

# WHITE PAPER

## Influence of Geology on Ground Vibrations from Rock Blasting in the City of Henderson, NV

Prepared for

CITY OF HENDERSON

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## SUMMARY

This White Paper summarizes the results of a study in which blast vibrations were measured in different geological materials to determine whether variations in ground motion amplitudes exist based on surface geology. The study site surrounds rock blasting to develop the R-30 Reservoir and home development for Canyons Parcels F and L. Blasting areas are shown in Figure 1. The study was initiated in response to concerns expressed by several residents living near the blasting areas that the City of Henderson blast vibration limit of 0.5 inches per second (in/s) is not applicable to protect structures near this project from cracking based on the nature of foundation fill materials on which structures are founded. Further, it is thought by some residents that vibration levels are affected by geology and that “sites with a thick layer of soil have been known to produce vibrations 10 times as great as locations with a thin layer of soil over rock”.<sup>1</sup>

To address these concerns, the City of Henderson contracted with Aimone-Martin Associates, LLC (AMA) to evaluate the influence of geology on ground vibrations. AMA worked with two independent seismic monitoring companies, VCE and Aztec Materials Testing both of Las Vegas, NV, to provide seismograph measurements during rock blasting at the R-30 Reservoir and Canyons Parcels F and L projects.



Figure 1 Study blasting areas

<sup>1</sup> U.S. Department of Energy, 2007, Western Greenbrier Co-Production Demonstration Project Final Environmental Impact Statement, Volume 1 of 3, DOE / EIS-0361, Office of Fossil Energy, National Energy Technology Laboratory, p 3.15-4.

Measurements were made at a variety of surface geologies that included construction cuts, fills, natural (virgin) soils and bedrock with thin overlying soils. Blasting-type seismographs were deployed at various sites representing different geologies near the outer ridgeline edge of Sunridge Heights and at the southern end of Canyon Heights Dr. from October 19, 2016 through March 14, 2017. This report summarizes the analysis of 316 ground vibration measurements recorded during 124 individual blasts.

Background information is found in Annex A that may help readers understand concepts on rock blasting vibrations, safe blasting standards, and structure response to ground vibrations supported by 70 years of research findings.

### COMPARISONS OF GROUND VIBRATIONS RECORDED IN VARYING GEOLOGIC MATERIALS

A ground motion study was conducted between October 19, 2016 and March 14, 2017 during which 124 blasts were instrumented with blasting-type seismographs deployed near residential sites. Nine monitoring locations, shown in Figure 2, included surface geologies comprising construction cuts (1 site), fill materials (3 sites), natural (virgin) soils (2 sites), and rock overlain with thin a soil layer (3 sites).

