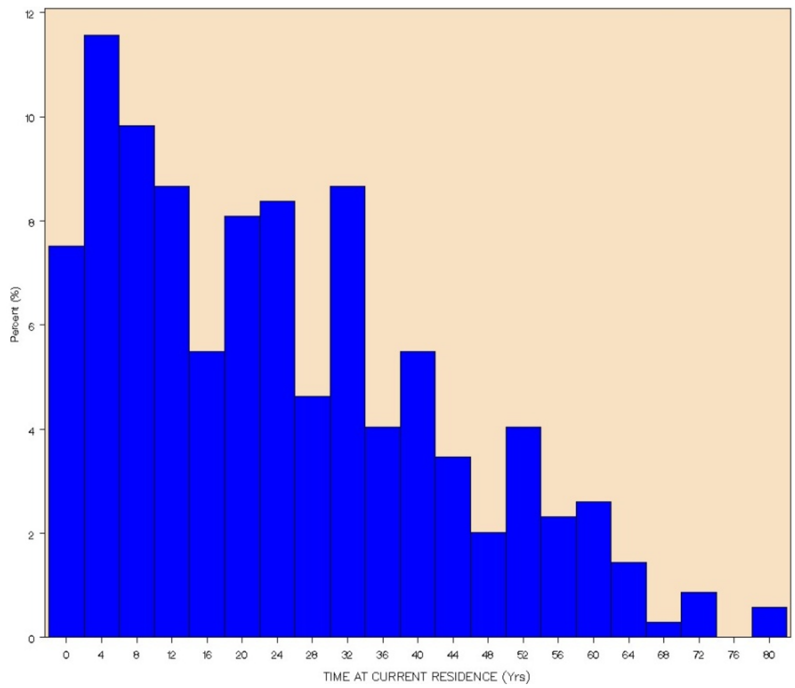


Figure 1.56 Question 3: How long have you lived at your current residence?

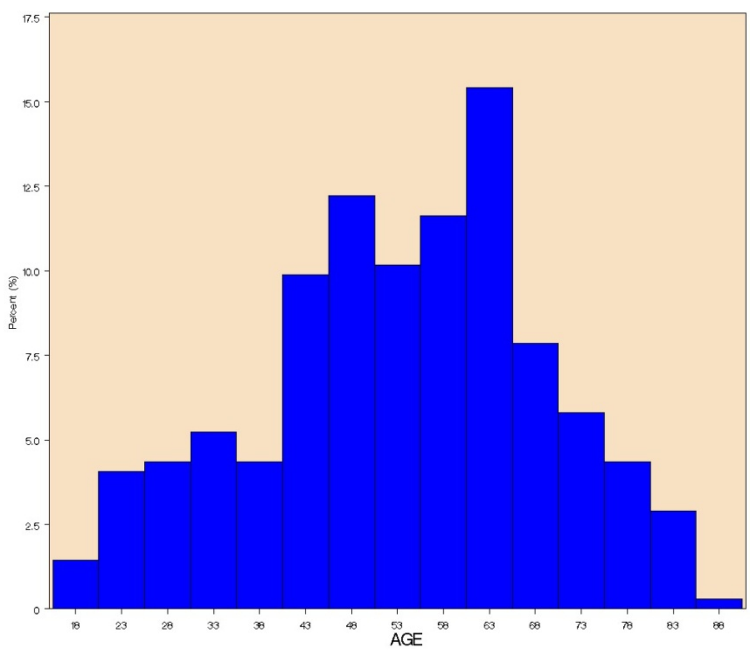


Figure 1.57 Question 4: What is your age?

Question five did not specify what close proximity was. It allowed the interviewee to decide that for themselves. Boone and Logan counties were selected for the high number of surface mining operations and the response to question 5 shows this to be true.

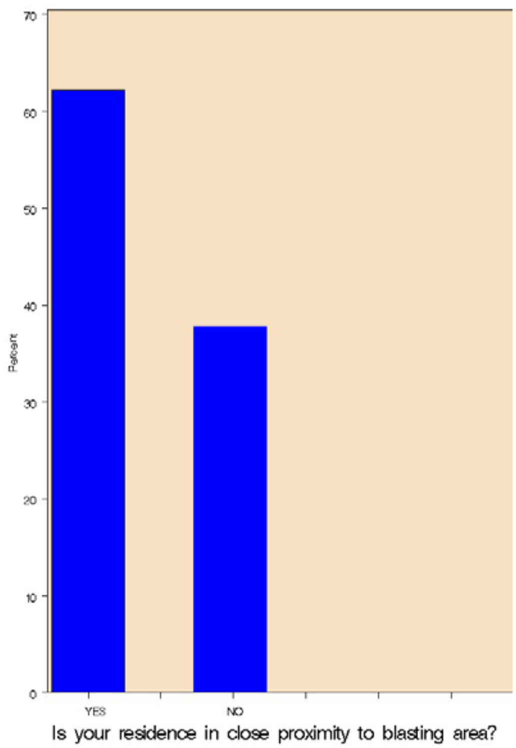


Figure 1.58 Question 5: Is your residence in close proximity to a mining or construction operation that utilizes blasting?

Ownership is important to note because the level of concern will vary on the level of equity an individual has in their residence. Question 6 asked whether the residents owned or rented their homes. More than 80% of the respondents claimed ownership of their residence.

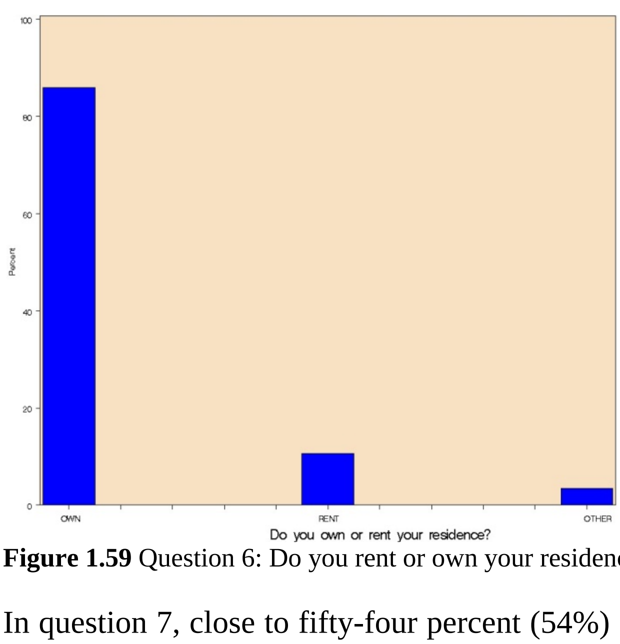


Figure 1.59 Question 6: Do you rent or own your residence?

In question 7, close to fifty-four percent (54%) of the interviewed individuals admit to not knowing what decibels are.

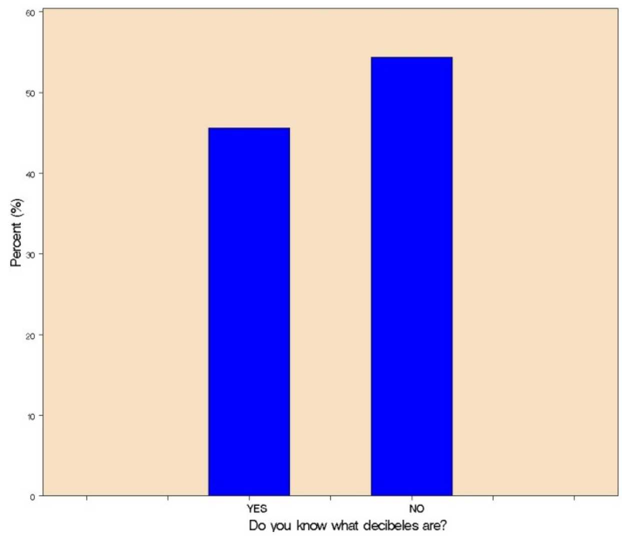


Figure 1.60 Question 7: Do you know what decibels are?

Decibels are the current unit in which blast overpressures are reported to the public. If the answer was "YES" the response to question 7 (Figure 1.60) question 8a was asked (Figure 1.61). If the answer was "NO" the response to question 7, question 8b was asked (Figure 1.62).

The top three choices amongst the subpopulation that stated that they knew what decibels were (Figure 1.61) accounted for 55% of the response. All three of these choices dealt with sound and noise. The majority of those who feel they know what decibels were believe that decibels measure sound and noise. The most correct answer to this question in regards to blasting would be choice 10, a measurement of pressure. Only 5.2% of this subpopulation chose this response.

In reality, decibels are simply a logarithmic unit. This means that it has nothing to do with blasting, airblast or pressure at all. Decibels can be used to describe any mathematical relationship where a logarithmic scale is called for. This fact alone suggests that using it for a blast vibration unit is erred. The individuals who chose option 2 – mathematical relationship are truly correct. All other answers are incorrect unless the decibel units are tied to sound pressure level. Less than 5% of the subpopulation chose this response.

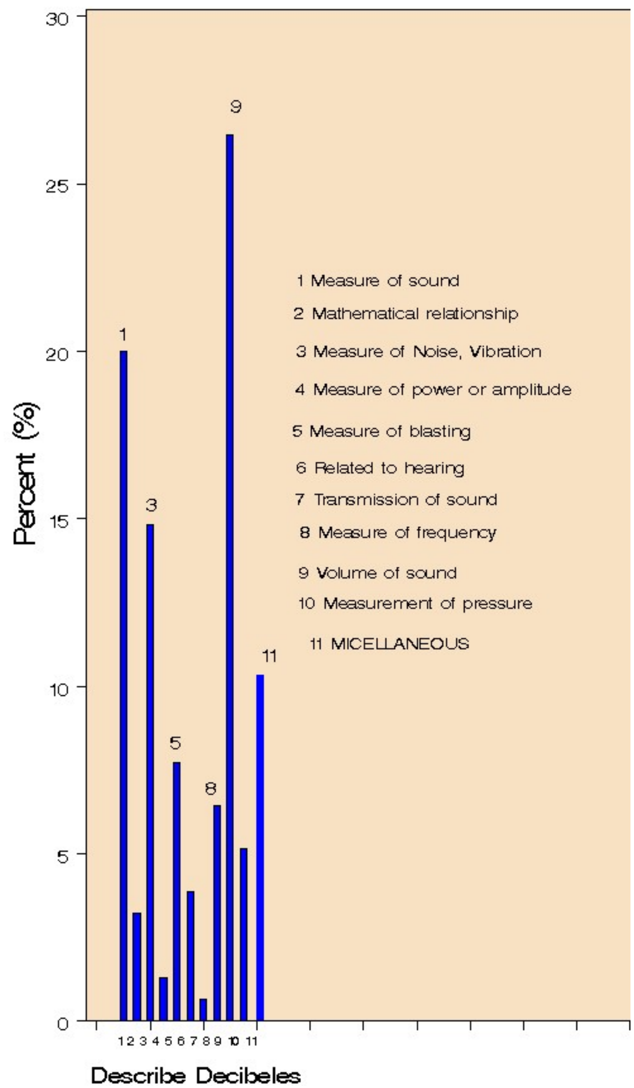


Figure 1.61 Question 8a: In your own words, please tell me what decibels are? (People who answered "Yes" question 7).

The top choice amongst the subpopulation that stated they did not know what decibels were (Figure 1.60) accounted for 45% of the response. This choice stated that decibels were a measure of blasting. This is not entirely false but being told this survey dealt with blasting one could see how this could be perceived as the correct response. The majority of those who feel they did not know what decibels were believe that decibels measure sound and noise or blasting. The most correct answer to this question in regards to blasting would be choice 9, a measurement of pressure. Only 6.9% of this subpopulation chose this response. Again, answer 2 – mathematical relationship is the true correct answer; however, less than 5% of the subpopulation chose this value.

