Blasting Attenuation Study
Crystal Ridge, MacDonald Ranch and MacDonald Highlands

For the

City of Henderson
240 Water St.
Henderson, Nevada

Prepared by

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President

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Dr. Aimone-Martin is President of Aimone-Martin Associates, LLC and a Professor Mining and Civil Engineering at New Mexico Institute of Mining and Technology. She has degrees in geological engineering (with emphasis in geophysics and mining), civil engineering, and mining engineering. Since 1971, she has worked in the mining and construction industries and with geotechnical consulting firms in both the U.S. and Canada, and with Sandia and Los Alamos National Laboratories as a research affiliate. Special projects with national laboratories have included research on electrohydraulic fracture, design of underground nuclear repositories, and solar-powered solution mining concepts for potash extraction. Dr. Aimone-Martin helped to fund for the development of the Center of Explosives Technology and Research at New Mexico Tech with a $5M grant and was Chair of the Mining, Geological, and Environmental Engineering Department for 9 years.

She currently serves as an advisor to Homeland Security and on several national committees and boards including the National Institute of Occupational Health under NIH and the New Mexico Mining Association Board of Directors. She has recently held important U.S. Presidential appointments to the Academy of Sciences of the National Research Council. Dr. Aimone-Martin served 13 years as a Director on the International Society of Explosives Engineering Board (ISEE) and continues to participate on Committees including Seismograph Standards Committee, Public Relations, and Education.

Dr. Aimone-Martin is an international invited speaker, author of over 90 publications, and has received over $ 500,000 in research grants while at New Mexico Tech.

Dr. Aimone-Martin's expertise is in the areas of explosives engineering, rock blasting, structure response to blasting, instrumentation for vibration control and structure response, geotechnical engineering, soil and rock mechanics, foundation design and analysis, risk assessments, regulatory compliance, and public relations. She serves as a consultant to construction, coal, quarrying, and hard rock mining companies in the areas of blast design, vibration monitoring and control, structure response, fragmentation, backbreak control, instrumentation, blasting impact plans, and public relations. Dr. Aimone-Martin has further worked for municipalities in the development of blasting standards and regulations to protect off-site structures and for federal agencies to validate federal safe blasting standards limiting vibration and airblast for general blasting applications throughout the U.S.

INTRODUCTION

A blasting attenuation study was initiated by Aimone-Martin Associates, LLC (AMA) on 2/25/05 for the City of Henderson to record and evaluate vibration and airblast measurements at locations near current blasting south of West Horizon Ridge Parkway along Crystal Ridge, MacDonald Ranch, and MacDonald Highlands. The purpose of this study was to

- evaluate seismograph measurements and data from blasting operators and vibration consultants, VCE, of Las Vegas, Nevada,
- validate measurements recorded by VCE,
- evaluate geological influences that may be contributing to unusual ground vibrations in various directions from blasting operations, and
- evaluate blasting methodology as it may be influencing unpredictable or unusual ground vibrations or airblast.

This report contains analyses of all data recorded in the Crystal Ridge, MacDonald Ranch, and MacDonald Highlands areas from 2/25/05 to 3/10/05 and ground motions and airblast data included in the Structure Response Study (Aimone-Martin, 2005) to insure completeness of data.

DECRIPTION OF BLASTING OPERATIONS

Methodology

The methodology used for blasting is typical state-of-art for construction practices elsewhere in the U.S. Blasting in Henderson uses modern tools and techniques and blasters possess the knowledge and expertise required to control off-site impacts of ground vibration, airblast, and flyrock. Meetings took place with the following blasters and/or consultants throughout the study period:

Sanders Construction, Inc. -	Mel Sannes
	Charles Murphy
	Danny Sanders
Donner Drilling and Blasting, Inc. -	Dave Donner
	Ronnie Campbell
Hinton Drilling and Blasting -	Bill Hinton

Drilling is performed with percussive or a combination of rotary and percussive type drill rigs drilling hole diameters ranging from 3 to 6 in. (nominal). Ammonium nitrate and fuel oil (ANFO) is used as the explosive charge, detonated with cast primers in weights from 0.33 to 0.5 lb. each. Dry holes are bottom primed and wet holes may include an additional primer near the top of the explosives column charge as a safety measure. Non-electric initiation systems, comprising blasting caps with time-delay elements for single-hole detonations, are used to minimize the total charge weight being detonated on one time delay. A single time delay has been defined by the explosives industry as 8 milliseconds (8 ms). The maximum charge weight per delay is further defined as the maximum explosives weight detonated within any 8 ms delay interval throughout the shot pattern.

Initiation timing varies from pattern to pattern and employs times ranging from 17, 25, 42, 67, 109 ms and others as needed. The sequence of hole initiation is dependent on rock cut type and can include a “V”, echelon (diagonal rows), or variety of “staggered” patterns. The purpose of each pattern is to break and displacement the rock in a confined area, limit throw of rock, and minimize vibrations and airblast.

Each hole is loaded with explosives to a safe distance from the hole top (collar), then filled with crushed rock (or stemming) to contain the explosives within the hole during detonation. The quality and quantity of stem material is selected to keep the energy within the hole for proper breakage and also prevent energy being expelled into the atmosphere thereby creating noticeable airblast.

Drill hole patterns, comprising spacings (along rows of holes) and burdens (between rows), vary depending on hole diameter, depth, and confinement. Hole depths can range from a few feet to 50 ft. while spacings and burdens can vary from 5 ft. to 12 ft or more. The resulting powder factor, or ratio of explosives pounds per hole divided by the total cubic yards shot per hole, averages 1.0 lb/yd^3, typical of the national average for all blasting.

Patterns, once loaded, are detonated on a pre-determined time generally known the day of blasting. Some separate patterns are shot together. One to two blasts per day are common while during many weeks, only two to three blasts many taken place.

SEISMOGRAPH MONITORING

Currently there are two companies in Las Vegas that are monitoring shots for blasting companies in Henderson. Meetings took place with representatives of the companies and include the following persons:

VCE - Aaron Jones
Geolines - Otto Holmquist

Information regarding current vibration monitoring practices was provided by Aaron Jones.

The number of blasting-type seismographs used to monitor off-site structures and the locations of monitoring are determined by the blasting companies. In some cases, VCE will suggest additional units or monitoring at other locations. Prior to each blast, VCE obtains and reports the GPS location for each blast site and GPS location of the seismograph(s) along with the distances in between. Prior to the start of this project, seismograph results in the form of peak ground motions over the time histories in the vertical (V), radial (R, toward the blast) and transverse (T, perpendicular to the direction toward the blast) and peak airblast were recorded along with the shot date and time on the shot report. As of March 2005, the maximum pounds detonated per delay have been included in the reports to better track correlation of monitoring with distance.

Blasting seismographs used by VCE are manufactured by different seismograph companies. This does not pose a problem as long as VCE understands the difference in output among the machines. For instance, airblast sensors are not manufactured alike and sensor responses should be calibrated against one another to ensure that each unit provides similar output.

It is also the practice of VCE to place a weighted bag on top of the geophone at the ground surface in many instances of monitoring as opposed to coupling the geophone into the ground by burial. Either method is acceptable practice as recommended by the International Society of Explosives Engineers (ISEE, 1999) seismograph standards committee (on which this author serves).

STUDY SITE DESCRIPTION

Location

The attenuation study site is located at Crystal Ridge, MacDonald Ranch, and MacDonald Highlands as shown in the aerial photograph of Figure 1. The topography varies from 2000 to over 3000 ft above sea level and forms ridgelines and small valleys of various orientations. The predominant ridgeline orientations run from east-west to northwest to north flanked with alluvial washed. Slopes are moderate to steep slopes at grade up to 35 percent. The communities that are potentially impacted by the blasting include Sun City, Roma Hills, and MacDonald Ranch and MacDonald Highlands.

Geology

Site geology was evaluated by inspection at the blast sites and within the communities. Rock and soil contacts were observed at home construction sites where rock breakers were employed to excavate foundations. A number of geotechnical investigation reports were reviewed for MacDonald Ranch, MacDonald Highlands and Crystal Ridge providing subsurface soil boring reports, and the results of laboratory and field soils testing (AMTI, 2004; Dineen, 2004; Western Technologies, 1997). These reports provided detailed information on soil and rock types and depth of cover. In addition, discussions with Otto Holmquist of Geolines took place to verify the structural geology of the region.

Rock blasting is being conducted along the northwest ridges of the McCullough Range. The slopes are moderately steep with thin soil cover. Underlying bedrock in the area primarily comprises andesite, tuff, and basalt flows. The surface is covered with small boulders and talus showing active and on-going rock movement down-slope. Crystal Ridge bedrock contains tuff flows interbedded with breccia flows locally cut by stream channels (alluvial sediments). The overlying thin, alluvial soil cover comprises silty gravels to poorly graded gravels and silty to poorly graded sand and can be well-cemented in varying degrees. Soil thickness is 7 ft. or less within the current development areas being blasted along the foothills while in some regions closer to Horizon Ridge Parkway, the upper soil layer may thicken to 25 ft. as indicted by shear wave velocity tests (but not verified by soils boring). The Unified Soil Classification System symbols for the soils are GP, GM, and SP-SM. The fines (less than 75 microns in size) percentage ranges from 12 to 22% and fines are chiefly non-plastic silts. There are no clays present and all soils are non-swelling.

Figure 1 Attenuation study area showing blast sites and relation to surrounding housing developments

Water was not intersected in borings accompanying soil reports through surface soils and within the upper, less cemented layer of the bedrock. Moisture contents for the soils ranged from 0.3% to 8% and are most likely related to the percentage of fine soil fraction less then 75 microns in size.

The upper bedrock shows only minor surface weathering for a few feet with little or no fracturing. No major faulting is present in this area as indicated in the literature. A shear wave velocity survey conducted by Geolines produced velocities for the upper soils between 1,500 and 3,200 ft/sec and for the upper bedrock between 4,500 and 12,500 ft/sec. These values are typical of dense silty, gravelly sands and weathered to competent igneous rock types.

In summary, the soils and bedrock present at all blasting sites and within the community are consistent with moderate elevation foothills formed within volcanic flow structures. Alluvial soils and talus of boulders and cobbles grade downslope to finer soils of sand and fine gravels. There is absence of problematic soil types and moisture conditions that may lead to unstable foundation conditions from close-in blasting operations in the area. These soils are capable of sustaining compression loads of well over 3,000 psf and 4,000 psf. These loads include seismic (earthquake) and wind forces typical of the region. There is no possibility that liquefaction could occur during blasting operations in this region as soils are devoid of free water and are relatively dense in place.

ATTENUATION STUDY METHODOLOGY

Seismographs were employed to measure ground motions and airblast throughout a time period beginning 2/25/05 and ending 4/14/05. The purpose of monitoring was to evaluate the attenuation characteristics of the near surface soils and rock in terms of peak ground motion velocities and airblast as a function of distance and direction of the blast sites and a function of the energy levels being used during blasting.

During this time three phases of data acquisition by AMA were undertaken as follows:

Phase I 2/25/05 – 3/10/05
Preliminary measurements were recorded at 1814 High Mesa in MacDonald Ranch, Sun City and 1795 Anelli Ct. in Roma Hills. The participation of these home owners were solicited based on the proximity of the residences to the active blasting area.

Phase II 3/15/05 – 3/18/05
Close-in attenuation data were obtained at blast sites for which access was available while detailed community monitoring continued.

Phase III 3/21/05 – 4/14/05
Community monitoring continued throughout the Structure Response Study (Aimone-Martin, 2005) period.

In addition, background vibration and airblast records used in analysis were supplied by VCE from blasting between 11/24/04 to 2/23/05.