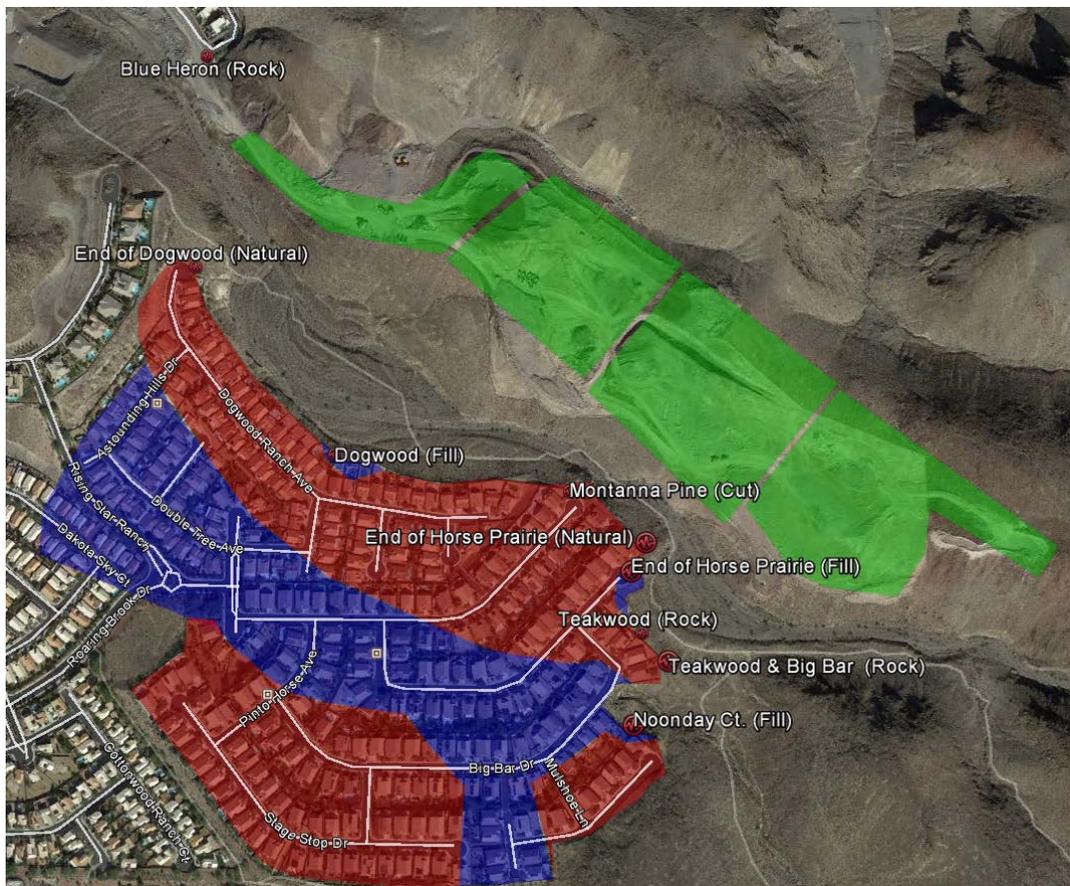


Figure 2 Location of ground vibration measurements in different site geologies; blast area is shown in green

Seismograph monitoring was conducted by two independent engineering companies. VCE monitored blasts from October 19, 2016 until March 14, 2017 and Aztec Materials Testing provided 3<sup>rd</sup> party, side-by-side, comparisons starting February 8, 2017 until March 14, 2017. Each company deployed different models of blasting-type seismographs and used various geophone coupling methods within the same geologies to monitor 458 independent locations.

Coupling methods included burial of the geophone into the surface geology, the placement of a geophone with bottom spikes on the ground surface and covered with a sand bag, and placement of the geophone in a hole dug in the surface overlain with a sandbag. Each of these methods comply with the recommended practices outlined in the International Society of Explosives Engineers (ISEE) Field Practice Guidelines for Blasting Seismographs (2015).

The distribution of seismograph monitoring at structures among the different geologies and number of blasts that triggered the seismographs are given in Table 1. The total number of blasts for which seismographs were deployed by VCE and Aztec were 360 and 98, respectively. In each case, seismographs were set to trigger and record ground motions at or above 0.03 in/s PPV. The total number of blasts for which ground motions met or exceeded the trigger amplitude at all site geologies was 248 and 68 for VCE and Aztec, respectively.

The range of distances from blasting to seismographs were similar among all geologies. However, about 50% of the blasts actually triggered the seismographs placed in fill because the amplitude of ground motions were below the 0.03 in/s trigger amplitudes. Seismographs placed in thin soil layers overlying rock at similar distances resulted in triggers for 75% to 85% of the total blasts. In the case of seismographs placed in cuts or natural (undisturbed) areas, seismographs triggered for 67% to 78% of the blasts. It is clear that the fill sites did not achieve the same amplitude of ground motions as the

Table 1 Number of rock blasts for which seismographs were deployed by VCE and Aztec near structures in various site geologies showing the percentage of blasts that triggered the seismographs

| Geology | VCE      |           | Aztec    |           |
|---------|----------|-----------|----------|-----------|
|         | deployed | triggered | deployed | triggered |
| Cut     | 110      | 86 (78%)  | 32       | 22 (67%)  |
| Natural | 117      | 87 (74%)  | 30       | 25 (69%)  |
| Rock    | 27       | 23 (85%)  | 12       | 9 (75%)   |
| Fill    | 106      | 52 (49%)  | 24       | 12 (50%)  |
|         | 360      | 248       | 98       | 68        |

other site geologies because ground motions were well below the low trigger amplitude of 0.03 in/s for half of the blasts. As such, fill sites tended to attenuate ground motions below those measured in all other geologies that were studied.