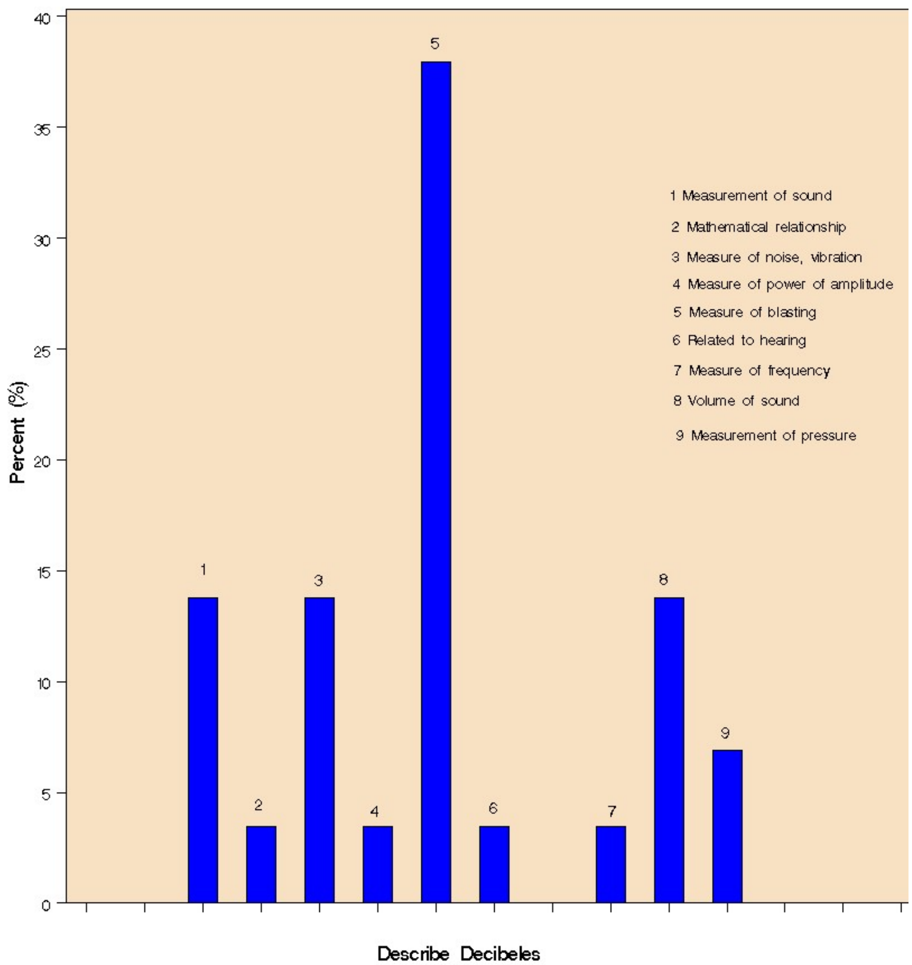


Figure 1.62 Question 8b: In your own words, please tell me what decibels are? (People who answered "NO" question 7)

In question nine the interviewed was asked about an alternate unit for airblast to evaluate its appropriateness as a replacement reporting unit. Of those interviewed 9.3% said they knew what millibars were. The populations was separated by this question and the results for the follow up question asking to describe millibars can be found in Figure 1.63 for the respondents who claimed to know what millibars were. Respondents who claimed not to know what millibars were not asked the follow up question.

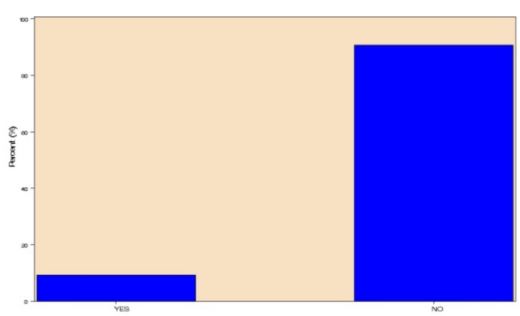


Figure 1.63 Question 9: Do you know what millibars are?

The subpopulation that chose "YES" to question nine "Do you know what millibars are?" were asked question ten (Figure 1.64). Of this subpopulation, 28.1% chose a measure of pressure. This is unlike the question about decibels where only five percent of the subpopulation that said they knew what decibels were chose a measure of pressure.

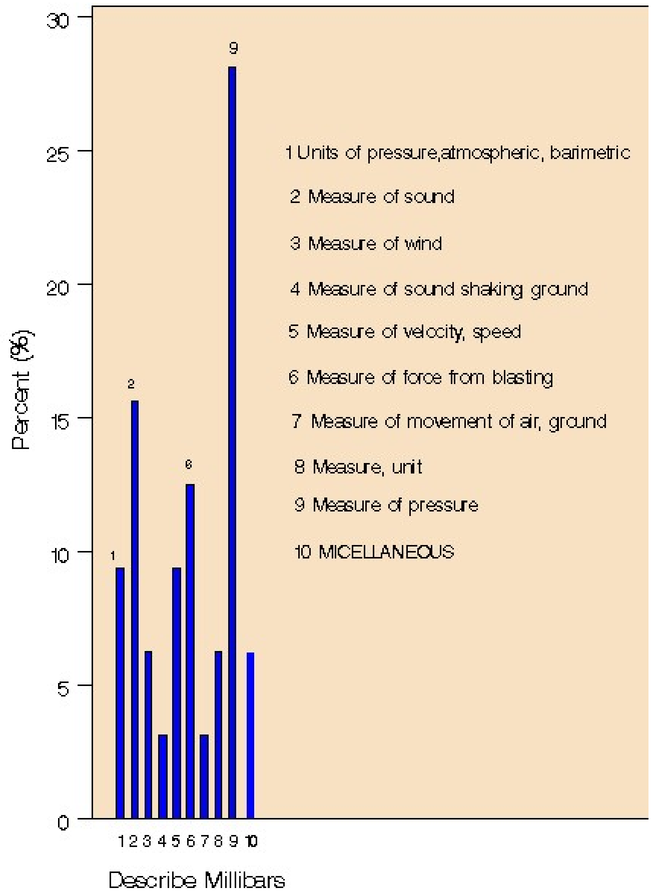


Figure 1.64 Question 10: In your own words, please tell me what millibars are?

In question eleven (Figure 1.65) the participants were asked about an alternate unit for airblast to evaluate its appropriateness as a replacement reporting unit. Of those interviewed 39.5% said they knew what PSI was. This was greater than millibars but lower than decibels. The population's claimed knowledge of PSI was only 6.1% less than that of decibels making it a good candidate for an alternative unit for blast overpressure reporting.

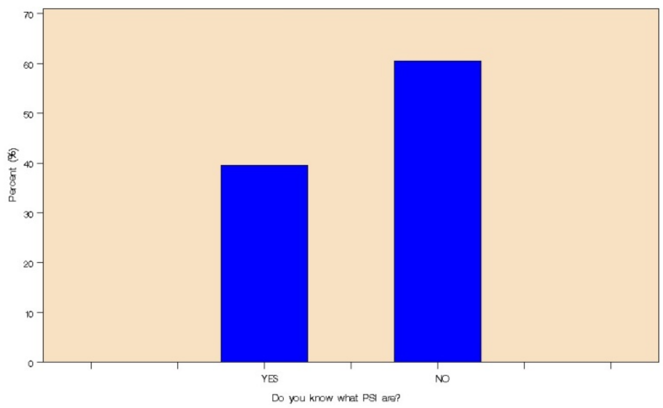


Figure 1.65 Question 11: Do you know what PSI are, or pounds per square inch?

The subpopulation that chose “YES” to question eleven “Do you know what PSI are?” were asked question twelve (Figure 1.66). Fifty-one percent of this subpopulation chose a measure of pressure or stress. Although this is not the technically best choice, of pounds force per square inch, it is still a correct one. So of the 39.5% that said they knew what PSI were 65% were correct with a response of 1, 2, or 3 (Figure 1.66.) This is higher than the level of correct responses for both decibels and millibars. Since a much higher percentage of the population understood this unit, it may be suggested that it would be a more suitable unit for reporting airblast data.

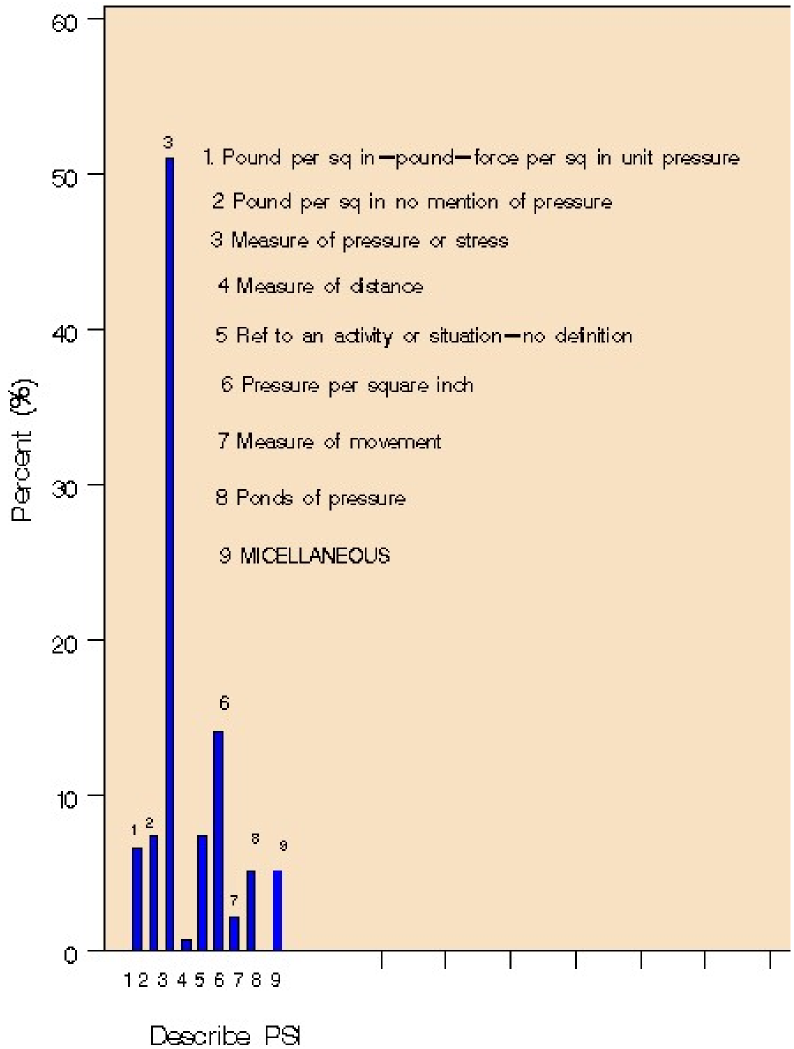


Figure 1.66 Question 12: In your own words, please tell me what PSI are?

Question 13 (Figure 1.67) asked about blasting within one mile of the interviewees' home. It appears as though the majority of people are "very uncomfortable" with blasting near their homes. This level of "very uncomfortable" stays in the majority for questions 14-16 (Figures 1.68-1.70). These questions ask the comfort level of the airblast from a single blast. The only thing that changed between the questions was the unit that over pressure was communicated in. Of the three units the blast was communicated in decibels ranked the lowest with having 71.2% response in "very uncomfortable" or "uncomfortable" and a 12.8% response with "comfortable" or "very comfortable". PSI ranked the highest with a 61.1% response in "very uncomfortable" or "uncomfortable" and a 21.3% response with "comfortable" or "very comfortable".