Seismographs employed by AMA for this study comprise tri-axial velocity geophones and airblast sensors manufactured by LARCOR of Dallas, TX. Sensors have a frequency response from 2 to 200 Hertz (Hz). The geophones record ground motions in the three mutually perpendicular directions of radial (R, toward the blast and in the direction of the ground motion propagation), vertical, V, and transverse (T, perpendicular to the radial motion). The seismographs are self-triggering and remain on, sensing ground motion and airblast levels above pre-determined trigger levels. Once the trigger level is met, the seismographs capture motion time histories over a pre-set recording time. The units used for this project were set to trigger at 0.02 inches per second (ips) of ground motion velocity, 125 decibels (dB) airblast levels and to record 10 to 12 seconds of waveform data. The airblast trigger level was intentionally set above the current regulated limit of 120 dB as wind conditions in the Henderson area often exceed 50 to 60 mph and can generate air pressures sound level equivalents in excess of 144 dB (0.046 psi or 6.6 psf of force). All airblast sound pressure levels (SPL) given in dB are linear dB (often specified dBL), as the sensors used in today's seismographs possess a linear voltage output over a frequency range 2 to 200 Hz.

Geophones operated by AMA were buried in the ground at 4 to 6 in. depth to ensure good coupling. Airblast sensors were supported above the ground 4 to 6 in. and fitted with a wind screen and cover to protect from moisture intrusion.

The locations of monitoring points are shown in Figure 2. These monitoring locations were used intermittently and not all locations were used for all blasts that were monitored. Table 1 gives the location descriptions.

Figure 2 Location of seismographs used in attenuation study (addresses given in Table 1)

Table 1 Physical location of seismographs used during this study

Seismograph owner	Unit	Location
VCE	A	1816 High Mesa
	B	800 Bolle
	C	1577 Harpsicord
	D	1440 MacDonald Ranch Dr.
Aimone-Martin Assoc., LLC	1	1814 High Mesa
	2	1795 Anelli Ct.
	3	525 Bighorn
	4	1528 MacDonald Ranch
	5	572 Carmel Mesa
	6	2148 Tiger Links
	7	Dragon Ridge Club Club

The locations of seismographs within the community were determined based on the following criteria:

- availability and cooperation of homeowners to participate in the attenuation study
- distance and orientation of the resident from the overall blasting operations
- topography
- estimated soil thickness on which the dwellings were founded
- proximity of the structures to other construction noise and vibrations and adverse weather conditions such as high winds and thunder.

Seismographs A through D were owned and operated by VCE. Seismograph locations 1 through 6 were owned and operated by AMA. Seismograph unit 2 in Roma Hills was only used during Phase I. The geophone shorted during operation due to its location in the heavily watered and limited yard space that was not covered by concrete. Therefore, this monitoring location was not used for additional Phases. During Phase III, seismograph units 1 and 3 remained at the two structures used during the Structure Response Study (Aimone-Martin, 2005).

During Phase II, a number of seismographs were employed to record attenuation along close-in arrays (40 ft from the blast and beyond) with seismographs aligned in a linear manner as allowed by terrain conditions. The purpose of the close-in arrays was to verify the full-field (close and far distances to over 5,000 ft. form the blasting) attenuation characteristics of the geology and terrain conditions.

ATTENUATION ANALYSIS

Equations Describing Intensity of Ground Motion and Airblast

The attenuation of ground vibrations in terms of the peak velocity component and airblast intensities is evaluated based on scaled distance, generally referred to as SD. The scaled distance factors for ground motions and airblast are given, respectively, by the following

Square-root scaled distance $$SRSD = \frac{D}{W^{1/2}} \qquad (1)$$

Cube-root scaled distance $$CRSD = \frac{D}{W^{1/3}} \qquad (2)$$

where D is the shot-to-seismograph distance and W is the maximum charge weight detonated within any 8 ms time period (referred to as one delay time period). Scaled distance is a means of incorporating the two most important factors contributing to the intensity of ground motion and airblast as intensity decreases proportionally with distance and inversely with the explosive weight detonated on one time delay. In the case of ground motion, the SRSD is used (commonly referred to as simply SD) as ground motion has been shown to correlate with the square root of the charge weight. In the airblast case, air pressures correlate best with the cube-root of the charge weight.

Best-fit equations describing attenuation were obtained by plotting the peak particle velocity (PPV) of the largest of the three components (R, V, or T) against SD on log-log axes and computing the “power” curve fit through the data. The equation takes on the form

$$PPV = a * SD^{-b} \tag{3}$$

where ‘a’ is the y-intercept value at SD =1 and ‘b’ is the attenuation exponent that describes the rate of decay in PPV. The parameter ‘a’ is the energy term that represents the relative magnitude of explosive energy coupled into the ground at the blast site and dependent on explosives type and rock quality. It is often referred to as the “site” factor in the literature.

The attenuation slope term ‘b’ is a function of geology transmitting the energy between the blast site and the seismograph in the form of motion within a shallow layer of ground surface. The slope term ‘b’ and, to a lesser extent, ‘a’ are good indicators of directional geology and can be used to determine azimuthal or directional difference of ground motion characteristics.

The equation describing airblast in terms of a sound pressure audible to the human ear is captured as an over pressure or a pressure rise over ambient air pressure, P, and converted to sound pressure level (SPL) where

$$SPL = 20 \log \frac{P}{P_o} \tag{4}$$

where P_o is a reference or standard pressures equal to 2.9 (10^{-9}) psi, P is the pressure measured by the seismograph, and SPL is given in terms of decibels, dB

Influences on Ground Motion and Airblast Data

Wave form time-histories generated in the ground and air are most simply characterized by amplitude (or intensity) and frequency, or the number of waves over a time period of one second. Frequencies of ground motion can influence the manner in which energy is transferred into structures near the blast site. When frequencies remain well above the natural or fundamental frequencies of structures, very little excitation energy is transferred within structures. When frequencies are low and near the structure natural frequency, some of the ground motion and airblast energy may be transferred within structures as structures respond with motions similar to those in the ground or air. Airblast waves generated in mining and quarrying may comprise low frequency energy and structure exterior walls may respond readily to airblast pressures. However, airblast generated during construction blasting generally contains high frequencies.

Ground motion and airblast data recorded during rock blasting are inherently characterized by data scatter and this scatter tends to increase as distance increases. The ground velocity intensity at any one measurement location can vary locally and directionally as influenced by geology (the type and quality of rock or soil) and geological structures, such as near-surface formations and topography (geomophology), jointing, fractures, and faulting. Time-history frequencies also are modified. Close-in to the blast site, high frequencies (and generally high intensities) prevail. Away from the blast site, these high frequencies are absorbed by the ground motions and low frequencies tend to predominate.

Blast designs and methods can temper both ground velocity amplitudes and frequencies to a certain degree. However, these differences, influenced by detonation timing, sequence and direction of initiation, and other factors, can only be measured close-in to the blast. Away from the blast site, blast design difference can rarely be detected except in the case of large variations in design factors.

The manner in which seismographs are employed by the operator also can influence the recorded data. Methods used to couple the geophone to the ground are of particular importance in obtaining consistent and accurate measurements. The International Society of Explosives Engineers (1999) has developed a set of recommended guidelines to be followed in the set-up and use of blasting seismographs. These procedures were developed to reduce operational variations in recorded data. The set-up of seismographs by AMA personnel throughout this study was performed in accordance with ISEE recommendations.

Airblast is influence by weather conditions that include wind speed and direction and temperature changes with altitude. As mentioned, airblast frequencies can vary by the type of blasting while intensities are influenced at the blast site by the size of the blast and the explosive energy that might escape from the blast holes during detonations.

Quality of Statistical Data

Attenuation studies rely on statistics. The quality of vibration and airblast data can widely vary and data scatter about tend lines fit with equation (3) can be influenced by geology, environmental conditions, and the accuracy of shot-to-seismograph distance measurements and reported charge weights that actually detonate within any 8 ms delay period. Many of these influences can be controlled and good data correlations can be achieved with careful measurements. Other influences that cannot be controlled, such as geology, are chiefly responsible for some data scatter that is normal and expected. This data scatter tends to increase with increasing distance from the blast site.

An important goal in this study was to minimize data scatter about trend lines (e.g. data fits) and this requires a statistically significant number of measurements in the data set. In addition, the data set must include a representative range of SD values (e.g. distance and charge weights) to ensure an accurate fit. When using equation (3) to characterize or predict ground motions, it is common practice to define the parameters ‘a’ and ‘b’ using the best-fit, or 50-percentile, line thorough the data. This line divides all data by the median where 50% of the data fall below and 50% of the data fall above the line. Because this line only provides a 50% confidence in predicting ground motions, it is generally industry practice to use the 95-percentile line (or in some cases the 100-percentile line) for conservative prediction. The 95-percentile describes the line below which 95% of the data fall below and 5% are above the line. In the case of the 100-percentile, 100% of the data fall below this upper line. In such cases, one is assured that all factors contributing to statistical scatter are understood and accounted for. As such, the confidence in prediction are then on the order of 95% and 100%, respectively. The only difference among the equations for the various lines (50-, 95-, and 100-percentiles) is the value of ‘a’ as the attenuation slope ‘b’ remains a constant.

Equations for these lines are often used for blast design and the cost of blasting is directly proportional to the restrictions on charge weight loaded in the blast holes placed by increasing the prediction confidence. Therefore, there is a tradeoff as high data confidence can cost the blasters more by restricting the amount of explosive charge weights detonated (e.g., SD) throughout the blast on any one time periods (8 ms intervals).

Data scatter or how well best fit lines characterize the data tend is measured statistically with the correlation coefficient, R^2. An R^2 of unity (1 or 100%) describes data that fall on the trend line. It was the goal of this project to achieve accurate data and produce tend line fits with the highest correlation coefficients possible. For blasting data, a correlation of 0.85 and above is considered to be good. This was achieved by working with the blasters to obtain accurate charge weight and delay timing data and take accurate distance measurements. In this manner, the bases of scatter are chiefly limited to geological (ground vibrations) and atmospheric (airblast) conditions.

Minimizing data scatter about trend lines also requires a statistically significant number of measurements in the data set. For blasting data, an average of 30 data points is generally needed. In addition, the data set must include a representative range of SD values (e.g. distance and charge weights) to ensure a representative fit. The data base provided by VCE for seismograph records between 11/2/04 to 2/23/05 were recorded at SD values ranging from 74.5 to 289 ft/lbs$^{1/2}$ or at SD values at which surrounding structures were located. There were insufficient close-in measurements and a large degree of scatter ($R^2 = 0.216$) to provide representative best-fit lines throughout all data and provide meaningful attenuation information. Therefore, Phase 2 measurements included both close-in and far field data to encompass a wider range of SD values from 10.1 to 356 ft/lbs$^{1/2}$ and improve correlations Both close-in data and far-field data were then used to evaluate directional variations in attenuation properties as indicated by parameters ‘a’ and ‘b’ in equation (3). The frequency content of close-in and far field ground motion data was also evaluated as ground motion frequencies are important to the manner in which structures respond to vibrations.

ATTENUATION STUDY RESULTS

The results of this study are divided into ground vibration and airblast analyses. Where possible, attenuation data were evaluated with reference to factors that could be readily measured or obtained by direct observations. The data set did not contain detailed information on blast designs as this was not a metric of this study.

Appendix A contains maps showing the shot date and time, approximate locations of the shots (given as white squares), and locations of seismographs used for monitoring during Phase II. These locations were transferred from more accurate GPS maps generated in Magellan MapSend® software and not included in this report. Lines are drawn on maps to show the approximate orientations used for attenuation analyses to evaluate geological trends in the ground vibration data and airblast trends based on elevation of the blast site.