### **Attenuation of ground vibrations**

Developing a site-specific attenuation model of ground vibrations in terms of PPV correlated with distance scaled with charge weight of explosives is a means of characterizing site geology and the performance of rock blast design. As discussed in Annex A, the US Bureau of Mines (USBM), used attenuation models in research to understand how PPV, duration, and peak frequency vary with distance and blast design.

The attenuation or decrease in ground vibrations is correlated with distance from the blast site scaled with the square root of the maximum charge weight of explosives used in the blast per time delay interval. Usually the interval of 8 millisecond (ms) is used to calculate the maximum charge weight of explosives that correlated best with ground vibrations. Thus, PPV attenuates with scaled distance (SD) that is computed as

$$SD = D / W^{1/2}$$

where D is the distance from the blast to the seismograph recording ground motions and W is the maximum pounds of explosives charge detonating within 8 ms.

The attenuation of ground motions is described with a linear regression best-fit through measurements of PPV plotted against SD on a graph using log axes. The equation describing the best-fit is of the form

$$PPV = K (SD)^{-b}$$

where K is the Y-intercept at SD = 1 and -b is the slope of regression line.

### **Attenuation of PPV measurements recorded for this study**

Ground vibration measurements provided by VCE and Aztec data are plotted in Figure 3 with measurements recorded during an attenuation study conducted by Aimone-Martin Associates (2005). The 2005 study took place during development of Crystal Ridge, approximately 1.4 miles NE of the present study site. The 2005 study best-fit (or 50-percentile median line) attenuation model is given by

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

The Aztec data set agrees with this model with a best-fit equation of

$$PPV = 120.7 SD^{-1.48}$$

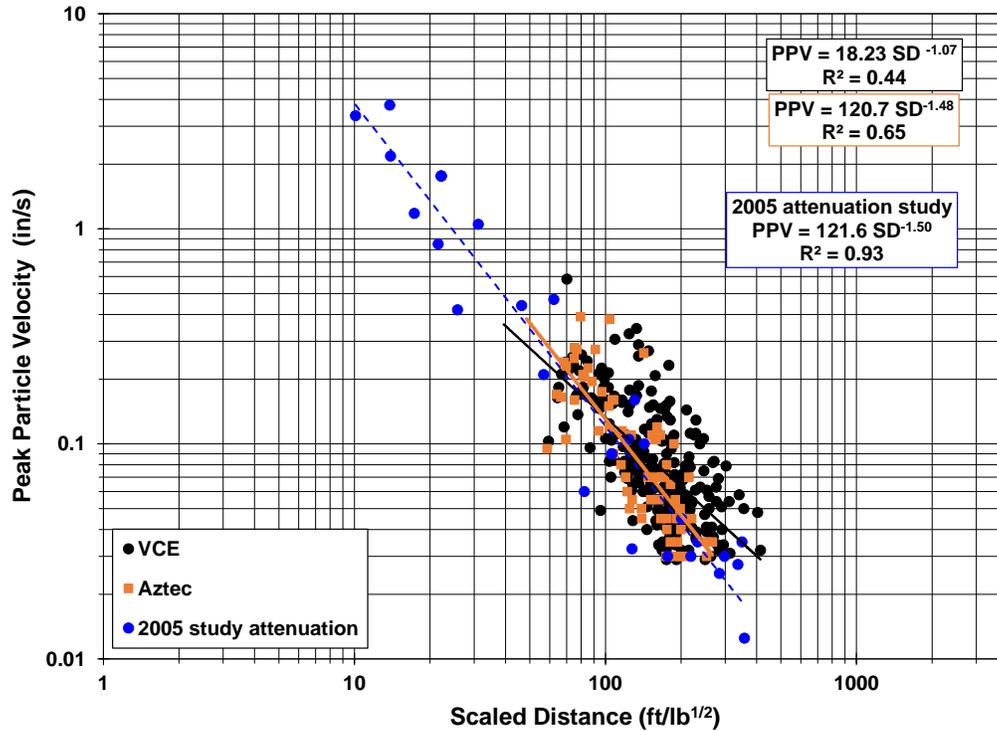


Figure 3 Comparison of attenuation models using ground vibration measurements from Aimone-Martin Associates (2005) and measurement recorded from this study by VCE and Aztec