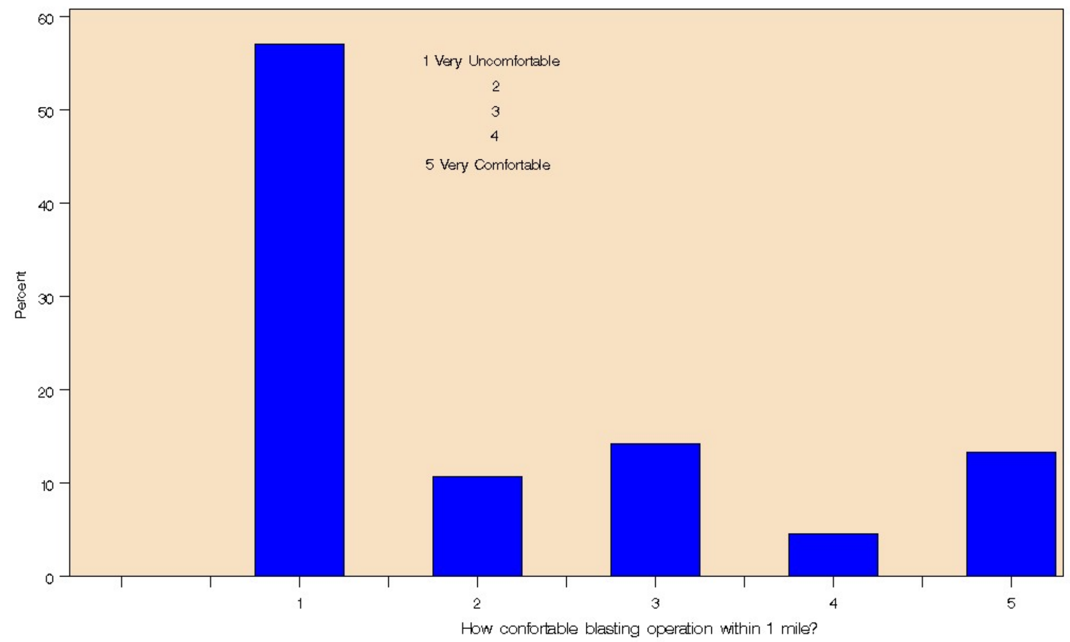


Figure 1.67 Question 13: How comfortable would you feel having a blast within 1 mile of you home?

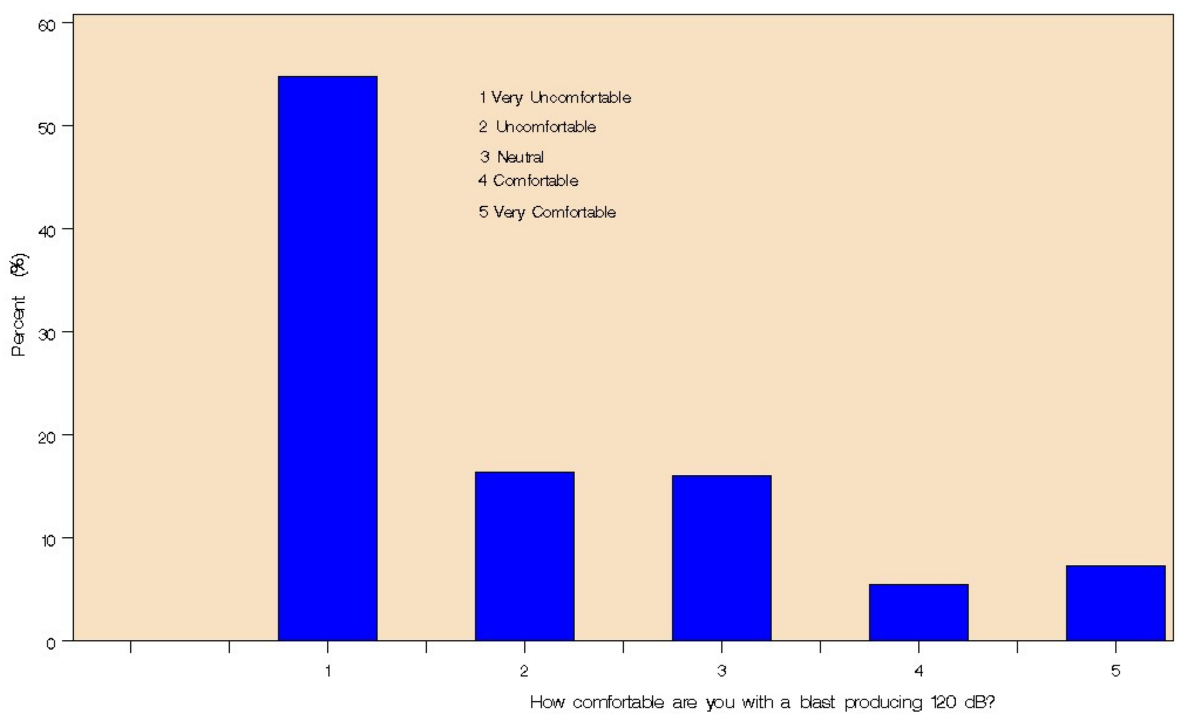


Figure 1.68 Question 14: How comfortable would you be with a blast producing 120 decibels of airblast overpressure?

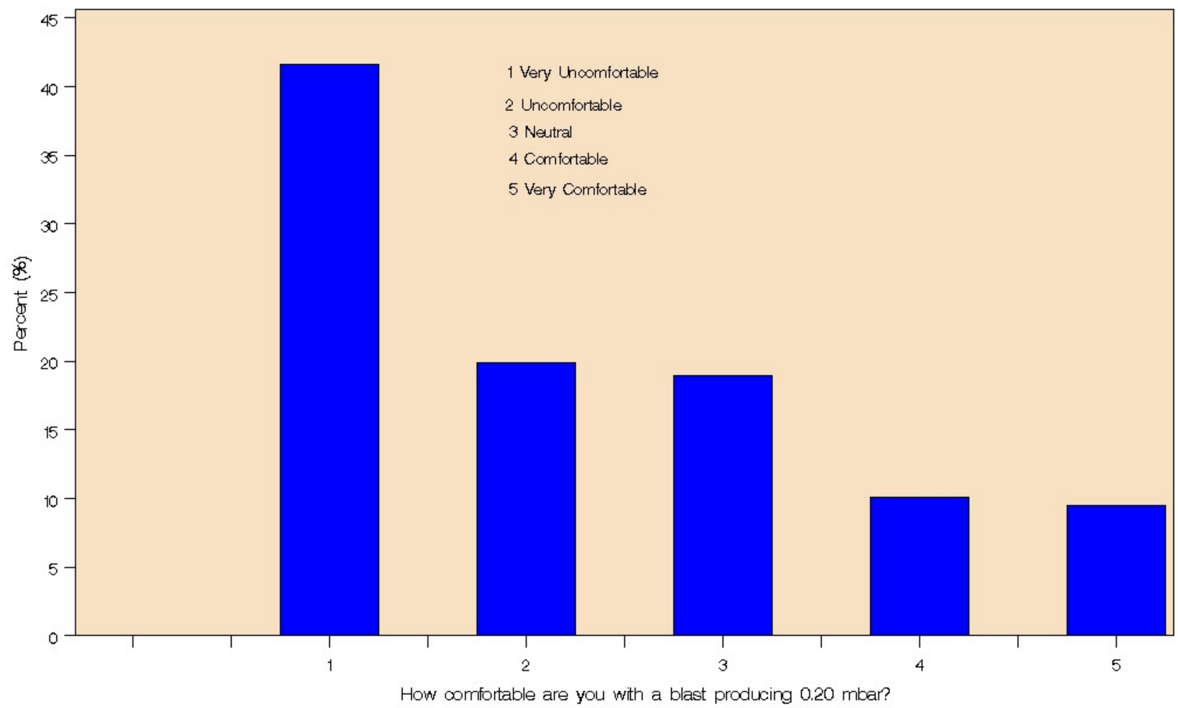


Figure 1.69 Question 15: How comfortable would you be with a blast producing POINT 2 millibars of airblast overpressure?

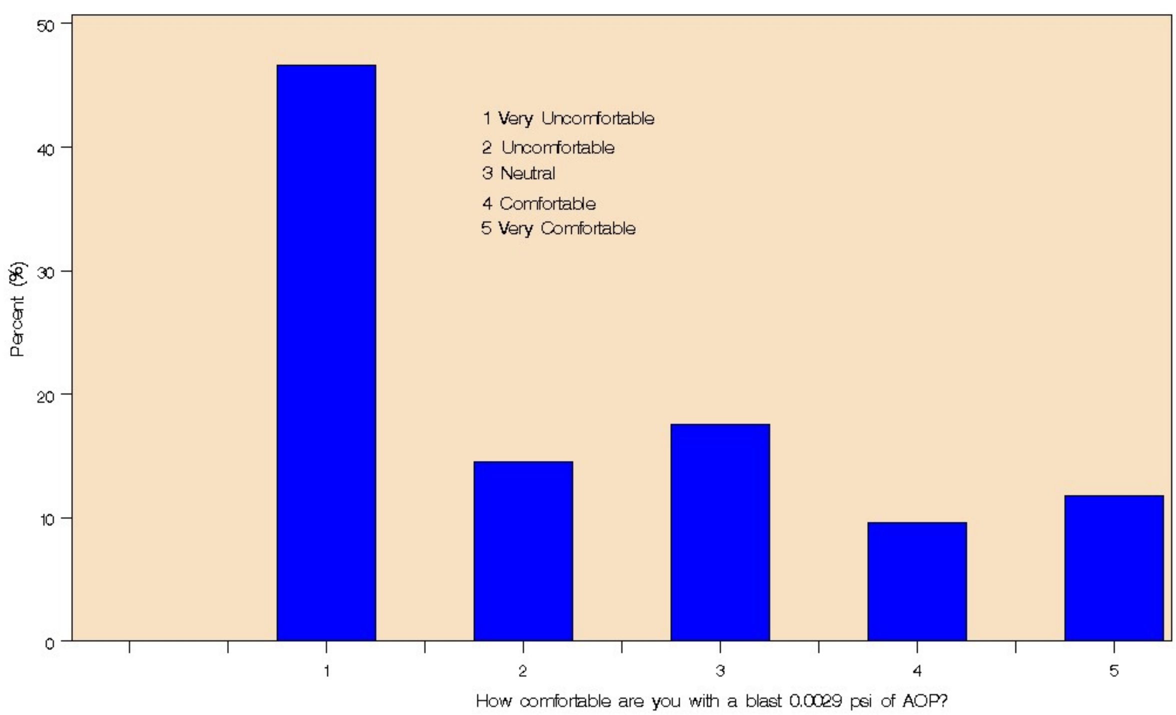
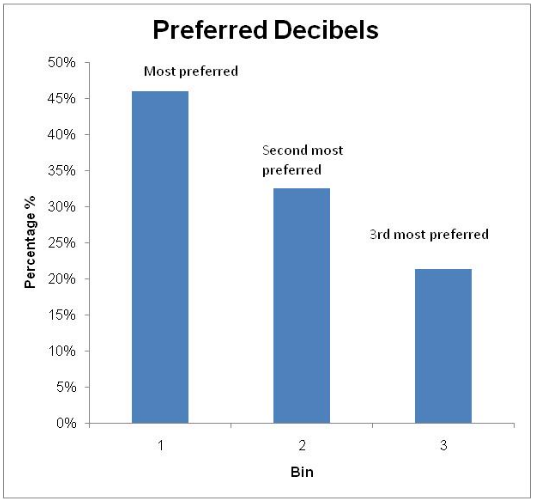
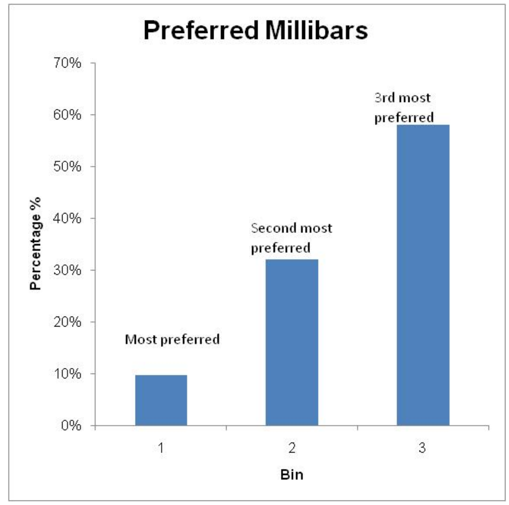


Figure 1.70 Question 16: How comfortable would you be with a blast producing 2 POINT 9 THOUSANDTHS PSI of airblast overpressure?

Question 17 (Figure 1.71) asked specifically which unit the resident would most prefer to have airblast data reported to them. The two most preferred units were decibels and PSI with 46% and 45.4% respectively. Millibars gained only 9.8% of the most preferred vote. When comparing the two most preferred units it is important to remember questions 14 and 16. When blast pressures are communicated in PSI there is 10.1% less response in the "very uncomfortable" and "uncomfortable" range when compared to decibels. This shift away from uncomfortable is concurrent with a rise in the comfort level of the interviewed by 8.5% between decibels and PSI. When it comes to the emotions of people incremental improvements like this are key to making them feel more at ease with what is happening around them.