Measurement data are given in Tables in Appendix B-1 for all data recorded from 3/15/05 to 4/14/05 and in Table B-2 for preliminary data recorded by both VCE and AMA during Phase I (from 2/25/05 to 3/10/05). In these tables, the date and time of each shot is given along with the blast site location and GPS, seismograph GPS and serial number, distance from the seismograph to the blast site, maximum charge weight per 8 ms delay, SRSD, CRSD, PPV, frequency at the PPC, dominate frequency, and airblast. The charge weights per 8 ms delay interval used for blasting during this period ranged from 9 to 1,040 lb/delay and the shot-to-seismograph distances ranged from 40 to 8,119 ft. SD factors for ground motions ranged from 10 to 1,160 ft/lbs$^{1/2}$.

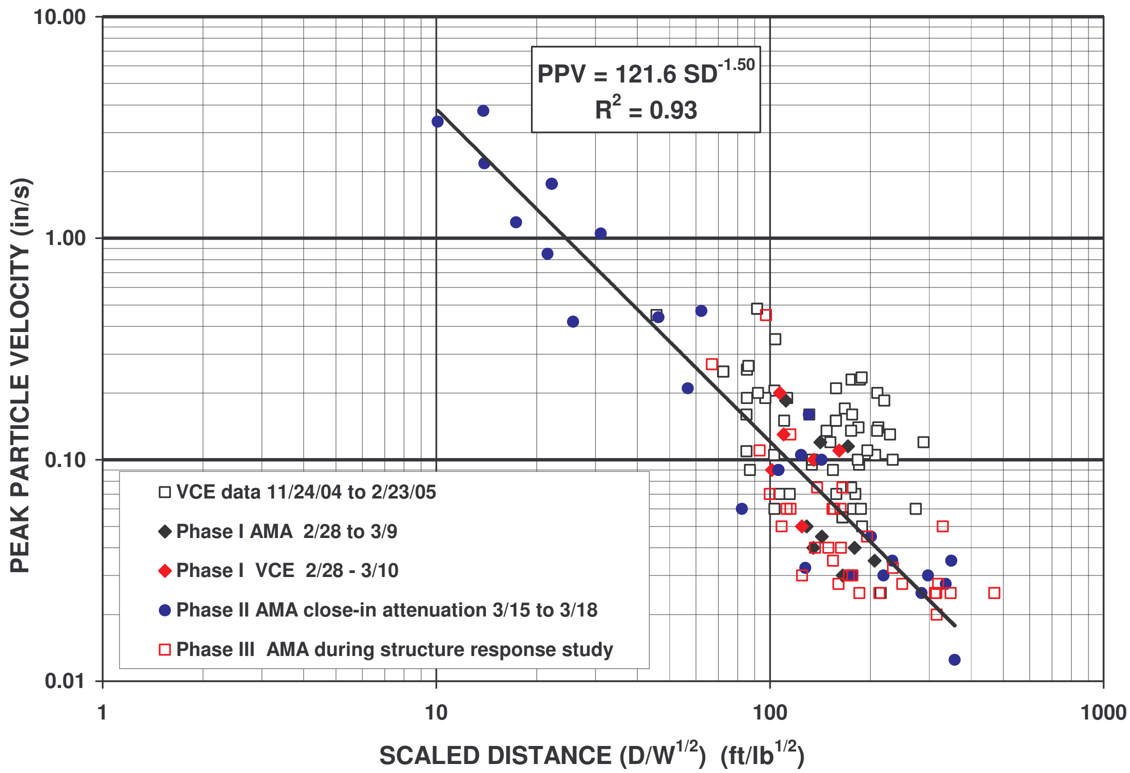


Figure 3 Peak particle velocity versus scaled distance

Ground Vibrations

Ground motion data in terms of PPV are plotted in Figure 3 for all data. A best-fit (50-percentile) line is drawn only through the shot data recorded during Phase II for which accurate charge weights and shot-to-seismograph distances are assured and obtained by AMA personnel. AMA personnel were present at all blast sites from 3/15/05 to 3/18/05 to set up close-in data arrays with the exception of the blast on 3/16/05b. A total of 34 data points were recorded for seismographs that triggered during Phase II. During Phases I and III, AMA was not present and blast site location data and charge weights used were supplied by VCE personnel. Any questionable data was scrutinized and data verified by blasting companies whose cooperation was requested and received during this study time. The best fit equation for Phase II data without regard for direction or topography was

$$PPV = 121.6 SD^{-1.50} \tag{5}$$

with a correlation, R^2, of 0.93.

Figure 3 shows that Phase II data fell within the scatter of all other data. However, the early VCE data plot well above and the Phase III AMA data plot well below this fit. The reason for these distributions is not clear. It is well known that for some blasting sites and methods, very close-in data (scaled distances less then 10 ft/lbs$^{1/2}$) will exhibit attenuation characteristics somewhat different compared with far-field data for reasons previously explained. Furthermore, it has been well established at many blast sites that data scatter increases with increased distance due to ground motions wave dispersion, energy absorption, and wave scattering by changes in geology. Therefore, the data shown in Figure 3 is considered to be representative of the blasting in the Crystal Ridge, MacDonald Ranch and MacDonald Highlands areas.

This fit given in equation (5) is very close to the fit obtained by Siskind, et al. (1980) during U.S. Bureau of Mines structure response research in mid-western coal mines in which ‘a’ and ‘b’ were determined to be 133 and -1.5, respectively. This illustrates that the effects of geology and blasting methodology on ground vibrations is essentially the same everywhere over a wide range of shot-to-seismograph distances for statistically significant and representative data. This statement does not preclude the detection of localized and close-in variations in ‘a’ and ‘b’ due to rock properties, explosive energy and coupling, shot pattern timing and design parameters. Indeed, directional properties of structural geology influence the characteristics of ground vibrations to some degree. However, these directional influences tend to be less measurable with distance as geology is a natural filter of the frequency or cyclical nature of the ground motions.

Upper 100-percentile lines were establish and shown in Figure 4 for Phases II and III data measured by AMA (combined) in comparison with early data provided by VCE. A modified attenuation slope for the 50-percentile now shows a lower ‘a’ term (105.8 compared with 121.6 previously) with the inclusion of far-field data recorded during the Phase III Structure Response

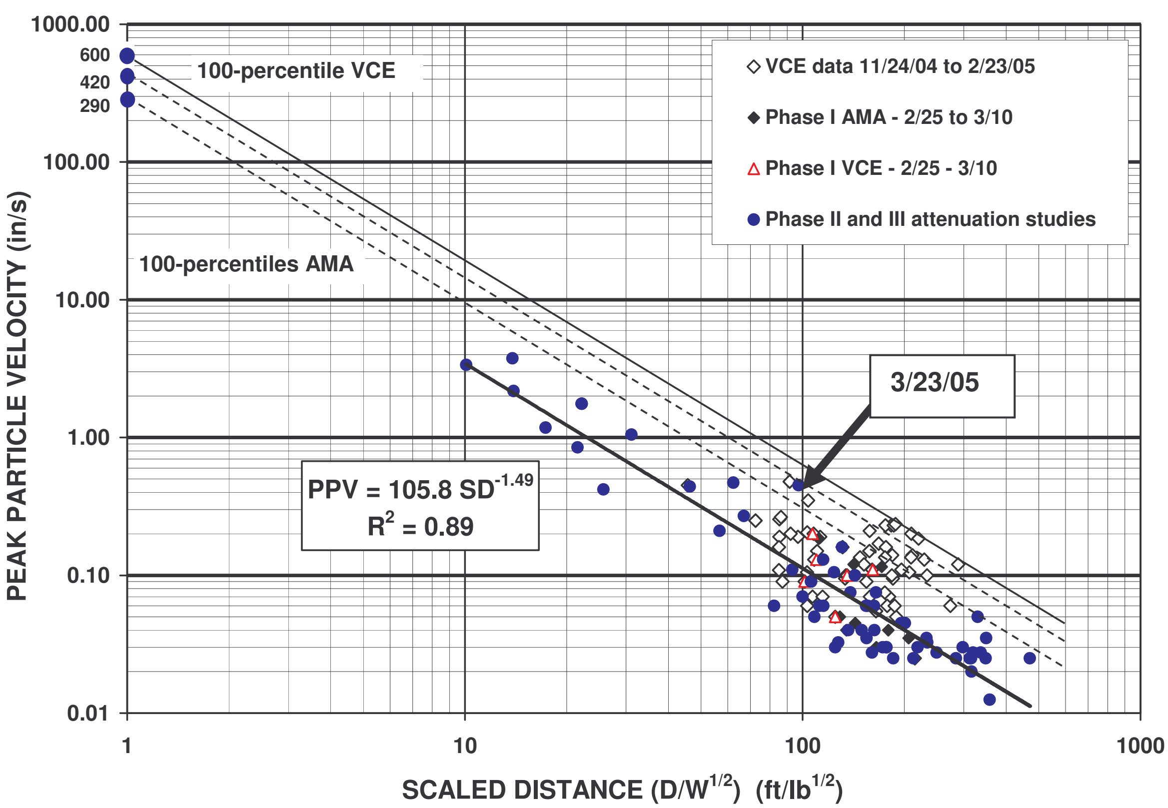


Figure 4 100-percentile attenuation lines for AMA data, Phases II and II combined and early data provided by VCE

Study (Aimone-Martin, 2005). However the slope, as influence by geology, is nearly the same (1.50 versus 1.48) and this similarity indicates the data can indeed be combined to show similar geological characteristics despite the lower, yet acceptable, 0.89 correlation coefficient. Conclusions drawn from the data in Figure 4 are as follows:

- VCE early data, generated from a limited number of vibration measurement locations at SD values greater than 72 ft/lbs$^{1/2}$, may be conservative and may not represent the true trend of ground vibrations over the general area

- The 100-percentile line for the AMA data set (upper dashed line) is greatly influence by one data point for the blast on 3/23/05 for which abnormally high airblast and ground vibration readings were obtained relative to the distance and maximum charge weight reported by the blasting company. It is likely that more than 92 lbs. per delay of explosives actually detonated at one time and this would results in a shift of this data point to the left, toward the best fit line. This fact has not been verified to date and this data point remains as the only anomaly noted during this study.

- The lower dashed line is most representative of the 100-percentile attenuation line for all data recorded during the attenuation study by AMA. Therefore, the equation to predict PPV as a function of SD for the Crystal Ridge, MacDonald Ranch, and MacDonald Highlands areas for this data set with a 100% confidence is therefore

$$PPV = 290SD^{-1.49} \tag{6}$$

Influence of Geology on Ground Vibrations

The influence of geology on ground vibration data was evaluated using directional attenuation lines trending in the azimuthal or compass bearings toward residential communities. These trends range from an approximate east-west line through a northwest alignment to a north-south to northeast line. The approximate alignments of nine blasts that took place during Phase II from 3/15/05 to 3/18/05 are shown on the maps in Appendix A and plotted in data sets in Figure 5. A description of each blast and date are given in the legend along with the approximate azimuthal orientation with respect to north as indicated by the compass in the upper right region of Figure 5. Best-fit lines were obtained for each shot array to obtain both the y-intercept, 'a', at SD = 1 and the attenuation slope, 'b', and determine if differences among the data were measurable. An example of one trend line is given in Figure 5 for the blast on 3/17/05 at a lower elevation to an existing rock wall at Crystal Ridge. This best-fit 50-percentile line has a perfect correlation coefficient (1.0) with an energy term ('a') of 78 and attenuation slope ('b') of 1.613.