The VCE data set is characterized with somewhat overall higher amplitudes of ground motion for SD values above 200. This is most likely the result of using a sand bag to couple the geophone to the ground as opposed to burying the geophone four to six inches in the ground. Burial methods were used by Aztec and for the 2005 study. Both methods of geophone coupling are acceptable as indicated by the ISEE Monitoring Guidelines (2015). However, the use of sandbags often results in slightly higher PPV measurements when compared to burial methods. As a result, the attenuation model for the VCE data is given by

$$PPV = 18.23 SD^{-1.07}$$

with close-in and far-field measurements that are higher and lower than the other measurements, respectively.

Geology-specific attenuation is given in Figure 4 and shows the distribution of PPV measured in cut, natural soil, rock with thin overlying soils, and fill. Measurements for cut and natural soil sites are uniformly spread over the range of scaled distances of 60 to 400 while measurements in rock and fill center on SD values between 120 and 270. However within each distance range the scatter in PPV measurements are roughly the same. For instance, over the SD range of 140 to 180 that contains measurements from all four geologies, the spread of PPV data (from low to high) is the same. There are nearly equal PPV measurements for all geologies around 0.03 in/s as well as near 0.3 in/s and for values

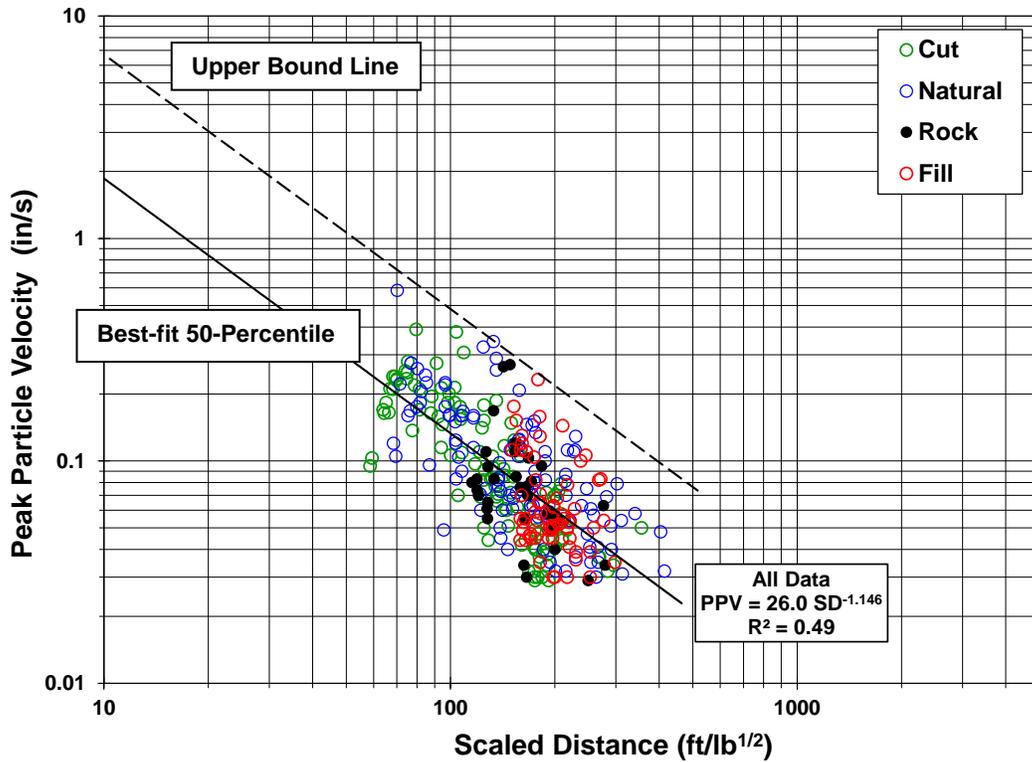


Figure 4 Peak particle velocity (PPV) versus scaled distance for all measurements