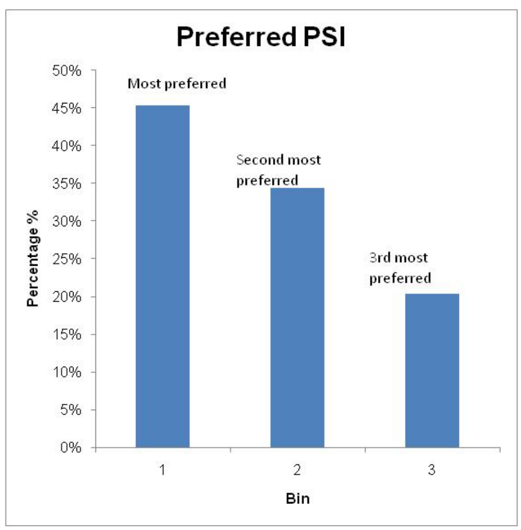


Figure 1.71 Question 17: Preferred method for receiving airblast measurements.

Like questions 14-16 the level of "very uncomfortable" stays in the majority for questions 18-20, but this time for amplitude and frequency (Figures 1.72-1.74). These questions ask the comfort level about a single blast but the units were changed in each question. Of the three units the blast ground vibrations was communicated in inches per second and Hertz, as well as, inches ranked comparably low. Inches per second and Hertz had a 69.4% response in "very uncomfortable" or "uncomfortable" and a 14.6 % response with "comfortable" or "very comfortable". Inches alone had a 70.8% response in "very uncomfortable" or "uncomfortable" and a 15.7 % response with "comfortable" or "very comfortable". Millimeters ranked the highest with a 60.3% in "very uncomfortable" or "uncomfortable" and a 23.3% response with "comfortable" or "very comfortable".

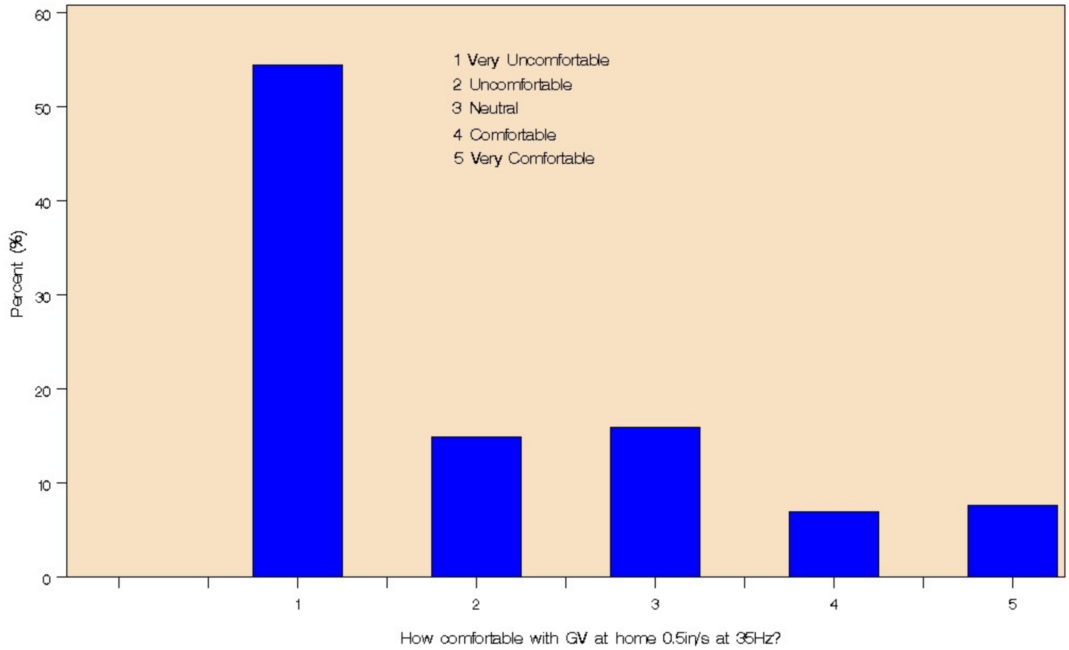


Figure 1.72 Question 18: How comfortable would you be with ground vibrations at your home with velocity in the range of POINT 5 inches per second at 35 Hertz?

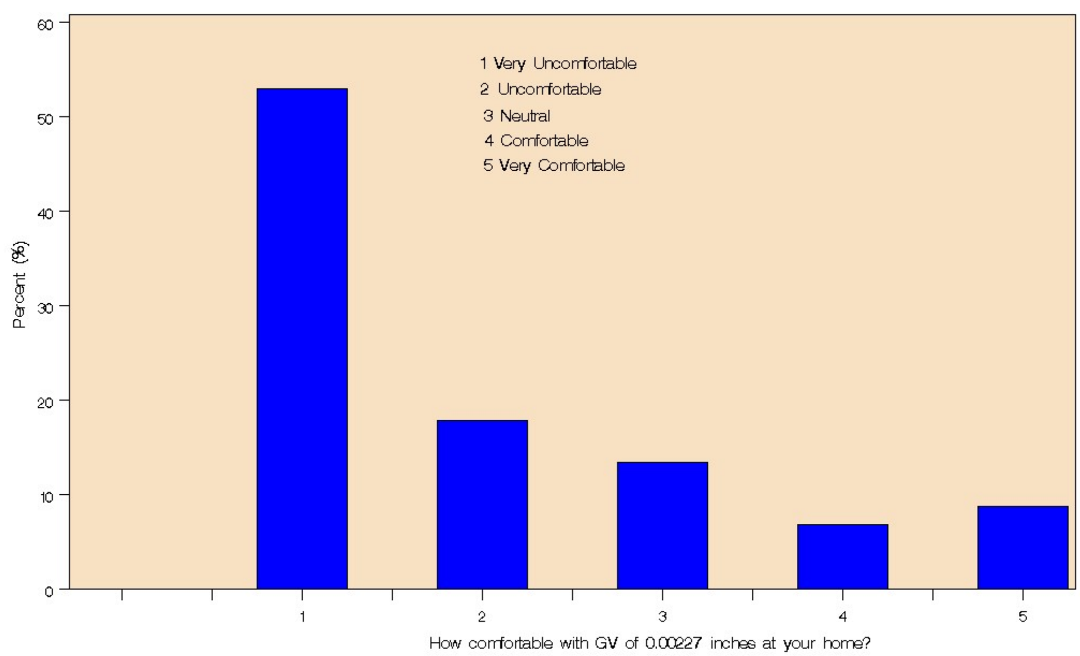


Figure 1.73 Question 19: How comfortable would you be with ground vibrations of 2 POINT 27 THOUSANDTHS inches at your home?

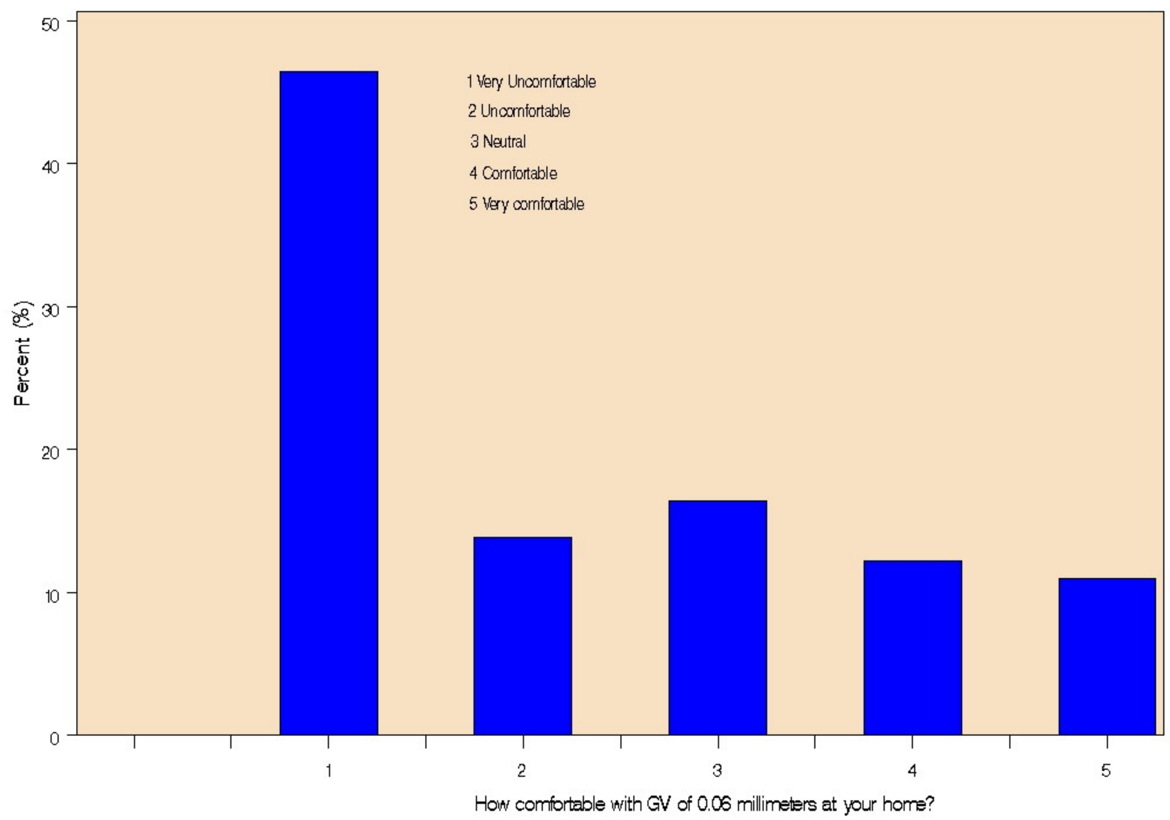


Figure 1.74 Question 20: How comfortable would you be with ground vibrations of POINT 06 millimeters at your home?

Question 21 (Figure 1.75) asked specifically which unit the resident would most prefer to have ground vibration data reported to them. The most preferred unit was inches of movement alone with 51.3%. Inches per second and Hertz gained 26.4% of the most preferred vote. Millimeters received 23.3% of the most preferred vote. Even though people chose inches of movement as the preferred unit for communicating ground vibrations from blasts, the results from questions 18-20 contradict this. This is directly contradicted by the results from question 20 in which it was shown that millimeters produced the most comfort when the interviewed was presented with an actual ground vibration value (Figure 1.74.) Questions 18-20 and 21 highlight the difference between which blasting units an individual thinks they are most comfortable with and what level of comfort is actually evoked by a blasting unit.