Table 2 summarizes all the best fit parameters, 'a, 'b', and R^2 for all array orientations fitted for data in Figure 5. The data for the Brennen site shot (trending N45 degrees) fell closely in line with the north-south tend for the blast on 3/16/05a (designated as 360 degrees in Table 2) and data were combined. Correlation coefficients for all attenuation lines are excellent. There are some differences shown in Table 2 to indicate variations in energy coupled into the ground as a function of site geological characteristics (assuming that each blast was designed with nearly the same type of charges, timing, and charge weights per delay and were accurately reported).

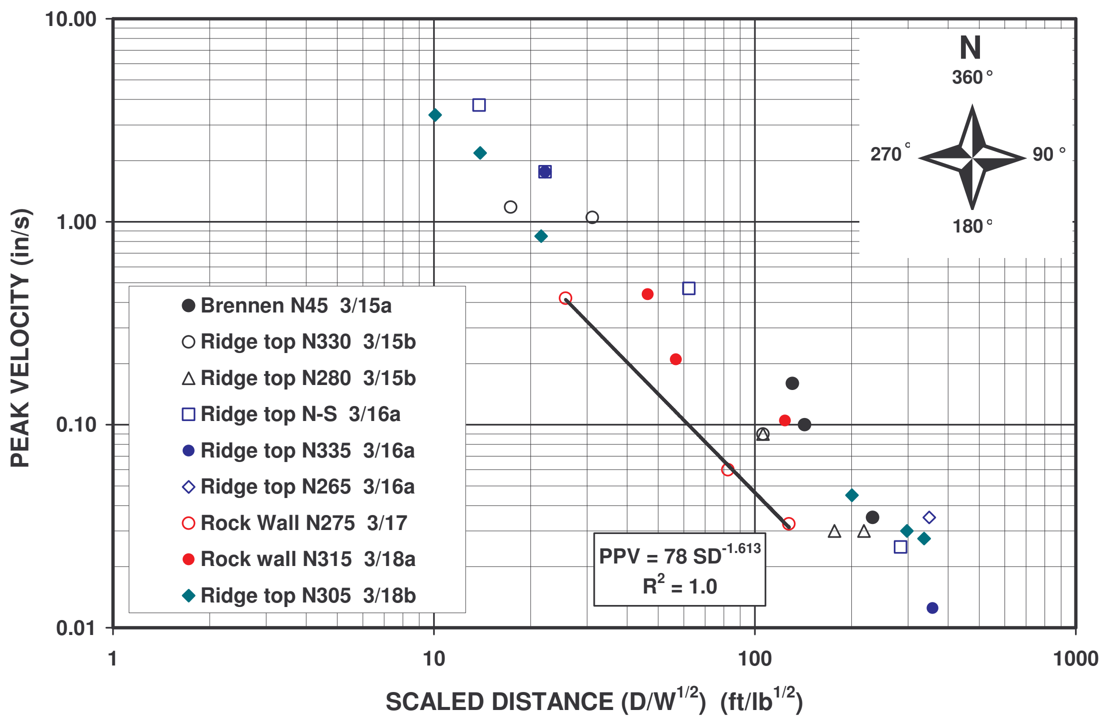


Figure 5 Attenuation line data plotted as PPV versus scaled distance for Phase II blasts

Table 2 Summary of fitting parameters for attenuation array blast data

Azimuth direction	Y-intercept Energy Factor (a)	Attenuation slope (b)	Correlation Coefficient R^2
(degress from North)	(in/sec)		
360	303.1	1.625	0.99
335	436.4	1.779	1.00
330	119.5	1.510	0.92
315	51.5	1.297	0.88
305	72.8	1.373	1.00
280	171.7	1.632	0.92
275	78.0	1.613	1.00
265	143.8	1.421	1.00

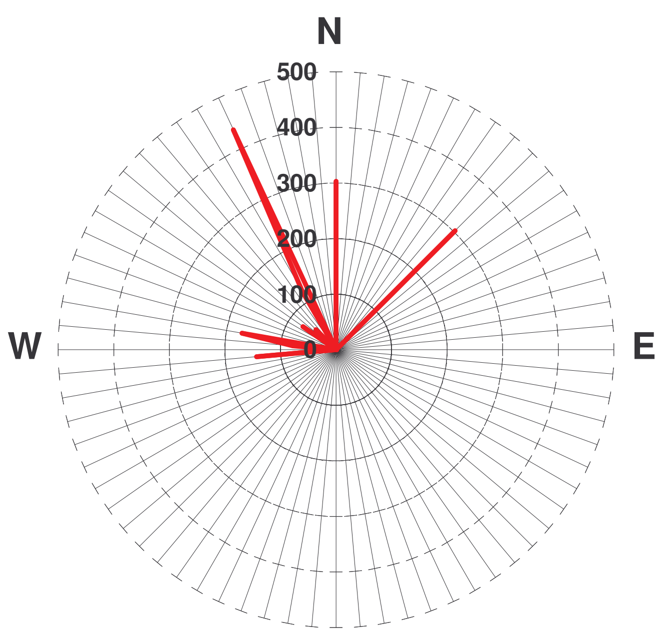
Furthermore, the attenuation slopes indicate that the transmission medium through which the ground motions traveled is not necessarily the same in all directions.

To visualize these differences, the ‘a’ and ‘b’ coefficients were plotted in histogram formats as a function of azimuth from 265 (toward the east) to 360 degrees (to the north) in Figures 6 and 7. The circular distribution of energy factors (the scale shown from 0 to 500 along the central vertical line) in Figure 6(a) shows that significant energy is coupled into the ground close-in along a northwest trend (335 degrees) while that direction attenuates or dissipates this energy the quickest (with the highest ‘b’ factor of 1.779) away from the site as shown in Figure 7.

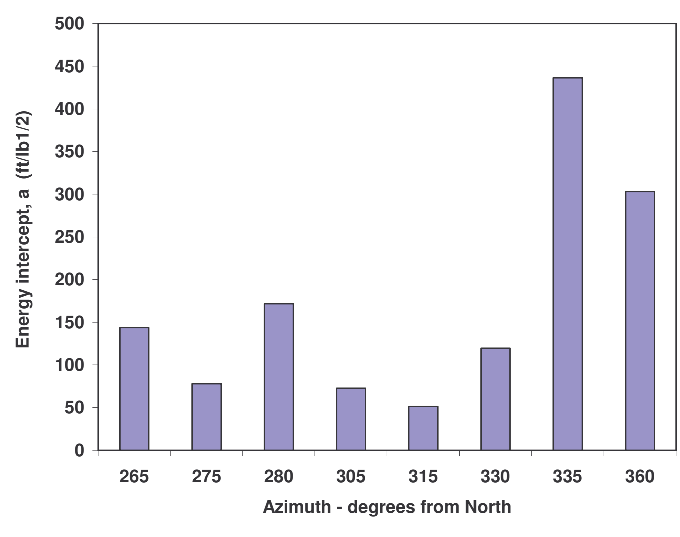
The data was further grouped with similar parameters and best fit lines for three strong predominate trends obtained as shown in Figure 8. These trends, each shown with best fits, coincidently align with the three predominate ridgeline orientations in the blasting areas shown in the aerial photograph of Figure 9. Therefore, it can be concluded that the three ridgeline directions along which competent bedrock trend have a slight influence on the manner in which energy is coupled into the ground and the peak intensities of ground motion decay with scaled distance.

Ground Motion Frequency

The frequency at the PPV is plotted against PPV in Figure 10 for both close-in ground motion data and data at SD greater the 58 ft/lbs$^{1/2}$. Plotted within the graph is the federal



(a)



(b)

Figure 6 Variation of energy factor (y-intercept) values as a function of azimuth for (a) a circular distribution and (b) a conventional histogram

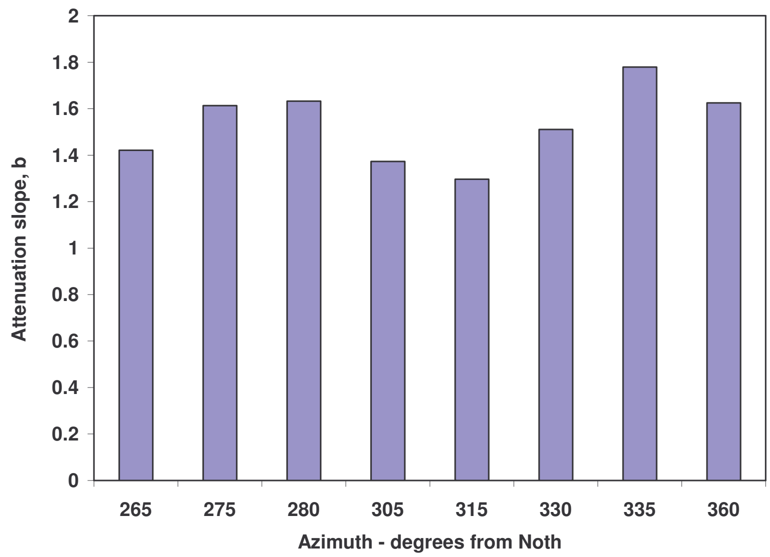


Figure 7 Variation of attenuation slope values as a function of azimuth

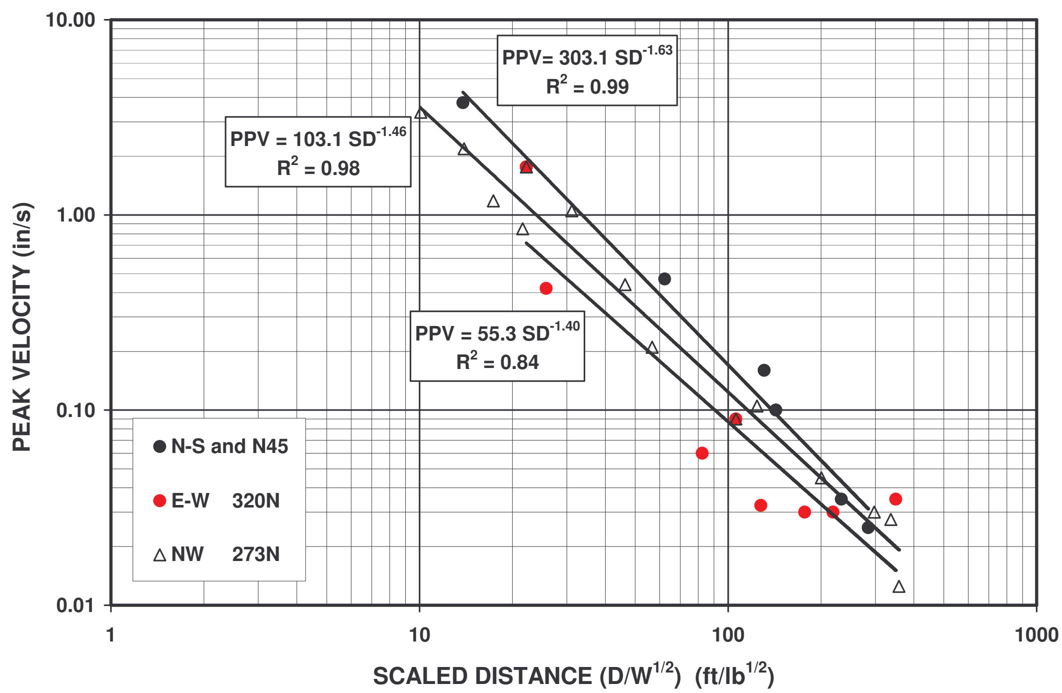


Figure 8 Variation of attenuation fits with three predominate topographic trends

Figure 9   Three topographic trends show in Figure 8 (black-north-south; red-northwest; yellow-east-west)