in between. As such, there is not one geology that shows higher values than others and data for each site is well distributed beyond a SD of 150. This important finding was established by the U.S. Bureau of Mines (USBM) and others during blasting studies throughout the U.S. since the 1950. For any range of scaled distance and vibration measurements representing several different geologies, the distribution of ground motion amplitudes at any one geology exhibit the same statistical variation (or spread in the data) as all other geologies.

### Comparison of site geology based on peak frequencies and PPV

In Figure 5, PPV and peak frequency measurements are plotted by site geology within the USBM safe blasting criteria established in 1980 to prevent threshold cracking and within the City of Henderson regulated vibration limits. All PPV measurements recorded throughout the course of this study remained well below the Henderson limit of 0.5 in/s with the exception of one measurement of 0.584 in/s in natural soil for a blast that was outside the blast area shown in Figure 2. This measurement was recorded at a distance closer than the nearest structure and the blast was deemed safe for all nearby structures.

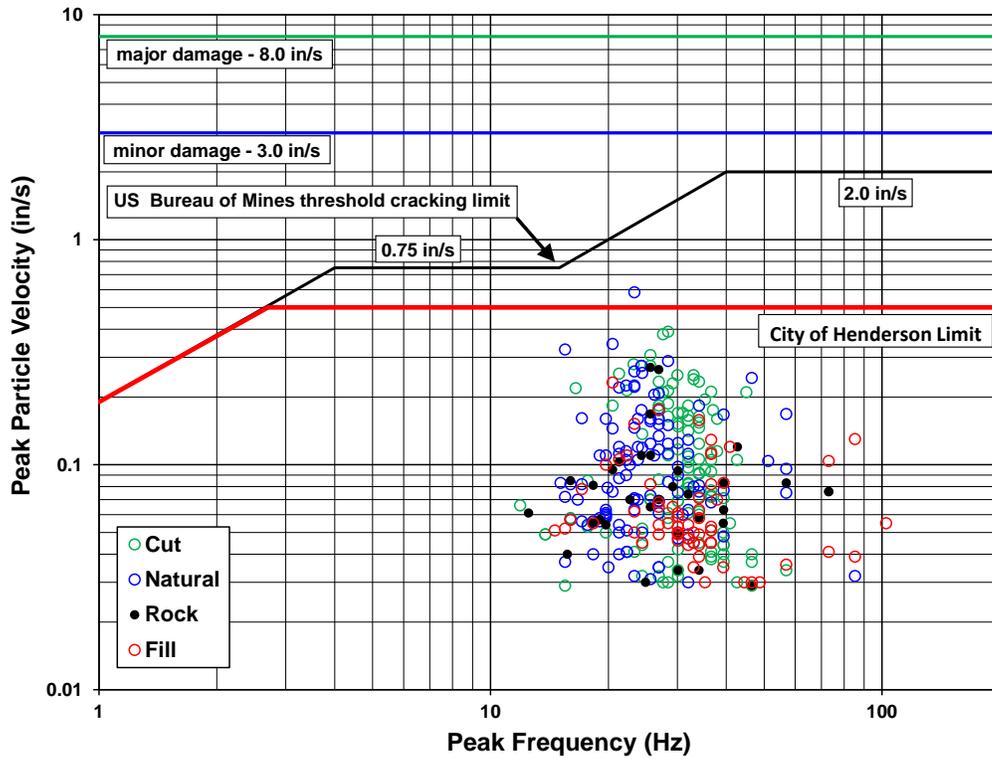


Figure 5 Peak particle velocity (PPV) versus peak frequency for all site geologies

Data plotted in Figure 5 shows that measurements recorded at natural, rock, and fill geologies generated peak frequencies from 12 to 102 Hz while the highest frequency for a cut site was 57 Hz.