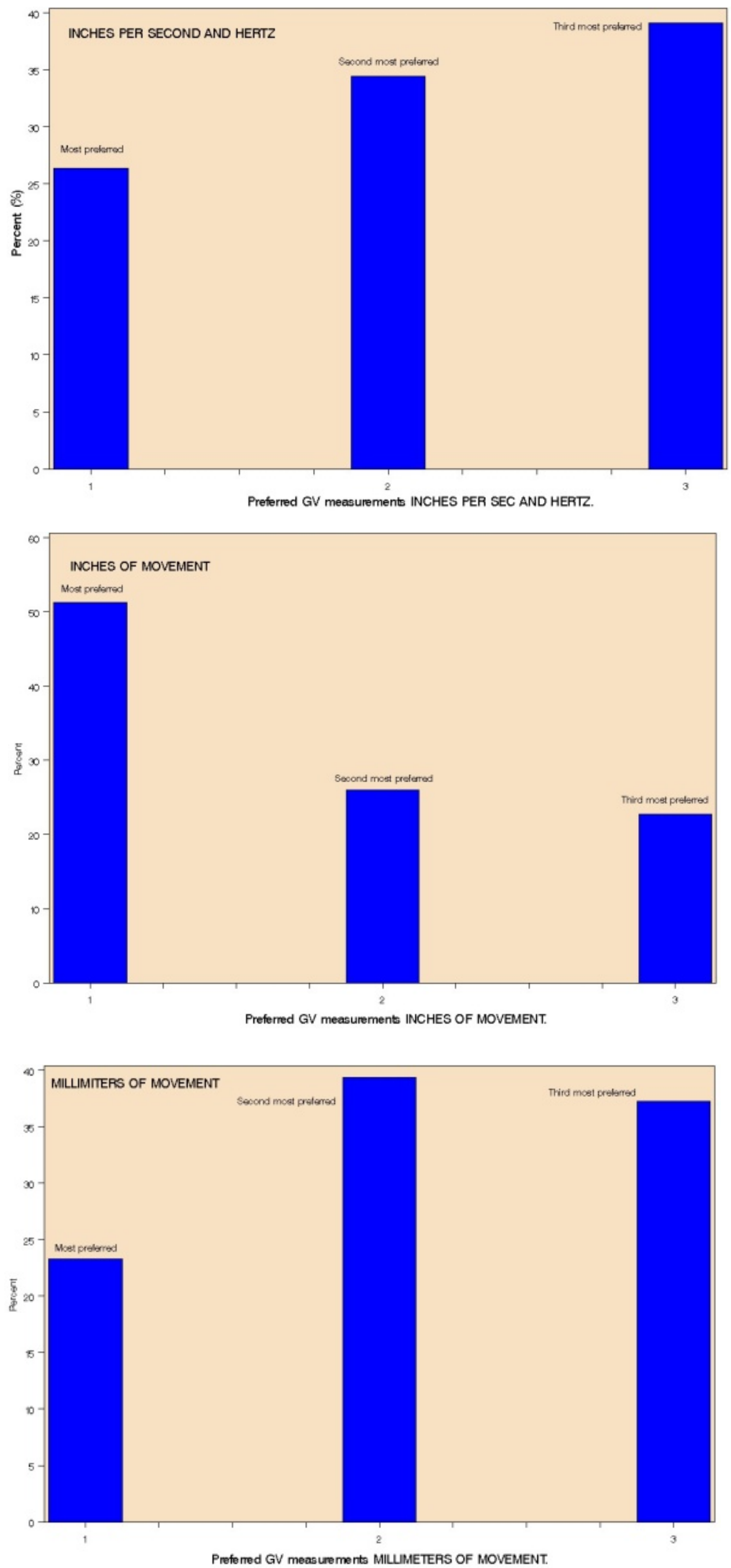


Figure 1.75 Question 21: Preferred method for receiving ground vibration measurements.

Questions 22 and 23 (Figures 1.76-1.77) were asked in order to determine overall agreement with blasting procedures and federal safety limits. These responses could be used for future analysis, but no conclusions were drawn specifically from this data.

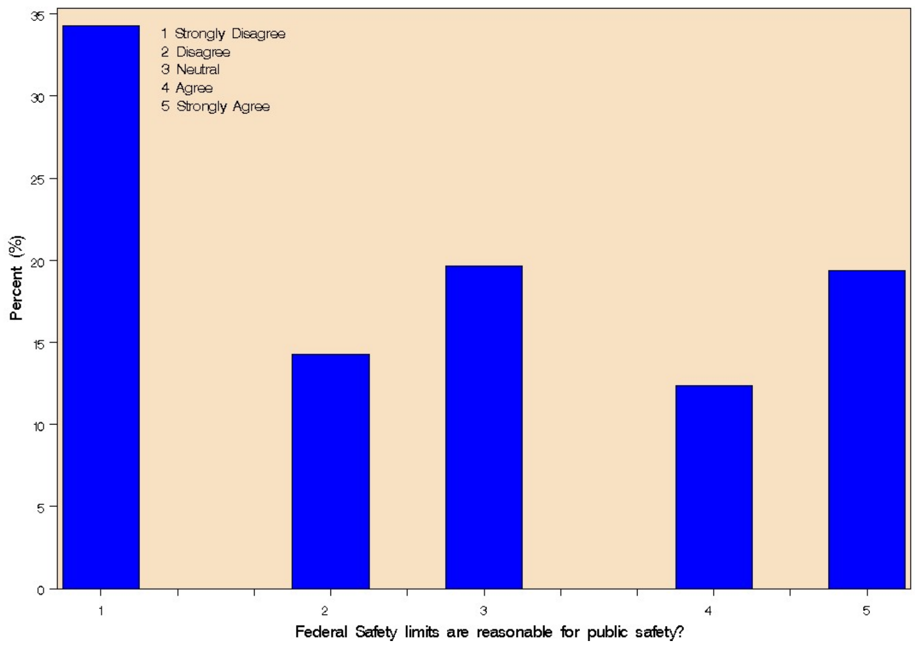


Figure 1.76 Question 22: Federal safety limits are reasonable for public safety?

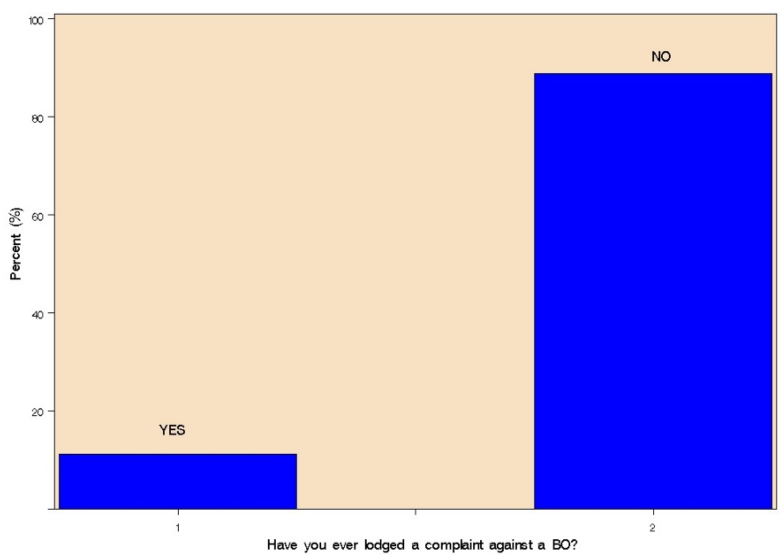


Figure 1.77 Question 23: Have you ever lodged a complaint against a blasting operation?

Knowing whether or not and individual has a job is important because it allows it to be seen if they are away from their residence at times in which blasting is normally conducted. Question 24 (Figure 1.78) asked whether the respondent was employed outside the home.

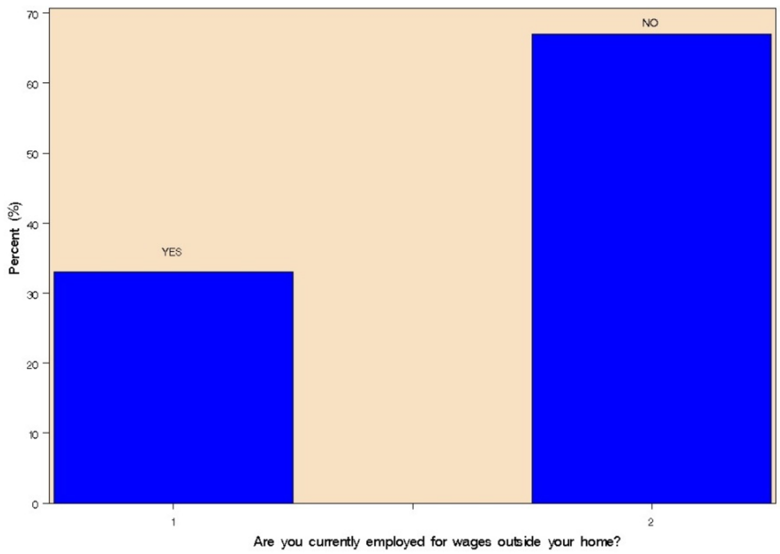


Figure 1.78 Question 24: Are you currently employed for wages outside your home?

Noting which shift and individual works is important because it allows it to be seen if they are at work at times in which blasting is normally conducted. Figure 1.79 shows the results from Question 25 and the distribution of respondents on day, afternoon and night shift.

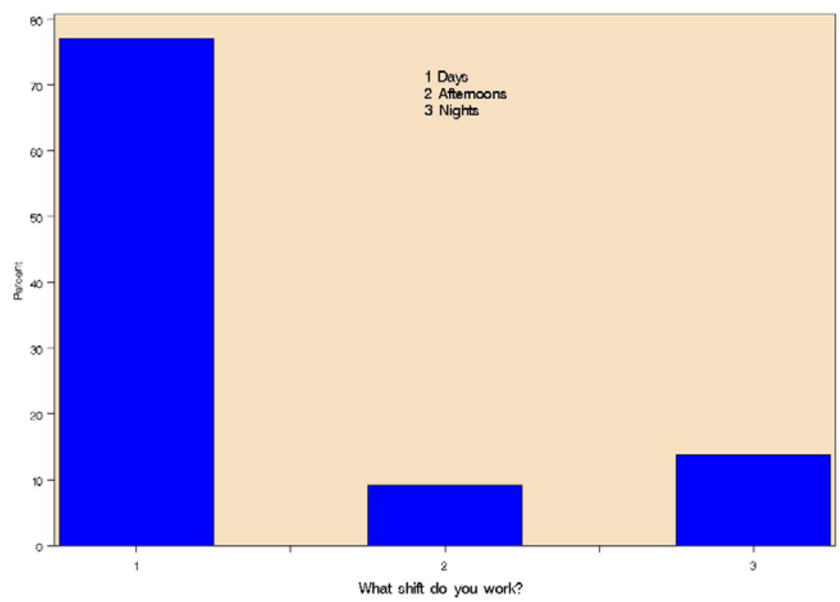


Figure 1.79 Question 25: What shift do you work?

A survey is only effective and well designed when it is widely and easily understood. Question 26 (Figure 1.80) checked for an understanding of this survey. Of those who took this survey 88.8% had an "Excellent" or "Good" understanding of the questions in the survey. 7.8% had a "Fair" understanding, and 3.4% had a "Poor" understanding. It is felt that these are very good results and the survey was well conceived.

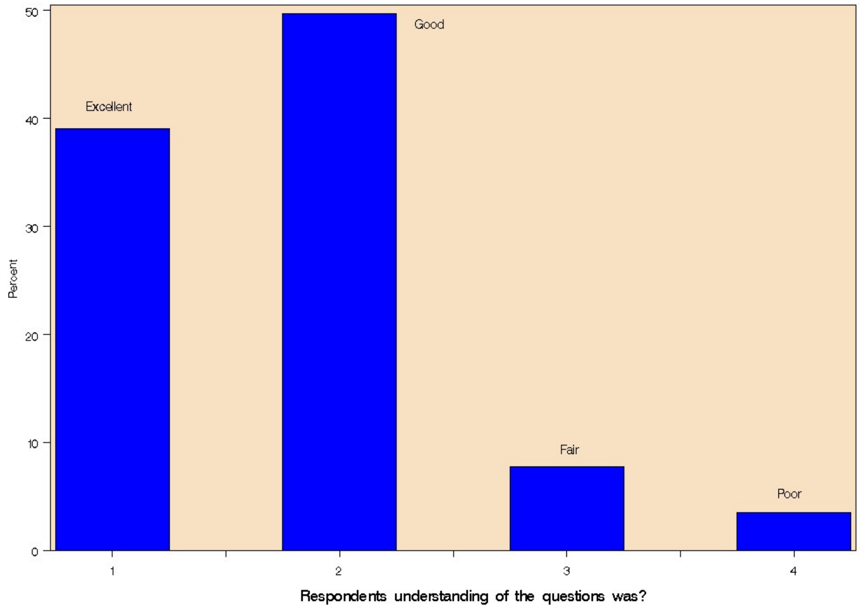


Figure 1.80 Question 26: The respondents understanding of the questions were?

The FIPS code was assigned to individuals based upon which county they reside. Code 54005 was for residents in Boone County, West Virginia and Code 54045 was for residents in Logan County, West Virginia. Figure 1.81 shows the percentage represented in each county.