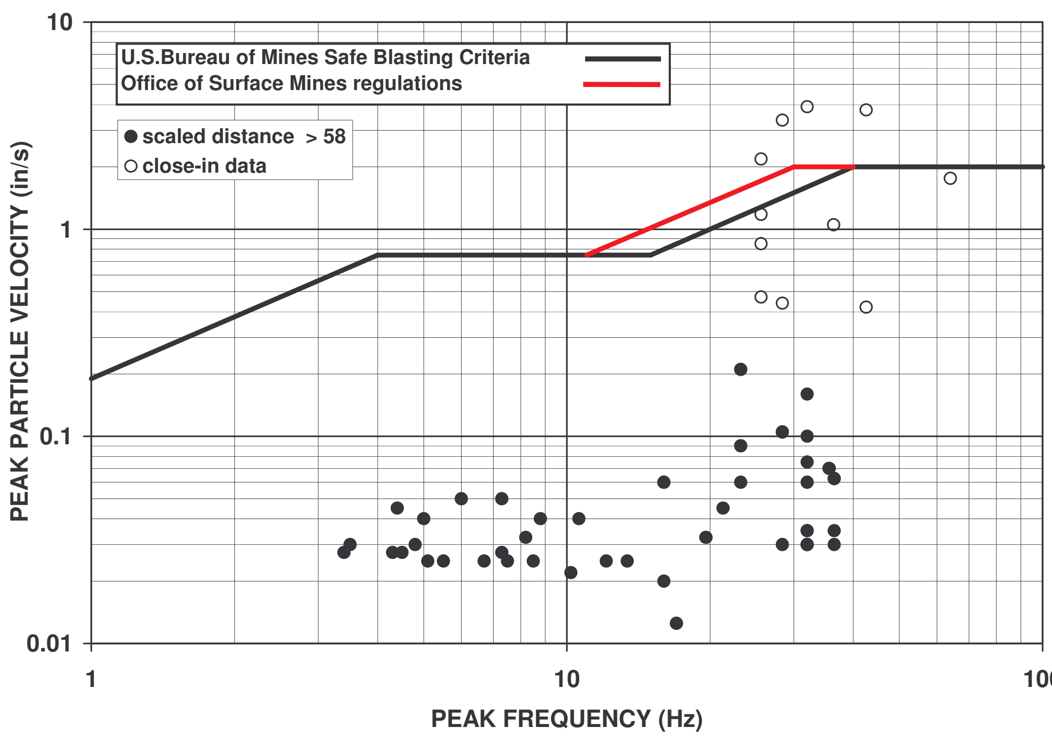


Figure 10 PPV versus frequency at the peak velocity for close-in adapt and far-field data ($SD > 58$ ft/lbs$^{1/2}$)

blasting regulations and U.S. Bureau of Mines recommended limits for safe blasting. The upper limits to safe blasting delineate the region below the upper bounds in which combinations of PPV and peak frequencies have been shown not to cause threshold or cosmetic hairlines cracking in residential structure walls for over a 40-year period of observations and measurements. This upper limit to safe blasting represents a 100% confidence line. Data recorded during this study demonstrate that ground motions at 0.06 ips and below, generally recorded at scaled distances greater than 100 ft/lbs$^{1/2}$, correspond with peak frequencies ranging from 4.5 to 20 Hz. Closer-in, high frequencies predominate while amplitudes can greatly vary. The close-in data at the higher frequencies were not associated with off-site structures and all measurements taken at residential structures were well within regulatory limits throughout this study.

Airblast

Figures 11 and 12 are plots of peak airblast versus cube-root scaled distance showing the typical scatter of data for airblast levels above 112 dB as influence by wind direction along close-in attenuation lines. Figure 11 shows two anomalous airblast measurements for the blast on 3/23/05. Similar to the ground motions, the airblast levels are abnormally high for the scaled distance factors computed with the reported data. Hence, these data points should not be considered part of the airblast data base until records can be verified.

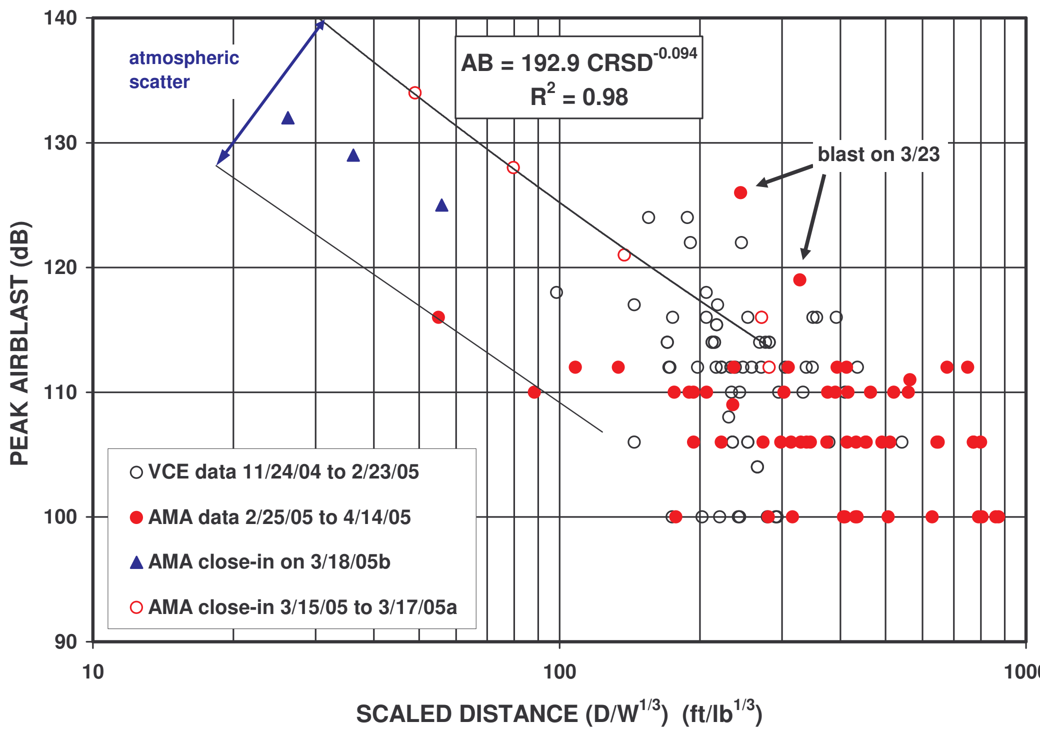


Figure 11 Peak airblast versus cube-root scaled distance

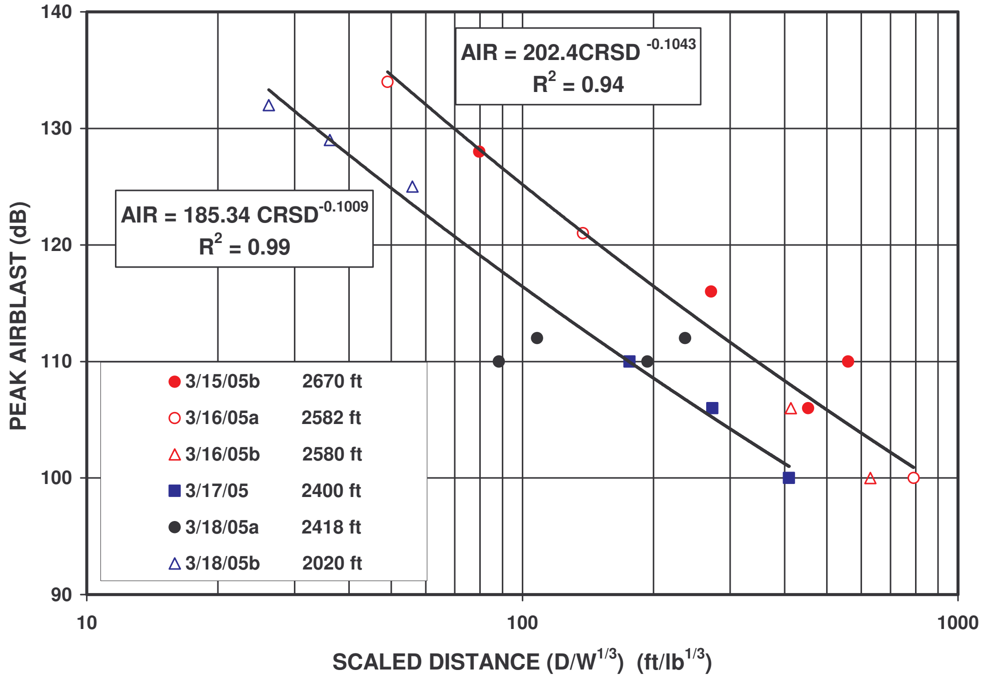


Figure 12 Peak airblast versus cube-root scaled distance for data plotted by blast data during the Phase II study

The attenuation line through the upper array

$$AIR = 192.9CRSD^{-0.094} \tag{7}$$

describes airblast amplitudes in the direction of the wind (from the southeast and considered to the worst case scenario) while the lower line bounding the atmospheric conditions are data included against the wind direction (from the northeast). In all cases, the attenuation of airblast data is typical of hilly terrain conditions.

Similar to the ground motions, the early data supplied by VCE in Figure 11 shows airblast readings for CRSD factors between 100 to 400 ft/lbs$^{1/3}$ to be higher than the data obtained during the AMA study period. There is no apparent reason for this difference. The scatter in data for airblast levels at 122 dB and below for the AMA data stems from the variations in predominant wind directions coming from the southeast or the northwest. Weather-induced scatter is typical at all scale distances.

The controls on airblast levels within surrounding communities appears to be somewhat influenced by the elevation of the blast site. The influence of elevation is shown in Figure 12. As blast site elevation is increased, airblast levels tend to be higher than airblast from blast sites at lower elevations. The data set is divided between blast site at elevation 2580 and higher and 2418 and lower. The attenuation term 'b' is similar for each best fit line (around 0.1) while the higher elevation blasts generated about 10% higher airblast sound.

CONCLUSIONS

A study of the attenuation characteristics of ground motion and airblast was conducted in three Phases for the City of Henderson during blasting at Crystal Ridge, MacDonald Ranch, and MacDonald Highlands. The purpose of this study was to evaluate blasting and seismic monitoring methodologies, determine controls on the variation of ground vibrations and airblast as a function of distance and direction from the blast sites, and characterize attenuation of airblast and ground vibrations in terms of controls.

Blasting and seismograph monitoring methodologies were consistent with state-of-the art practices used elsewhere in the U.S. Seismograph data was within normal and expected ranges. All seismograph data fell within acceptable data scatter at computed scaled distance factors above 70 ft/lb$^{1/2}$ typically used for blast design.

Data was largely devoid of anomalous readings with the exception of the blast conducted on 3/23/05. The airblast and ground vibration data for this blast was higher than expected for the reported charge weight and measurement distances. No explanation has been provided for these readings and it is concluded that the net charge weight may have been greater than the 92 lbs. per delay reported.

Close-in attenuation data did not demonstrate any significant influence from blast design. Directional differences in ground vibrations were controlled to some degree by geology at the blast site and in the geologic medium transmitting the ground vibrations. Differences were measured in terms of the scaled distance formula where the energy coupling and attenuation terms were the largest along the northwest trend of the ridgelines. Although energy coupling is high in this direction, the decay of energy in the ground is also high and intensities of ground motions tend to normalize at large values of scaled distance.

Airblast is affected to some degree by the direction of wind and the elevation of the blast site. Airblast levels at blast site elevations above 2580 ft. measured 10% higher than airblast levels recorded below 2418 ft.

The following summarizes the important findings and conclusions of this report:

- Blasting and vibration monitoring and control methods currently employed are state-of-art and represent best practices available in the rock blasting industry.