Regarding PPV values, the highest and average PPV measurements for each site geology are given in Table 2. Fill materials generated the lowest amplitudes of ground vibrations among all geologies for both the highest and average values.

Table 2 Highest and average PPV for four site geologies

|         | Highest PPV<br>(in/s) | Average PPV<br>(in/s) |
|---------|-----------------------|-----------------------|
| Fill    | 0.232                 | 0.070                 |
| Rock    | 0.271                 | 0.085                 |
| Cut     | 0.390                 | 0.114                 |
| Natural | 0.584                 | 0.112                 |

## SUMMARY AND CONCLUSIONS

A study of ground vibrations recorded during rock blasting at the R-30 Reservoir and Canyons Parcels F and L sites included measurements in construction cuts, natural (virgin) soils, fill soils, and rock overlain with thin soils layers. All PPV measurements recorded throughout the course of this study remained well below the safe criteria defined by the US Bureau of Mines and well below the 0.5 limits imposed by the City of Henderson with the exception of one measurement of 0.584 in/s in natural soil for a blast that was outside the blast area shown in Figure 2.

This study showed that sites with fill soils did not amplify ground vibrations over other geologies. In fact, fill soils tended to produce ground vibrations that were lower in amplitude than vibrations measured in rock, cuts, and natural soils. The statistical variation of vibration amplitudes based on scaled distance were found to be the same when comparing different site geologies. This important finding was established by the U.S. Bureau of Mines (USBM) and others during blasting studies throughout the U.S. since the 1950.

Peak frequencies measured at the PPV in fills did not indicate any unusual characteristics that would require a PPV limit for structures founded on fills to be lower than for other geologies. Based on the vibration measurements recorded during this study, it is not possible that blasting at the R-30 Reservoir and Canyons Parcels F and L have contributed to any nearby structure cracking.

## REFERENCES

NOTE: Research on the effects of blasting on structures as well as all U.S Bureau of Mines publications may be found on the following Office of Surface Mining (OSM) website:

<https://www.osmre.gov/resources/blasting/ARblast.shtm>

Aimone-Martin, C.T., M.A. Martell, L.M. McKenna, D.E. Siskind, and C.H. Dowding (2003) Comparative Study of Structure Response to Coal Mine Blasting, prepared for the Office of Surface Mining Reclamation and Enforcement, Pittsburgh.

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Aimone-Martin Associates, LLC (2005) Structure Response Study - Crystal Ridge, MacDonald Ranch, and MacDonald Highlands, report to the City of Henderson.

American Insurance Services Group, 1990, Blasting Damage and Other Structural Cracking, A Guide for Adjustors and Engineers, 3<sup>rd</sup> ed.

Bakri, N. N. O, and M. A. O. Mydin, 2014, General Building Defects: Causes, Symptoms, and Remedial Work, European Journal of Technology and Design, Vol. (3) No 1.

International Society of Explosives Engineers (ISEE) Field Practice Guidelines for Blasting Seismographs (2015) <https://www.isee.org/digital-downloads/290-isee-field-practice-guidelines-for-blasting-seismographs-2015>.

Nichols, H. R., C.F. Johnson, and W. I. Duval (1971) Blasting Vibrations and Their Effects on Structures, U.S. Bureau of Mines, U.S. Department of the Interior, Bulletin 656.

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, U.S. Department of the Interior, Report of Investigation (RI) 8507.

Stagg, M.S, D. E. Siskind, M. G. Stevens, and C. H. Dowding (1984) Effects of Repeated Blasting on a Wood-Frame House, U.S. Bureau of Mines, U.S. Department of the Interior, Report of Investigation (RI) 8896.

## ANNEX A BACKGROUND ON ROCK BLASTING

This annex provides a background on rock blasting vibrations, the development of safe blasting standards to protect structures from blast-induced cracking, and studies involving structure response to ground vibrations. The purpose of this section is to provide residents with an understanding of the findings contained in reports covering 70 years of rock blasting research that culminated in, and continues to support, safe blasting standards in place throughout the U.S. In addition, these studies support vibration standards adopted by the City of Henderson to protect structures from any crack damage.