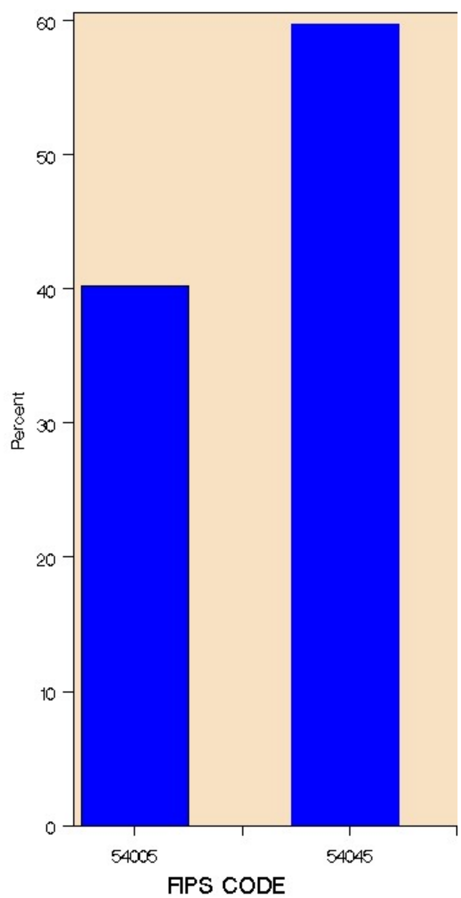


Figure 1.81 Question 27: The FIPS code was?

1.6.4 Interpretation of Survey Results

The majority of the questions in the surveys evaluated the comfort levels of individuals about several reporting units for ground vibrations and airblast. Current reporting practices have shown to be ineffective for both communication and creation of sound policy. Since these reporting practices are interwoven into public policy, recommendations will need to be made as to the requirements listed in the regulations. It is hoped that the results of this work will be utilized to create an open and candid relationship with the public, regulators and administrators, and the blasting industry. A subsequent goal is to reduce the amount of complaints from residents in proximity to blasting operations by creating an understanding of the process involved, through the implementation of the recommendations of this work.

The recommendations created here will be presented to the industry through conferences, journals, and other publications. Hopefully, the process can continue through implementation; although, this will be a long process over many years.

Two important questions which this survey was designed to help answer were: Do people understand the units that blasts events are reported in? Are there alternative units that people are more comfortable with?

The units that airblast is communicated to the public is currently decibels. This unit was perceived, by the majority of the interviewed who knew or claimed to know what decibels are, to be associated with sound or noise, not pressures (Figure 1.61.) Although decibel is the unit that gained the majority of preference from the interviewed, decibel was not understood to be a unit of pressure. The unit of decibel was preferred by 0.6% over PSI. The unit of PSI was understood to be related to pressure by 58.7% of those who claimed they knew what PSI was.

In addition to being more understood PSI instills more comfort than decibels (Figures 1.68 & 1.70.) When the airblast was communicated in PSI there was a 10.1% less response in the “very uncomfortable” and “uncomfortable” range when compared to decibels. This decrease in uncomfortable was countered by a rise in the comfort level of the interviewed by 8.5% between decibels and PSI. The switch from decibel to PSI for reporting blast over pressure is the type of improvement to be made to foster a better means of communication between members of the blasting community and their neighbors. When it comes to communication between people, both understanding what’s being said and feeling comfortable with what’s being reported is critical to making them feel more at ease with what is happening around them.

The use of simpler units is advisable. PSI is the recommended choice of the three units selected in this study for reporting airblast measurements. This is based upon the data gathered by this survey that suggests that PSI is understood to be related to pressure and also PSI instills more comfort in the individuals interviewed. It is believed that the higher comfort values for PSI are generated by the fact that many people are familiar with the unit, based on regular activities such as tire maintenance on their personal vehicles.

Results for analysis of questions involving units for ground vibration measurement yielded similar conclusions. Currently ground vibrations are communicated to the public in inches per second and Hertz. This unit was not found to be the most preferred unit by the population of this survey, nor did it produce the best comfort levels. Average comfort values were highest for millimeters of displacement as opposed to peak particle velocity and frequency or inches displacement; however, the distribution shift was marginal suggesting that there is perhaps another variable which could instill higher comfort levels. Future studies could ask qualitative questions about the descriptors for the units to provide insight as to why comfort levels were low. For instance, respondents may have been uncomfortable with the word displacement or vibration or movement. Perhaps there is a better term that would not cause such anxiety. Even though the data does not solidly support millimeters displacement as an optimum unit for ground vibration reporting, it is advisable to use such units for simplicity when communicating with neighbors.

1.6.5 Comparison to Past Work

A similar survey was conducted in the summer of 2006 around Missouri and Arkansas limestone quarries. The survey employed in 2006 was a predecessor to that which was used during this study and as a result the two surveys share many questions. A notable difference was the fact that the 2006 survey was conducted via mailers as opposed to the phone interviews conducted in this study. This section will compare the results from the phone survey and two of the surveys from 2006. The two surveys selected from 2006 are from populations less than a mile from the mine (Alpha survey) and greater than a mile from a mine (Beta survey). The Alpha survey was returned by 149 individuals and the Beta survey was returned by 52 individuals. Keep in mind that the results from the phone survey combine these two population subsets. The full results from the 2006 survey can be found in Dr. Braden Lusk's dissertation entitled *An Analysis and Policy Implications of Comfort Levels of Diverse Constituents with Reported Units for Blast Vibrations and Limits: Closing the Communication Gap.*

The first sets of questions that are shared by both surveys are those which ask the individuals understanding of each of the three units. The wording between the 2006 survey and the phone survey differ slightly. The 2006 survey posed the question: What do you associate with decibels (millibars, psi)? The group surveyed who lived near blasting operations (Alpha group) responses' to this question can be seen in Table 1.5, and the Phone survey responses'' can be seen in Table 1.6.

Table 1.5 Summary of responses (percentage) to Alpha Survey (< 1 mile), What do you associate with decibels (millibars, PSI?).

	Decibels	**millibar**	**PSI**
Sound	74.3%	2%	1.3%
Pressure	2%	27%	61.2%
No Answer or "Don't Know"	19%	57.2%	28.3%
Other 1		5.3% Weather	13%
Other 2		8.6% Other	

Table 1.6 Summary of responses (percentage) to Phone Survey(< 1 and >1 mile), What do you associate with (decibels, millibars, PSI?)

Decibels		millibars		PSI	
Measure of Sound	8.9	Measure of Sound	1.4	Pound per sq in-pound-force per sq in + unit pressure	2.6
Mathematicial Relationship	1.4	Units of Pressure, Atmospheric Pressure,	0.9	Pound per square in - no mention of pressure	2.9
Measure of Noise, Vibration	6.6	Measure of Wind	0.6	Measure of Pressure or Stress	19.8
Measure of Power or Amplitude	0.6	Measure of Sound Shaking Ground	0.3	Measure of Distance	0.3
Measure of Blasting	3.4	Measure of Velocity/Speed	0.9	Reference to an Activity of situation - no definition	2.9
Related to Hearing	1.7	Measure of Force from Blasting	1.1	Pressure Per Square Inch	5.5
Transmission of Sound	0.3	Measure of Movement of Air/Ground	0.3	Measure of Movement	0.9
Measure of Frequency	2.9	Measure, Unit	0.6	Pounds of Pressure	2
Volume of Sound	11.8	Measure of Pressure	2.6	Miscellaneous	2
Measurement of Pressure	2.3	Miscellaneous	0.6	Don't Know	59.9
Miscellaneous	4.6	Don’t Know	89.7		
Don't Know	53.4				
	97.9		99		98.8

Although more exaggerated in the Phone Survey, the order of confidence of interviewed in knowledge of each unit remains the same as the Alpha Survey. In both surveys the interviewees responded to this question with the answer of “don’t know” most to millibars second most to PSI and the least with decibels. It is unclear whether this exaggeration is a product of natural bias in the form of survey or other variables such as region or prevalence of types of mining around the demographic (Coal mines, Limestone quarries). Another factor to take into account in this results are related with the way the survey was conducted. In the situation where the survey was conducted using mail letters, the interviewee has more “thought time” to answer the question against the phone survey where the response would be more “impromptu” or lack of preparation.

The majority of those who thought they knew what decibels were associated decibels with something to do with sound in both interviews. As for millibars both surveys showed that the most popular association (aside from not knowing) was with some form of pressure. With PSI pressure again was the most common association in both surveys. In both surveys PSI was the most understood unit of the three.

The total percentage for each question from the Phone survey does not add up to 100% because of some errors in data collection. Either the interviewee did not answer the question, or the question was skipped by the interviewer.

The next set of common questions were those that asked the interviewees comfort level about an equivalent airblast reported in the three different units. The 2006 survey also used a Likert scale. The wording between the 2006 survey and the phone survey varied slightly. The 2006 survey posed the question: Based on good scientific research, the Federal Safety limit for airblast overpressure is 133 decibels (0.89 millibars, 0.013 psi). How comfortable are you with a blast producing 120 decibels (0.2 millibars, 0.0029 psi) of airblast overpressure? The Alpha group's responses' to this question can be seen in Figure 1.82. Likewise the results from the Phone survey are presented in Figure 1.83.

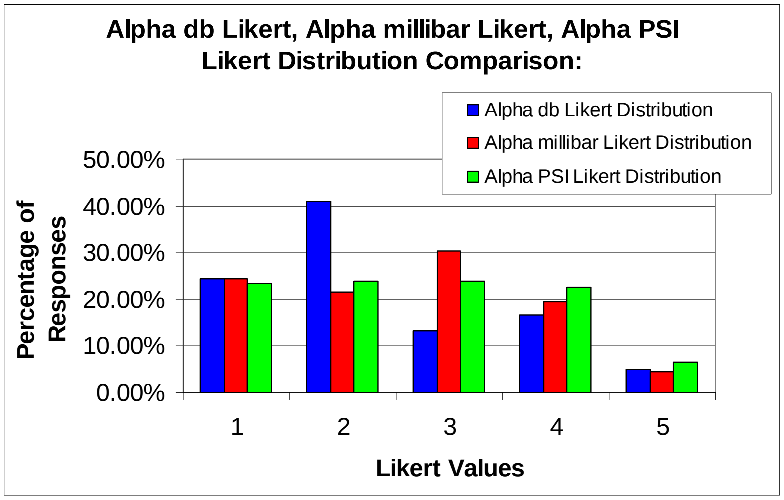


Figure 1.82 Distribution comparisons for Alpha Likert responses to pressure.

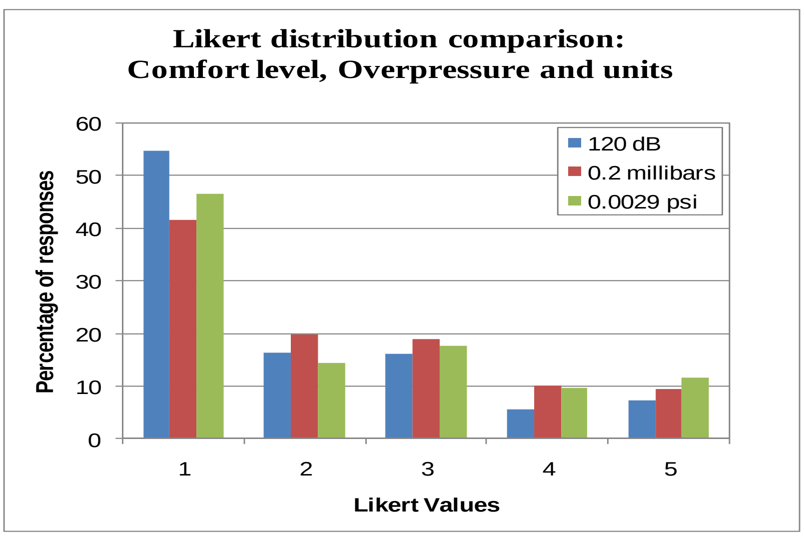


Figure 1.83 Distribution comparisons for Phone Likert responses to pressure.