- Historical vibration records from VCE (prior to 2/25/05, or the commencement of these studies) showed vibration levels slightly higher than those recorded by both VCE and AMA from 2/25/05 to 4/14/05, given a constant distance and explosive charge weight. However all historical data for ground motions were within regulatory limits.

  This may indicate that <u>more control</u> on blasting was exercised since that inceptions of scientific studies and elevated oversight by the City.

- Post-blast record keeping of blasting and vibrations information was somewhat deficient in key data upon commencement of this study and greatly improved over the following 3 months. As a result, blasters were more aware of off-site impacts and responded with improved control measures.

- The best-fit equation (50-percentile) for data recorded during this study was

  $$PPV = 121.6SD^{-1.50}$$

  with a correlation, R^2, of 0.93. This fit is very close to the fit obtained by Siskind, et al. (1980) during U.S. Bureau of Mines structure response research. The 100% confidence line was given as

  $$PPV = 290SD^{-1.49}$$

- There are measurable yet minor influences of geology and terrain conditions that appear to enhance ground vibrations in directions that align with the surface ridge lines from the blast sites.

  The attenuation or decrease in vibration amplitudes with distance in different directions is not statistically significant and does not warrant special regulatory consideration.

REFERENCES

Aimone-Martin Associates, LLC, 2005, Structure Response Study, for the City of Henderson, Nevada.

AMTI, 2004, Preliminary Geotechnical Engineering Exploration Proposed Crystal Ridge Residential Subdivision (640 acres) Located Roma Hills Drive, South for Horizon Ridge Parkway, Henderson, NV.

Dineen, J. B., 2004, Geotechnical Investigation Report Planning Area 6 at MacDonald Highlands, J.A. Cesare and Associates, Las Vegas.

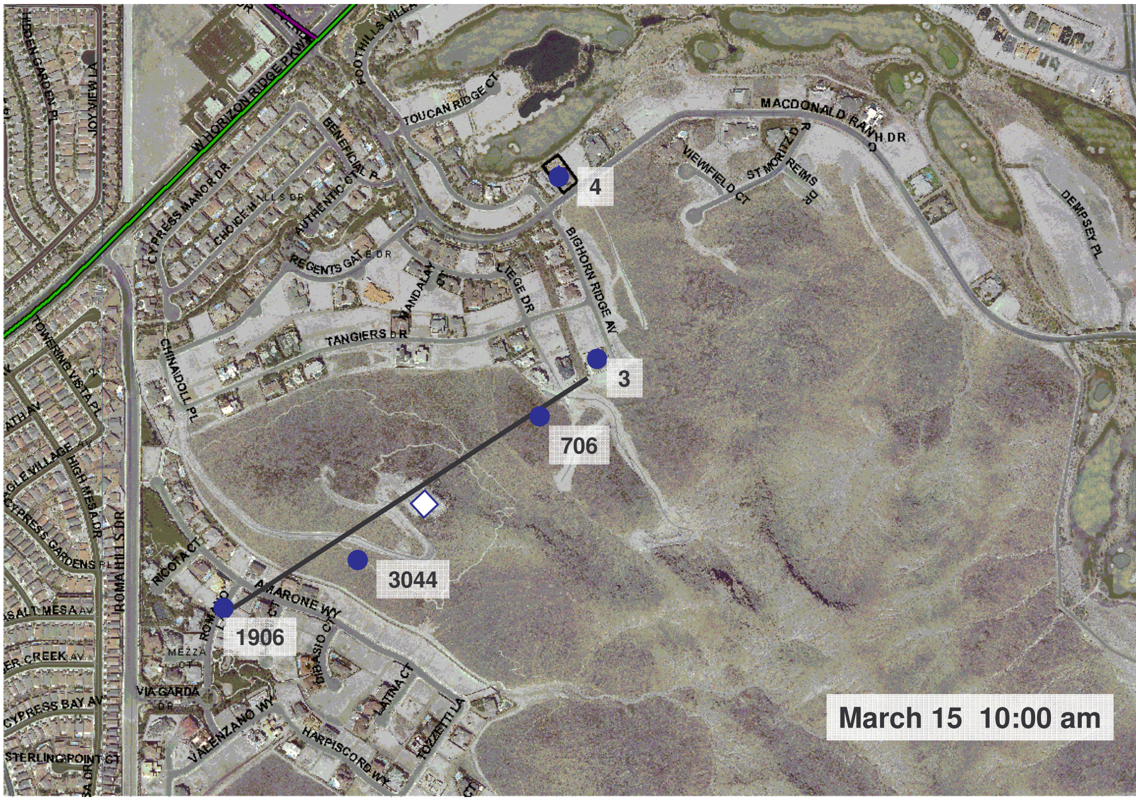
International Society of Explosives Engineers, 1999, ISEE Field Practice Guidelines for Blasting Seismographs, Seismograph Standards Committee.

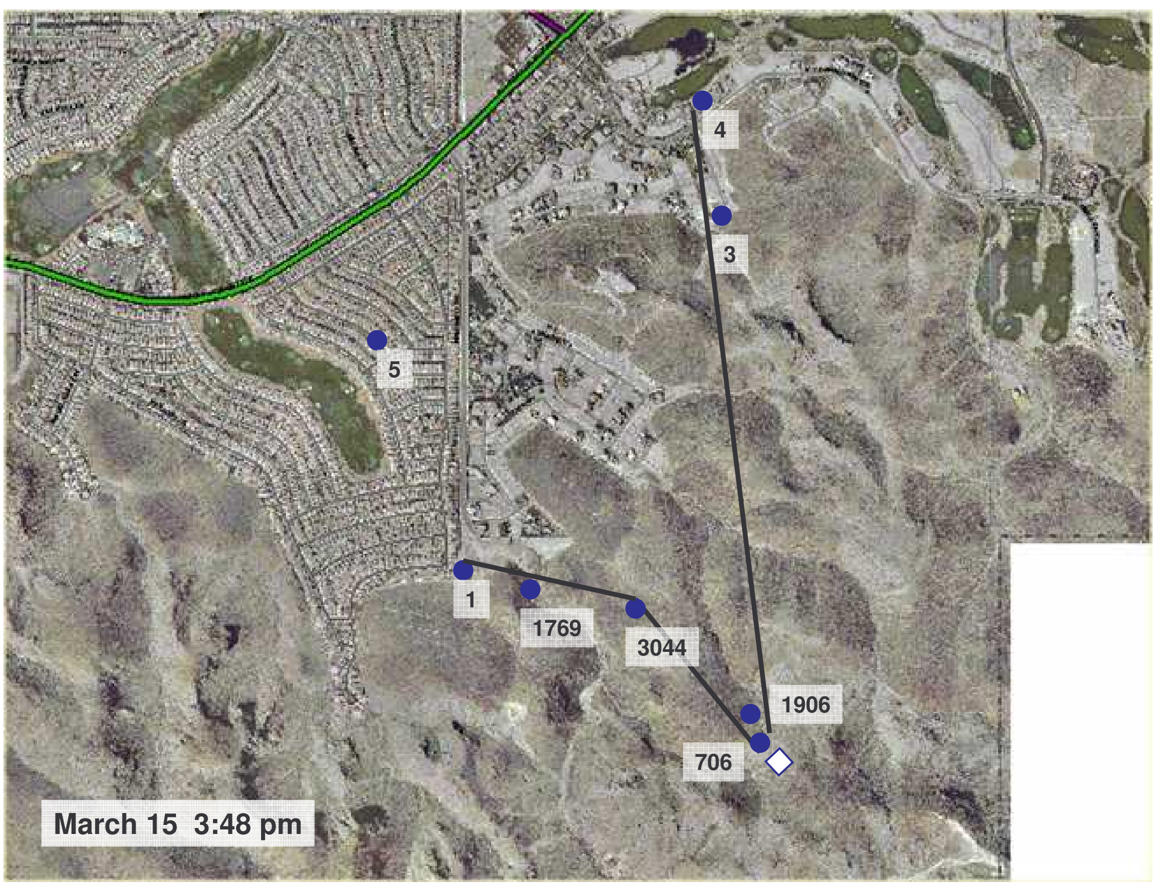
Siskind, D.E., M. S. Stagg, J. W. Kopp, and C. H. Dowding, 1980, Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, U.S. Bureau of Mines RI 8507.

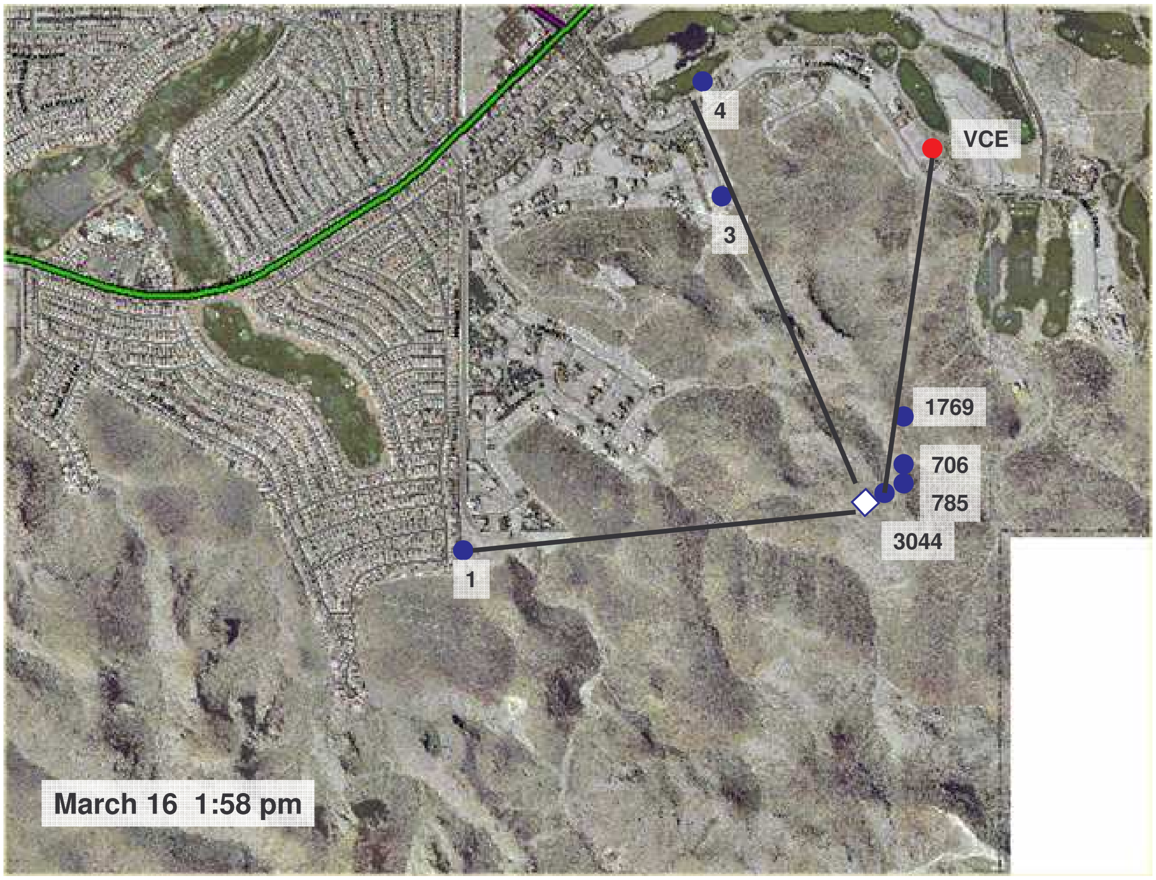
Western Technologies, Inc., 1994, Geotechnical Evaluation Proposed MacDonald Ranch E/O Green Valley Parkway, Henderson, NV.