When comparing these two sets of results some similarities and differences can be found. Although the individuals from both surveys displayed a general tendency to lean towards discomfort despite the units of reportage this tendency is much more apparent in the recent phone survey. This phenomenon could be a regional one linked to any number of variables such as type of mining near the interviewed or, images of mining that they have been exposed to. Observing the trends between units one can see the lack of comfort most prevalent with the unit of decibels. This discomfort of decibels is found in both surveys. Those who were interviewed during the Alpha and Phone surveys had slightly more comfort with PSI although the comfort levels were relatively close both between millibars and PSI.

The final set of common questions were those that asked the interviewees comfort level about an equivalent ground vibrations reported in the three different units. The 2006 survey also used a Likert scale. The wording between the 2006 survey and the phone survey varied slightly. The 2006 survey posed the question: Based on good scientific research, the Office of Surface Mining and Reclamation Enforcement also has a regulated safety limit for ground vibration of 1.8 inches/second at 35 Hz (0.00818 inches, 0.21 millimeters). How comfortable are you with ground vibrations at your home with velocity in the range of 0.5 inches/second at 35 Hz (0.00227 inches, 0.06 millimeters)? The Alpha group's responses' to this question (<1 mile) can be seen in Figure 1.84, while the Phone survey responses'' are found in Figure 1.85.

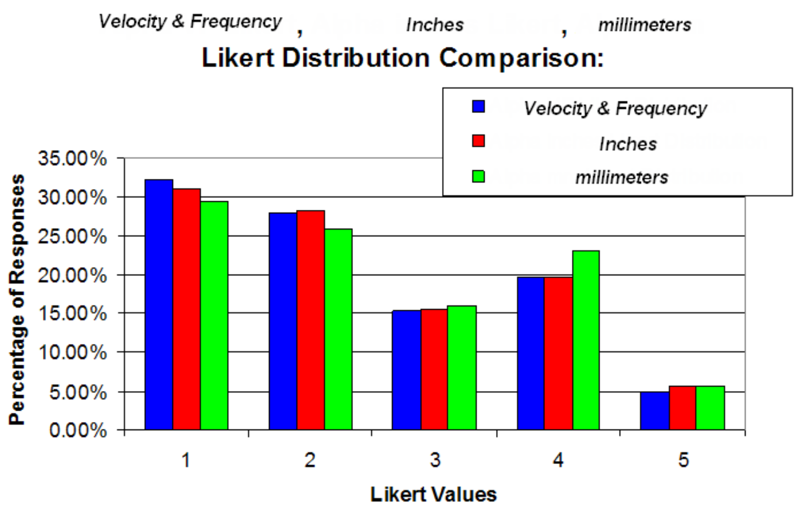


Figure 1.84 Distribution comparisons for Alpha Likert responses to vibration units.

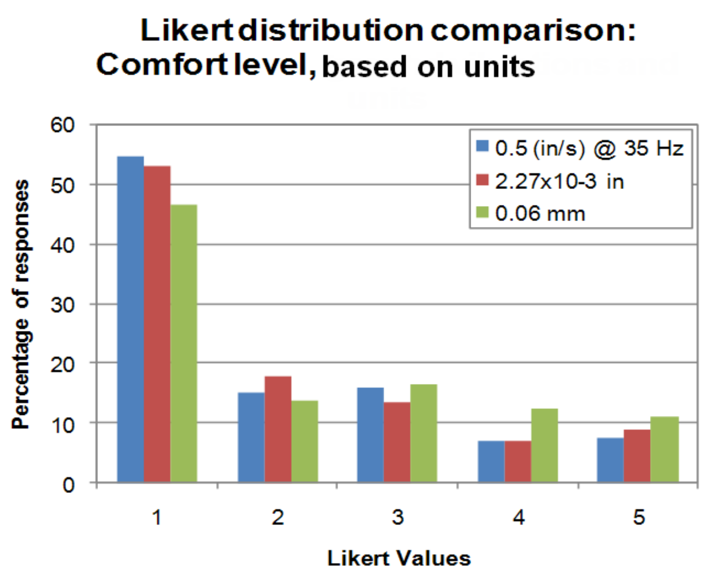


Figure 1.32 Distribution comparisons for Phone Likert responses to vibration units.

When comparing these two sets of results some similarities and differences can be found. Again individuals from both surveys displayed a general tendency to lean towards discomfort despite the units of reportage this tendency is much more apparent in the recent phone survey. Much like the question about overpressure units, this phenomenon too could be a regional one linked to any number of variables such as type of mining near the interviewed or, images of mining that they have been exposed to. Observing the trends between units one can see the lack of comfort most prevalent with the units of inches/second and frequency. The discomfort with this unit system is found in both surveys. Those who were interviewed in both surveys were most comfortable with the vibration being reported in millimeters. There is not a strong trend supporting any unit system; however, reporting in millimeters or inches of displacement seem to provide a simpler method for communication.

1.6.6 Public Relations

It is technically and scientifically proven that blast vibrations already have accepted limits that are safe and preclude damage from blasting. The problem of complaints about blast vibrations is now one of annoyance levels and public relations. Public relations overall offers the most fruitful path as zero annoyance will only occur when blast vibrations are completely eliminated. Mining operations and regulatory agencies should create proactive public relations policies especially concerning the use of explosives. Surveys could be a pivotal tool for determining what types of information neighbors might like to see regarding blast vibration and airblast data. Baseline surveys could determine a level of education that is currently found amongst the majority of its neighbors. This provides an excellent starting point for developing quality public-mine relations. Other factors that would play an important role in opinions of neighbors would include age, hours of work, and the history of the mines presence.

The first step in achieving positive public relations is educating the public on how blasting operations conduct business, and how these operations affect the public. People are naturally uncomfortable with events that they perceive as potentially dangerous to their homes. Current vibration reporting practices leave much to be desired when considering that the public must understand what is actually happening when blasting takes place. In order for the blasting industry to sustain positive public relations, the information that is reported about each particular blast not only must be easily understood by the public, policy makers, and explosives users alike, but it is imperative that they also have a good comfort level with these numbers in order to close the communication gap.

2 SUMMARY OF RESULTS AND CONCLUSIONS

2.1 Acoustic Data Conclusions Summary

Analysis of data shows that during a blast event, there are two types of acoustic response inside the house. The sounds are related to the source of generation (Figure 2.1). In the near field the source can be either airblast or ground vibration while the ground vibration is the predominant generator in far field. In this case near field includes events within 2500 ft, and greater distances were considered far field. This distinction was based on the ABRF analysis required to generate Figure 1.36. The amplitude and type of acoustic sound during a blast event (rattle, slams, etc) are related to the items placed in each location in the house. The monitoring system used to collect the data described in this research can differentiate between sounds induced by ground vibration and that produced by airblast due to the difference in times of arrival.

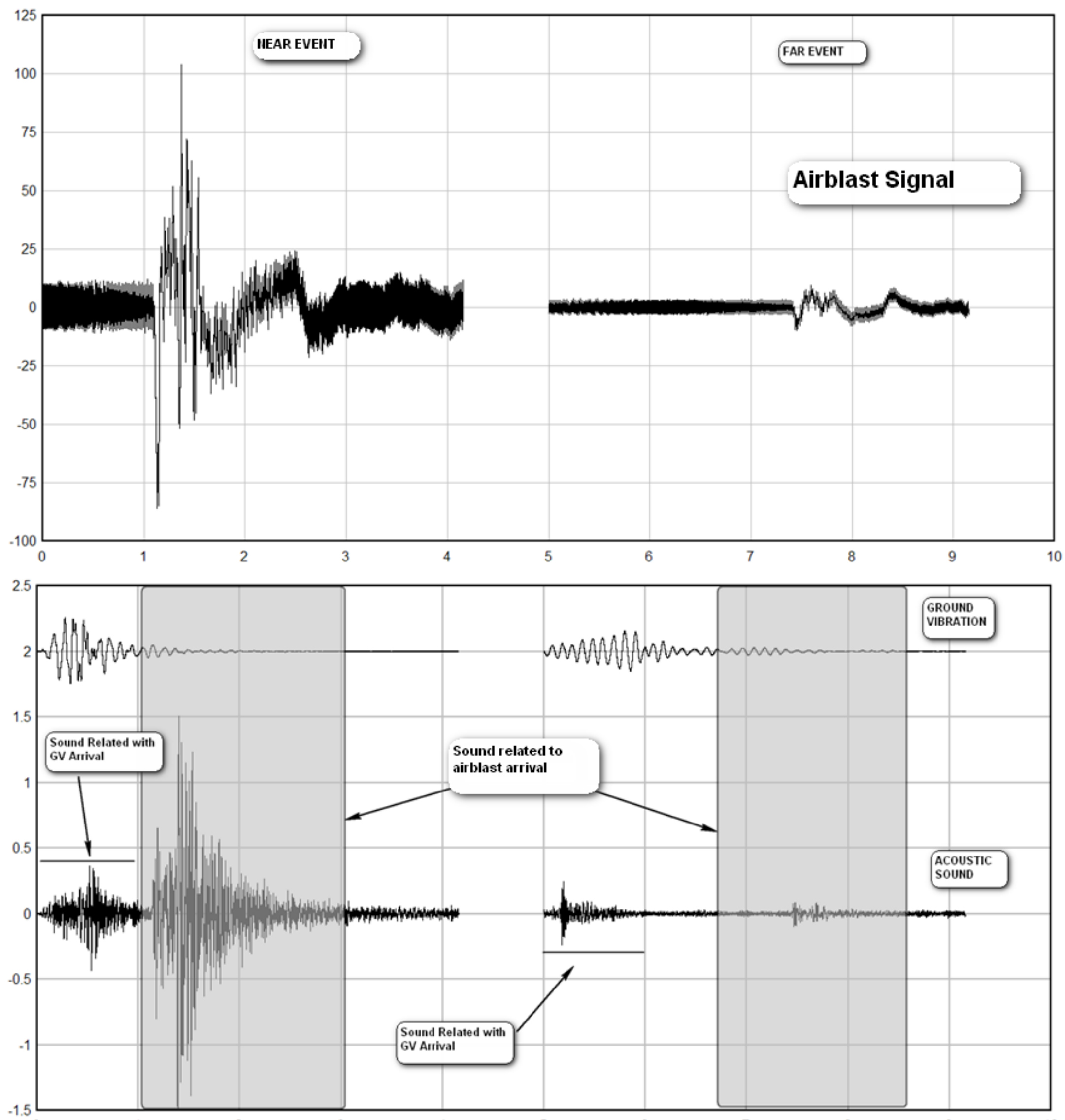


Figure 2.1 Types of acoustic sound and their sources.

In a blast event (near and far) the two types of acoustic responses inside a house are present however, the dominant generator varies.

In order to establish the source of acoustic response, a new factor was proposed, the Airblast Response Factor (**ABRF**) relating the peak arrival times of the response of the house (midwall response) to the time of peak for the Airblast.

$$ABRF = \frac{Time_{Peak\_Response}}{Time_{Peak\_Airblast}}$$

In this research, for events (blasts) with distances to the monitored house less than 2500 ft (near field), maximum acoustic response often occurred at the same time as maximum Airblast. Due to this the ABRF is close to one and the acoustic response inside the house during a blast event is related to the amplitude of airblast. Some events in the near field did generate ABRF values less than one meaning that ground vibration was the dominant sound generator.

When the major source of acoustic response is the airblast, comparisons with TV sound shows that the maximum amplitudes are between 8 and 10 times the TV sound. In these cases, the acoustic response generated by ground vibrations had amplitudes between 1.5 and 2 times the TV sound.

On the other hand, for events occurring at a distance greater than 2500 ft, and values of ABRF much lower than one (far field), acoustic response generated by ground vibrations are predominant over sounds generated by airblast. In all cases beyond 2500 ft, ABRF was less than one and thus ground vibration generated the maximum sound response.

The analysis shows that when the source of acoustic response is the ground vibrations it is more difficult to correlate the sound amplitude with ground vibration amplitude, however the comparison with TV sound as reference shows that acoustic sounds amplitudes are between 1 and 1.5 times the TV sound.

Analysis of the dataset showed that the frequency content of the sounds recorded inside the house was not related to the frequency content of the airblast or ground vibration regardless of the generating source of the sound. As expected, the frequency content of the acoustic response recordings inside the house were in the audible range, were generated by the house responding to the blast vibrations (ground vibration and airblast), and were not related to the airblast imparted on the house alone. This suggests (as expected) that neighbors would not be able to tell the difference between sounds generated by airblast and those generated by ground vibration without further information, and proves that residents can not actually hear airblast inside their homes.

The ability to determine that peak sound response is always generated by ground vibrations for far field events (>762 meters (2500 feet)) is important when for public relations planning and response. In this case, if complaints are received from residents living greater than 762 meters (2500 feet) from the blast, ground vibration is likely the source of the complaint. In addition, the data has shown that reducing ground vibration amplitude may not reduce the sound amplitude induced in the house. Furthermore, residents would not be able to audibly distinguish airblast induced sounds from ground vibration induced sounds due to the similarity in frequency content. In such cases, a further investigation into the types of alarming sounds which are causing complaints is warranted.

There is a possibility that preventative measures could be employed to satisfy the neighbor and thus create positive public relations.

2.2 Survey Conclusions Summary

The survey was designed to help answer two questions:
1. Do people understand the units that blasts events are reported in? and
2. Are there alternative units that people prefers?

Currently the public is not comfortable with any of the current descriptors of airblast, now the airblast is communicated to the public in decibels. This unit was perceived, by the majority of the interviewed who knew or claimed to know what decibels are, to be associated with sound or noise, not pressures.

Although decibel is the unit that gained the majority of preference from the interviewed, decibel was not understood to be a unit of pressure. The unit of decibel was equal to PSI unit. The unit of PSI was understood to be related to pressure by 58.7% of those who claimed they knew what PSI was.

In addition to being more understood PSI instills more comfort than decibels (Figures 1.68 & 1.70). When airblast was communicated in PSI there was a 10.1% less response in the "very uncomfortable" and "uncomfortable" range when compared to decibels. This decrease in uncomfortable was countered by a rise in the comfort level of the interviewed by 8.5% between decibels and PSI. The switch from decibel to PSI for reporting blast over pressure is the type of improvement to be made to foster a better means of communication between members of the blasting community and their neighbors. When it comes to communication between people, both understanding what's being said and feeling comfortable with what's being reported is critical to making them feel more at ease with what is happening around them.

PSI is the suggested choice of the three units selected in this study for reporting airblast measurements. This suggestion is based upon the data gathered by this survey that suggests that PSI is understood to be related to pressure and also PSI instills more comfort in the individuals interviewed. It is believed that the higher comfort values for PSI may have been generated by the fact that many people are familiar with the unit, and indeed use it on a regular basis for activities such as tire maintenance on their personal vehicles.

The results involving units for ground vibration measurement yielded similar conclusions. Currently ground vibrations are communicated to the public in inches per second and Hertz. This unit was not found to be the most preferred unit by the population of this survey, nor did it produce the best comfort levels. Average comfort values were highest for millimeters of displacement as opposed to peak particle velocity and frequency or inches displacement; however, the distribution shift was marginal suggesting that there is perhaps another variable which could instill higher comfort levels. Future studies could ask qualitative questions about the descriptors for the units to provide insight as to why comfort levels were low. For instance, respondents may have been uncomfortable with the word displacement or vibration or movement. Perhaps there is a better term that would not cause such anxiety. Even though the data does not solidly support inches or millimeters displacement as an optimum unit for ground vibration reporting, it is advisable to use such units for simplicity when communicating with neighbors. In order to maintain consistency in units between airblast and ground vibration, inches displacement is recommended for reporting ground vibration data.

3 FINAL PUBLIC RELATIONS PLAN

The combined efforts of this project were planned and executed with an end goal of producing useful public relations tools with regards to blasting in surface coal mining. The acoustic response data collected for the project led to some very site specific information; however, much of the information could be applied to other operations in Central Appalachia. In addition to the physical data collected, the survey information added insight to the process for developing public relations tools. The following public relations plan is a recommended public relations plan for the specific site studied for this project. Components of the plan that are site specific will be distinctly called out. These items could be developed for any site using the methodologies described in the previous sections; thus the overall plan can be generally applied to any surface coal operation.

Site specific information for the Raven Crest operation showed that acoustic responses inside of homes are generated by two sources: ground vibration and airblast. In the near field (< 2500 ft), the component that generated the maximum response varied between airblast and ground vibration (ABRF range from 0.1-1.4). In the far field (> 2500 ft), maximum response was generated by ground vibration without exception (ABRF range from 0.0 to 0.4). The proposed AirBlast Response Factor (ABRF) provides a definitive way to determine the source of maximum response given by:

$$ABRF = \frac{Time_{Peak\_Response}}{Time_{Peak\_Airblast}}$$

Figure 3.1 shows site specific data that identifies the far field threshold at 2500 ft for the Raven Crest Mine.

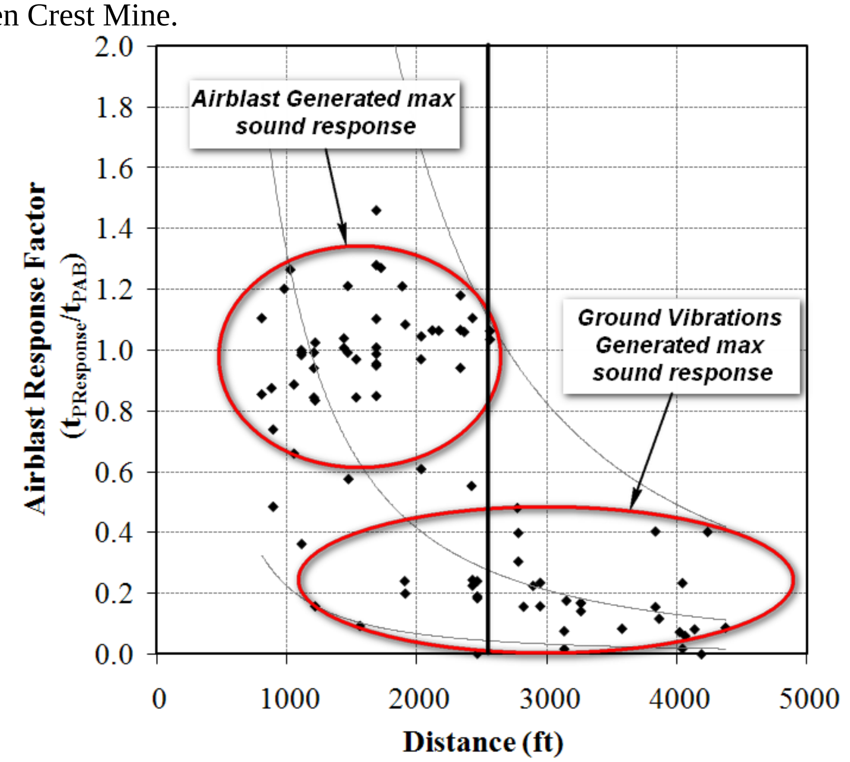


Figure 3.1 Airblast Response Factor (ABRF) vs Distance for Raven Crest Mine

A plot similar to Figure 3.1 could be developed for any operation utilizing blasting. The application for this information is in the form of neighbor relations. For example, when neighbor complaints come from distances greater than 2500 ft from the blast, the source of the complaint can most likely be attributed to ground vibration. Likewise, complaints that come from locations closer than 2500 ft from the blast could be attributed to ground vibration or airblast. In the case of near field complaints, more information could be solicited to determine the actual source of the noise complaint. Asking the complainant about the specifics of the sounds that are bothersome could yield identification of the problem. Based on the analysis of the acoustic data, sound responses generated by ground vibration are generally sudden in nature and are associated with objects within the house. Potential abatement of the complaints could be assisting the homeowner or resident with securing the loose items that caused a startling noise. Conversely, air blast sound responses were more closely associated with a louder sound that was not as related to the objects in the house. Determination of the source of the complaint will definitely aid the mining operation when troubleshooting blast designs to make the blasting more palatable to neighbors. Blast design parameters can be adjusted to shift energy and reduce airblast and or ground vibration specifically.

A few other general observations gleaned from the data analysis could prove useful for public relations communication. These general observations include:

- In order to compare the levels of acoustic response due to blasting, TV sound was used as a proxy. Some records showed acoustic response up to 10 times background sound (TV sound).
- No frequency dependence was observed in the analyzed records, the intensity (amplitude) and frequency of the acoustic response is not related to frequency or other characteristic of the source (ground vibration or airblast).
- Large noises, rattling and "knick-knack" sounds depend on the objects and specific location inside the house.
- Based on the phone survey, locals do not understand deeply the units used to quantify airblast or ground vibrations.
- The data showed that residents do prefer airblast and ground vibration data in linear units. The scales are more readily understood.

By combining the conclusions from the two distinct portions of this project, a general public relations program can be developed that includes the following items. This public relations template is especially useful for new operations; however, component of the plan can also be used for active operations.

- Survey mine neighbors to determine preferred units for communication as well as levels of understanding for the units used to describe airblast and ground vibration.
- Utilizing the results of the survey, design a site specific blasting seminar to address the specific concerns of neighbors. The level of information presented should be adjusted to meet the understanding level of the survey participants. The seminar should describe vibrations and address regulatory limits. Offer this blasting and vibration units seminar to neighboring residents prior to the start of mine blasting.

The seminar should prepare the residents for what they might experience during blasting.

- Work closely with the party selected to conduct preblast surveys at neighboring homes. The preblast surveyors should be instructed to look for and identify loose items in the homes that could generate a startling "slam" or noise. They should also identify potential noise sources that are a part of the house such as loose windows or doors. The mining operations could assist the resident in securing loose windows and doors with weather stripping and adequate latches. Finally, preblast surveyors should be encouraged to discuss how the blast might be experienced.
- During the blasting seminar, and preblast surveys, provide neighbors with contact information that will allow them to have questions about blasting answered.
- Guide residents to less noisy rooms during the blast. If the mine is on a regular schedule, the neighbors might be encouraged to experience the blast from one of the less responsive rooms of the house. For example, the site specific data for this study showed that the kitchen repeatedly generated the maximum acoustic response. The resident might be encouraged to avoid the kitchen during blasting.
- Continue communicating with neighbors as mining progresses. Report ground vibration and airblast data in the preferred unit system. A linear scale such as PSI is recommended for airblast data while a simple unit system such as inches of displacement is recommended for ground vibration data.

4 FUTURE WORK

4.1 Acoustic and Vibration Data Collection

The conclusions are appropriate for the specific site monitored during this study. Future studies should collect similar data in other areas. The effects of geology, topography, home construction, and wide ranging blast parameters can only be effectively determined by expanding the scope of data collection. Future proposals will be written to continue this research:

Continued research using the data already collected will include an in depth analysis of captured events that were not triggered by a blast. By analyzing the sounds in the home that were triggered by events such as thunderstorms, haul trucks, slamming doors, and other non blast events, more can be gleaned concerning how neighbors perceive blast events. There is a distinct possibility that blast events create less noise in the home than other normal events such as those listed above.

The data collected during this study can be analyzed for many correlations to blast parameters such as timing, shot configuration, explosive weight, and weather conditions. There are multiple possibilities when considering the analysis methods to employ. It is expected that the database will continue to be analyzed and expanded as the research continues. Future studies could also employ this monitoring system in an environment where blast parameters could be easily changed in a controlled manner. This would allow for more correlation between sound generation in the house and blast parameters.

The monitoring system will include a calibrating the acoustic response microphones. While the microphones are not calibrated instruments and are not expected to be linear in response, a sound pressure level meter could be added to the system to provide quantitative information about the sounds generated. In this study, the TV sound was used as a reference proxy, but a calibrated instrument would provide much better data. The monitoring system should also be integrated into a whole structure response system by utilizing geophones and accelerometers at specific points inside the monitored house.

4.2 Survey Data Collection

In order to more clearly define the possible advantages to educating quarry neighbors for public relations efforts, more surveys should be administered. The study could include two groups that reside away from any blasting operations. One group could be exposed to educational efforts followed by a survey asking about blasting and reporting units. The other group would then be administered the same survey without any educational efforts. This study would potentially quantify the positive effects of educating mine neighbors on blasting and how it is reported. It could also allow for honing public relations and educational efforts for the best results.

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