APPENDIX A

Phase II Seismograph Layout Maps


4
3
706
3044
1906
March 15 10:00 am


4
3
5
1
1769
3044
1906
706
March 15 3:48 pm


4
VCE
3
1769
706
785
3044
1
March 16 1:58 pm


4
3
1
March 16 3:17 pm


3
6
5
1906
706
1
3045
3044
March 17 3:05 pm


3
706
1906
3045
1
3044
March 18 11:00 am


3
6
5
1
1906
3045
3044
March 18 3:07 pm

APPENDIX B

Summary of Seismograph Data

Table B-1 Summary of Seismograph Data

Date	Shot time	Blast Site	Blast site GPS	Seismograph GPS	Seismograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs$^{1/2}$)	(ft/lbs$^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
3/15/05a	10:00	Brennan	36°00.305 115°03.587	36 00.427 115 03.405	525 Bighorn	3047	1163	50	164.5	315.7	0.035	32	30.9	100
				36 00.557 115 03.443	1528 MacDonald R.	3045		50			nt			
				36 00.363 115 03.461	NE slope	706	714	50	101.0	193.8	0.1	32	35.3	106
				36°00.225 115°03.676	SE slope	3044	654	50	92.5	177.5	0.16	32	35.8	100
				36°00.088 115°03.828	empty lot, Roma Hills	1906		50			nt			
				35 59.856 115 03.936	1814 High Mesa	1258		50			nt			
				36°00.234 115°04.080	572 Carmel Mesa	785		50			nt			
				36°00.263 115°04.465	2148 Tiger Links	1769		50			nt			
3/15/05b	3:48	Crystal Ridge	35°59.575 115°03.279	36°00.427 115°03.405	525 Bighorn	3047	5206	280			nt			
				36°00.557 115°03.443	1528 MacDonald R.	3045		280			nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3661	280	218.8	559.6	0.03	32	34.5	110
				36°00.234 115°04.080	572 Carmel Mesa	785		280			nt			
				35°59.606 115°03.326	close-in array	706	290	280	17.3	44.3	1.18	25.6	35.4	132
				35°59.640 115°03.348	close-in array	1906	521	280	31.1	79.6	1.05	36.4	33.9	128
				35°59.813 115°03.488	close-in array	3044	1774	280	106.0	271.2	0.09	23.2	24.8	116
				35°59.842 115°03.782	close-in array	1769	2962	280	177.0	452.8	0.03	32	25.1	106
3/16/05a	1:58	MacDonald	35° 59.966 115° 03.158	36 00.584 115°03.432	1528 MacDonald R.	1906	3986	124	358.0	799.4	0.0125	17	15.81	100
		Highlands		35 59.969 115 03.127	close-in array	3044	154	124	13.8	30.9	3.76	42.6	33	134
				36 00.032 115 03.043	close-in array	706	694	124	62.3	139.2	0.47	25.6	29.3	121
				35 59.968 115 03.108	close-in array	785	247	124	22.2	49.5	1.76	64	58.5	134
				36 00.213 115 03.057	close-in array	1769	1580	124	141.9	316.9	0.0625	36.5	34.31	106
				36 00.427 115 03.405	525 Bighorn	3047	1017	124	91.3	203.9	nd			
				35 59.856 115 03.936	1814 High Mesa	1258	3893	124	349.6	780.7	0.035	36.5	34.1	100
			35° 59.993 115° 03.167	36 00.427 115 03.405	1444 MacDon R.	200203	3168	124			0.25			100
3/16/05b	3:17	Crystal Ridge	35° 59.760 115° 03.272	36 00.584 115 03.432	1528 MacDonald R.	1906	5061	520	221.9	629.4	0.022	10.2	8.63	100
				35 59.856 115 03.936	1814 High Mesa	1258	3325	520	145.8	413.5	0.05	6	8.6	106
				36 00.427 115 03.405	525 Bighorn	3047	4100	520	179.8	509.9	nd			
3/17/05	3:05	Crystal Ridge	35° 59.847 115° 03.556	35 59.856 115 03.936	1814 High Mesa	1258	1874	96	191.3	409.3	0.035	32	33.31	100
		rock wall		36°00.234 115°04.080	572 Carmel Mesa	785	3491	96	356.3	762.4	nt			
				36°00.263 115° 04.465	2148 Tiger Links	1769	5143	96	524.9	1123.2	nt			
				36°00.427 115°03.405	525 Bighorn	3047	3597	96	367.1	785.6	nt			
			35° 59.848 115° 03.528	35 59.843 115 03.527	close-in array	3044	40	96	4.1	8.7	3.9	32	16.1	133
				35 59.850 115 03.607	close-in array	3045	252	96	25.7	55.0	0.42	42.6	42.5	116
				35 59.871 115 03.717	close-in array	706	807	96	82.4	176.2	0.06	16	6.8	110
				35 59.869 115 03.808	close-in array	1906	1250	96	127.6	273.0	0.0325	19.6	20.7	106
3/18/05a	11:00	Crystal Ridge	35° 59.836 115° 3.531	35 59.860 115 03.605	close-in array	3045	393	48	56.7	108.1	0.21	23.2	32.4	112
		rock wall		35 59.840 115 03.596	close-in array	3044	321	48	46.3	88.3	0.44	28.4	28.4	110
				35 59.910 115 03.641	close-in array	1906	704	48	101.6	193.7	0.07	35.6	31.9	110
				35 59.933 115 03.658	close-in array	706	859	48	124.0	236.4	0.105	28.4	16.2	112
				35 59.856 115 03.936	1814 High Mesa	1258	2000	48	288.7	550.3	0.025	12.1	7.3	100
				36 00.427 115 03.405	525 Bighorn	3047	3639	48	525.2	1001.3	nt			

nt - no trigger
nd- no data

Table B-1 Summary of Seismograph Data (cont.)

Date	Shot time	Blast Site	Blast site GPS	Seimsograph GPS	Seimsograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs$^{1/2}$)	(ft/lbs$^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
3/18/05b	3:07	Crystal Ridge	35° 59.708 115° 3.250	35 59.699 115 03.298	close-in array	3045	243	304	13.9	36.1	2.18	25.6	55.6	129
				35 59.704 115 03.284	close-in array	3044	176	304	10.1	26.2	3.36	28.4	27.1	132
				35 59.697 115 03.325	close-in array	1906	376	304	21.6	55.9	0.85	25.6	6	125
				36°00.234 115°04.080	572 Carmel Mesa	785	5189	304	297.6	771.7	0.03	4.8	5	106
				36 00.263 115 04.465	2148 Tiger Links	1769	5871	304	336.7	873.2	0.0275	3.4	5.3	100
				35 59.856 115 03.936	1814 High Mesa	1258	3500	304	200.7	520.5	0.045	4.4	3.56	110
				36 00.427 115 03.405	525 Bighorn	3047	4429	304	254.0	658.7	nt			
03/21/05	11:07	Crystal Ridge	35° 59.878' 115° 03.532'	36 00.263 115 04.465	2148 Tiger Links	785	5159	300	297.9	770.7	nt			
		rock wall		36°00.234 115°04.080	572 Carmel Mesa	1769	3459	300	199.7	516.7	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5151	300	297.4	769.4	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	4685	300	270.5	699.9	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	1996	300	115.3	298.2	0.06	32	28.9	106
				36 00.427 115 03.405	525 Bighorn	3047	3389	300	195.7	506.3	0.045	21.3	22.1	100
03/22/05	12:35	Crystal Ridge	35° 59.713' 115° 03.249'	36 00.263 115 04.465	2148 Tiger Links	785	6861	1040	212.8	677.2	0.025	6.7	4.4	112
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5175	1040	160.5	510.8	0.0275	4.5	9.1	106
				36 00.450 115 02.760	DR Golf Course	1906	5080	1040	157.5	501.4	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5329	1040	165.2	526.0				
				35 59.856 115 03.936	1814 High Mesa	1258	3497	1040	108.4	345.1	0.05	7.3	13.1	106
				36 00.427 115 03.405	525 Bighorn	3047	4400	1040	136.4	434.3	0.04	8.8	7.06	100
03/23/05	12:09	Crystal Ridge	35° 59.776' 115° 03.180'	36 00.263 115 04.465	2148 Tiger Links	785	6990	44.1	1052.7	1978.6	nt			
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5236	44.1	788.4	1481.9	nt			
				36 00.450 115 02.760	DR Golf Course	1906	4584	44.1	690.2	1297.4	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5030	44.1	757.4	1423.7				
				35 59.856 115 03.936	1814 High Mesa	1258	3759	44.1	566.0	1063.9	nt			
				36 00.427 115 03.405	525 Bighorn	3047	4161	44.1	626.6	1177.8	nt			
03/23/05	2:47	MacDonald	36° 00.418' 115° 03.216'	36 00.263 115 04.465	2148 Tiger Links	785	6229	92	649.4	1379.8	nt			
		Highlands		36°00.234 115°04.080	572 Carmel Mesa	1769	4403	92	459.0	975.3	nt			
				36 00.450 115 02.760	DR Golf Course	1906	2256	92	235.2	499.7	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	1478	92	154.1	327.4	0.06	23.2	16.7	119
				35 59.856 115 03.936	1814 High Mesa	1258	4922	92	513.2	1090.3	nt			
				36 00.427 115 03.405	525 Bighorn	3047	933	92	97.3	206.7	0.45	21.3	21.13	110
				36 00.495 115 03.013	1444 MacDon R.	200203	1104	92	115.1	244.6	0.13			126
03/24/05	1:17	Crystal Ridge	35° 59.589' 115° 03.446'	36 00.263 115 04.465	2148 Tiger Links	785	6478	246	413.0	1033.9	nt			
		S. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5009	246	319.3	799.4	0.0275	7.3	6.06	106
				36 00.450 115 02.760	DR Golf Course	1906	6223	246	396.8	993.2	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5995	246	382.2	956.7	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	2909	246	185.5	464.2	0.025	5.5	5.3	110
				36 00.427 115 03.405	525 Bighorn	3047	5088	246	324.4	812.1	nt			
				36 59.894 115 03.770	800 Bolle	2262	2445	246	155.9	390.2	0.06			110

Table B-1 Summary of Seismograph Data (cont.)

Date	Shot time	Blast Site	Blast site GPS	Seimsograph GPS	Seimsograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs$^{1/2}$)	(ft/lbs$^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
03/25/05	10:58	Crystal Ridge	35° 59.486' 115° 03.902'	36 00.263 115 04.465	2148 Tiger Links	785	5471	170	419.6	987.6	nt			
				36°00.234 115°04.080	572 Carmel Mesa	1769	4622	170	354.5	834.4	nt			
				36 00.450 115 02.760	DR Golf Course	1906	8119	170	622.7	1465.6	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	6996	170	536.5	1262.8	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	2251	170	172.6	406.3	0.03	28.4	31.7	100
				36 00.427 115 03.405	525 Bighorn	3047	6213	170	476.5	1121.6	nt			
				36 59.629 115 04.099	1875 Cypress Mesa	2490	1302	170	99.9	235.1	0.07			109
3/29/05	2:01	Crystal Ridge	35° 59.702 115° 03.273	36 00.263 115 04.465	2148 Tiger Links	785	6791	742	249.3	750.2	0.0275	4.3	3.25	112
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5123	742	188.1	565.9	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5196	742	190.7	573.9	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5375	742	197.3	593.7	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3400	742	124.8	375.5	0.03	3.5	3.3	110
				36 00.427 115 03.405	525 Bighorn	3047	4447	742	163.2	491.2	0.04	5	3.9	106
				36 00.023 115 03.603	1577 Harpsicord	2436	2538	742	93.2	280.3	0.11			100
3/30/05	3:41	in back	35° 59.650 115° 03.211	36 00.263 115 04.465	2148 Tiger Links	785	7215	636	286.1	839.0	nt			
				36°00.234 115°04.080	572 Carmel Mesa	1769	5560	636	220.5	646.5	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5339	636	211.7	620.8	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5740	636	227.6	667.4	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3787	636	150.2	440.3	nt			
				36 00.427 115 03.405	525 Bighorn	3047	4810	636	190.7	559.4	nt			
				36 00.023 115 03.603	1577 Harpsicord	2436	2976	636	118.0	346.1	nt			
3/31/05	10:30	Crystal Ridge	35° 59.747 115° 03.256	36 00.263 115 04.465	2148 Tiger Links	785	6733	192	485.9	1167.1	nt			
		N. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5023	192	362.5	870.8	nt			
				36 00.450 115 02.760	DR Golf Course	1906	4917	192	354.8	852.3	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5120	192	369.5	887.4	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3417	192	246.6	592.4	nt			
				36 00.427 115 03.405	525 Bighorn	3047	4191	192	302.4	726.4	nt			
				36 00.023 115 03.603	1577 Harpsicord	200203	2394	192	172.8	415.0	nt			
3/31/05	2:25	Crystal Ridge	35° 59.747 115° 03.478	36 00.263 115 04.465	2148 Tiger Links	785	5786	25	1157.2	1978.9	nt			
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	4188	25	837.6	1432.3	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5543	25	1108.6	1895.7	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5039	25	1007.8	1723.3	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	2353	25	470.6	804.7	0.025	13.4	6.4	100
				36 00.427 115 03.405	525 Bighorn	3047	4141	25	828.3	1416.4	nt			
				35 59.898 115 03.756	800 Bolle	200070	1649	25	329.7	563.8	0.05			111
4/1/05	11:42	Crystal Ridge	35° 59.584 115° 03.377	36 00.263 115 04.465	2148 Tiger Links	785	6764	200	478.3	1156.6	nt			
		S. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5250	200	371.3	897.8	nt			
				36 00.450 115 02.760	DR Golf Course	1906	6071	200	429.3	1038.2	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	6034	200	426.6	1031.7	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3212	200	227.2	549.3	nt			
				36 00.427 115 03.405	525 Bighorn	3047	5117	200	361.8	874.9	nt			
				35 59.898 115 03.756	800 Bolle	2435	2669	200	188.7	456.3	nt			

Table B-1 Summary of Seismograph Data (cont.)

Date	Shot time	Blast Site	Blast site GPS	Seimsograph GPS	Seimsograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	($ft/lbs^{1/2}$)	($ft/lbs^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
4/5/05	10:08	Crystal Ridge	35° 59.600 115° 03.188	36 00.263 115 04.465	2148 Tiger Links	785	7471	46	1101.6	2085.2	nt			
		E. side		36°00.234 115°04.080	572 Carmel Mesa	1769	5843	46	861.5	1630.7	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5572	46	821.6	1555.2	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	6060	46	893.4	1691.2	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	4002	46	590.0	1116.9	nt			
				36 00.427 115 03.405	525 Bighorn	3047	5131	46	756.5	1431.9	nt			
				36 00.023 115 03.603	1577 Harpsicord	200203	3282	46	483.9	916.1	nt			
4/6/05	12:39	Crystal Ridge	35° 59.777 115° 03.183	36 00.263 115 04.465	2148 Tiger Links	785	6975	273	422.1	1075.1	nt			
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5220	273	315.9	804.7	0.02	16	17.5	<100
				36 00.450 115 02.760	DR Golf Course	1906	4585	273	277.5	706.8	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5020	273	303.8	773.9	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3743	273	226.6	577.1	nt			
				36 00.427 115 03.405	525 Bighorn	3047	4091	273	247.6	630.7	nt			
				36 00.023 115 03.603	1577 Harpsicord	2490	2553	273	154.5	393.5	0.035			112
4/7/05	12:33	Crystal Ridge	35° 59.669 115° 03.237	36 00.263 115 04.465	2148 Tiger Links	785	7046	280	421.1	1077.0	nt			
		E. of crusher		36°00.234 115°04.080	572 Carmel Mesa	1769	5388	280	322.0	823.5	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5290	280	316.1	808.6	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5602	280	334.8	856.3	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3628	280	216.8	554.6	nt			
				36 00.427 115 03.405	525 Bighorn	3047	4673	280	279.3	714.3	nt			
				36 00.023 115 03.603	1577 Harpsicord	2490	2805	280	167.6	428.8	nt			
4/8/05	11:15	Crystal Ridge	35° 59.844 115° 03.671	36 00.263 115 04.465	2148 Tiger Links	785	4769	63	600.9	1198.6	nt			
				36°00.234 115°04.080	572 Carmel Mesa	1769	3109	63	391.7	781.3	nt			
				36 00.450 115 02.760	DR Golf Course	1906	5804	63	731.3	1458.7	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	4587	63	577.9	1152.9	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	1309	63	164.9	328.9	0.075	32	37.9	106
				36 00.427 115 03.405	525 Bighorn	3047	3773	63	475.3	948.1	nt			
				35 59.898 115 03.756	800 Bolle	2435	532	63	67.0	133.7	0.27			112
4/12/05	2:21	Crystal Ridge	35° 59.881 115° 03.481	36 00.263 115 04.465	2148 Tiger Links	785	5377	41.7	832.6	1550.5	nt			
				36°00.234 115°04.080	572 Carmel Mesa	1769	3648	41.7	564.9	1052.0	nt			
				36 00.450 115 02.760	DR Golf Course	1906	4955	41.7	767.3	1428.9	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	4227	41.7	654.6	1219.0	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	2248	41.7	348.2	648.4	0.25	8.5	6.9	106
				36 00.427 115 03.405	525 Bighorn	3047	3334	41.7	516.3	961.4	nt			
				36 00.023 115 03.603	1577 Harpsicord	2490	1051	41.7	162.7	303.0	0.06			110

Table B-1 Summary of Seismograph Data (cont.)

Date	Shot time	Blast Site	Blast site GPS	Seimsograph GPS	Seimsograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs$^{1/2}$)	(ft/lbs$^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
4/13/05	3:40	Crystal Ridge	35° 59.656 115° 03.473	36 00.263 115 04.465	2148 Tiger Links	785	2041	214	139.5	341.2	nt			
				36°00.234 115°04.080	572 Carmel Mesa	1769	4610	214	315.2	770.8	0.025	5.1	5.44	106
				36 00.450 115 02.760	DR Golf Course	1906	5964	214	407.7	997.0	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5590	214	382.1	934.6	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	2585	214	176.7	432.2	0.03	36.5	5.38	106
				36 00.427 115 03.405	525 Bighorn	3047	4690	214	320.6	784.1	nt			
				35 59.898 115 03.756	800 Bolle	2435	2026	214	138.5	338.6	0.075			106
4/14/05	4:00	Crystal Ridge	35° 59.707 115° 03.327	36 00.263 115 04.465	2148 Tiger Links	785	6547	439	312.5	861.4	0.025	7.5	6.1	106
				36°00.234 115°04.080	572 Carmel Mesa	1769	4900	439	233.8	644.7	0.0325	8.2	5.88	106
				36 00.450 115 02.760	DR Golf Course	1906	5305	439	253.2	698.0	nt			
				36 00.577 115 03.443	1528 MacDonald R.	706	5310	439	253.4	698.6	nt			
				35 59.856 115 03.936	1814 High Mesa	1258	3136	439	149.7	412.6	0.04	10.6	6.56	112
				36 00.427 115 03.405	525 Bighorn	3047	4385	439	209.3	577.0	nt			
				36 00.023 115 03.603	1577 Harpsicord	2490	2351	439	112.2	309.4	0.06			112

Table B-2 Summary of Seismograph Data Phase 1

Date	Shot time	Blast Site	Blast site GPS	Seimsograph GPS	Seimsograph Location	unit S/N	Distance to blast	Charge Mass W_{max}	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F_{peak}	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs$^{1/2}$)	(ft/lbs$^{1/3}$)	(in/sec)	(Hz)	(Hz)	(dB)
2/25/05	12:10	Crystal Ridge	35 59.785 115 03.879	35 59.905 115 03.847	1795 Anelli Ct.	785	748	9	249.3	359.6	nt			
			35 59.785 115 03.879	35 59.856 115 03.936	1814 High Mesa	1258	514	9	171.3	247.1	0.12	51.2	34.3	106
2/25/05	3:12	Crystal Ridge	35 59.848 115 03.489	35 59.905 115 03.847	1795 Anelli Ct.	785	1799	178	134.8	319.8	0.04	16	16.75	106
			35 59.848 115 03.489	35 59.856 115 03.936	1814 High Mesa	1258	2204	178	165.2	391.8	0.03	25.6	35.1	106
2/28/05	3:58	Crystal Ridge	35-59.741,115-3.24	36 0.022 115-3.606	1755 Harpsicord	BA-6175	2483	600	101.4	294.4	0.09			112
		E. of crusher	35-59.741,115-3.24	35 59.905 115 03.847	1795 Anelli Ct.	785	3154	600	128.8	374.0	0.05	14.2	13.9	106
			35-59.741,115-3.24	35 59.856 115 03.936	1814 High Mesa	1258	3502	600	143.0	415.2	0.05	4.3	3.94	110
3/1/05	2:21	Crystal Ridge	35 59.741’ 115 03.240’	36 00.022’ 115 03.606’	1755 Harpsicord	BA-6175	2483	396	124.8	338.1	0.05			110
		E. of crusher	35 59.741’ 115 03.240’	35 59.905 115 03.847	1795 Anelli Ct.	785	3154	396	158.5	429.5	nt			
			35 59.741’ 115 03.240’	35 59.856 115 03.936	1814 High Mesa	1258	3502	396	176.0	476.9	nt			
3/2/05	1:15	Crystal Ridge	35 59.791’ 115 03.859’	35 59.856’ 115 03.929’	1816 High Mesa	2490	524	15	135.3	212.5	0.10			112
			35 59.791’ 115 03.859’	35 59.905 115 03.847	1795 Anelli Ct.	785	694	15	179.2	281.4	0.04	36.5	18.9	112
			35 59.791’ 115 03.859’	35 59.856 115 03.936	1814 High Mesa	1258	548	15	141.5	222.2	0.12	51.2	41.7	106
3/7/05	2:38	Crystal Ridge	35 59.791’ 115 03.859’	35 59.856 115 3.929	1816 High Mesa	2536	524	24	107.0	181.7	0.20			100
			35 59.791’ 115 03.859’	35 59.856 115 03.936	1814 High Mesa	1258	547	24	111.7	189.6	0.19	36.5	34.6	110
3/8/05	1:11	Crystal Ridge	35 59.853 115 3.488	36-0.023 115-3.603	1755 Harpsicord	2435	1177	115	109.8	242.0	0.13			106
		E. of crusher	35 59.853 115 3.488	35 59.856 115 03.936	1814 High Mesa	1258	2209	115	206.0	454.3	0.04	5.9	6.06	106
3/9/05	3:29	Crystal Ridge	35 59.638 115 3.243	36-0.023 115-3.603	1755 Harpsicord	2262	2934	224	196.0	483.1	nt			
		E. of crusher	35 59.638 115 3.243	35 59.856 115 03.936	1814 High Mesa	1258	3364	224	224.8	553.9	nt			
3/10/05	3:07	Crystal Ridge	35 59.634 115 3.235	35 59.895 115 3.77	800 Bolle	2436	3076	364	161.2	430.8	0.11			100
		E. of crusher	35 59.634 115 3.235	35 59.856 115 03.936	1814 High Mesa	1258	3709	364	194.4	519.5	nt			

nt - no trigger