### Nature of Blasting Vibrations: Amplitude, Frequency and Duration

Ground vibrations are measured as time-histories shown in Figure A-1 using blasting seismographs. Vibration characteristics include amplitude, frequency, and duration (in time) of the blast wave. The amplitude of ground vibration, measured in terms of speed or velocity (inches per second or in/s), attenuates or decays with distance. Ground vibrations are measured with a 3-component velocity transducer housed in a geophone. When measuring vibrations, the maximum velocity in any one of three components (one vertical and two horizontal) is reported as the peak particle velocity (PPV).

The magnitude of PPV is affected by distance and the maximum explosive charge weight detonated within an 8 milliseconds (ms) time depending on the blast design and arrangement of delay blasting caps. Because of this, PPV is evaluated based on distance between the blast site and seismograph (or a structure) scaled to charge weight to predict and control vibrations.

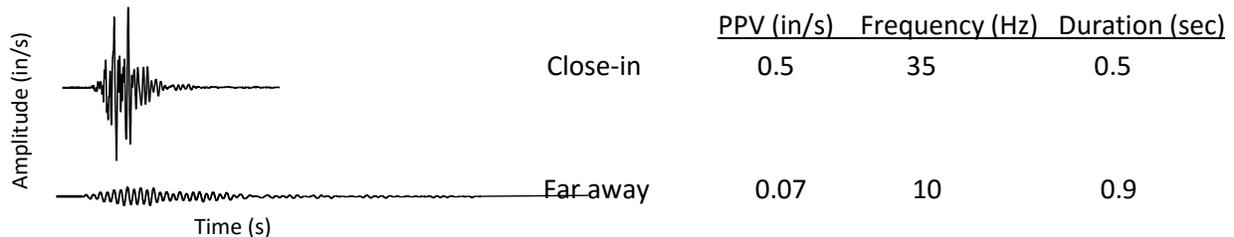


Figure A-1 Ground motion time histories plotting PPV amplitude versus time in seconds for two monitoring locations close-in and far away; values for PPV, peak frequency and duration are noted

The frequency at the PPV is used to evaluate the way in which structures respond to blasting. Frequency is computed as the number of oscillations or positive and negative cycles per second given in Hertz (Hz). Frequency tends to decrease with distance as the time over which one cycle increases based on dispersion or spreading of the wave front. This decrease in frequency can be observed in Figure A-1 by comparing the close-in and far away time histories.

The time duration of a blast wave increases with distance as noted in Figure A-1. The designed time duration of most blasts is extremely small and generally ranges from 0.5 to 1 second. However, the ground motion time duration, as measured by the time-history, can increase to 2 to 3 seconds or more as the surface wave travels away from the blast site.

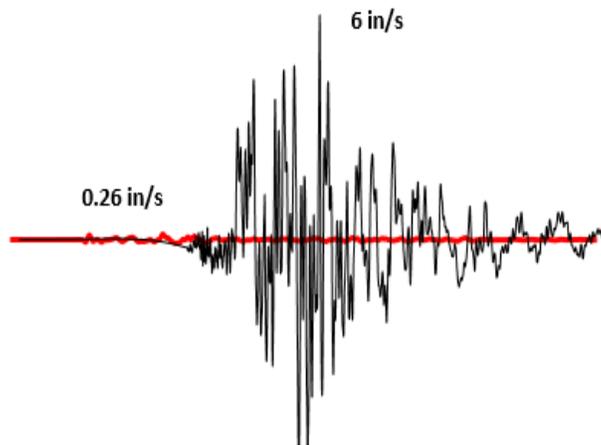
### **Comparison of Blasting with Earthquakes**

Residents near rock blasting operations may have experienced an earthquake in the past and often compared the blasting to an earthquake. Even though blasts and earthquakes may *seem* similar, they are very different for a number of reasons. Blasting generates ground motions that are much lower in amplitude, far shorter in duration and higher in frequency than earthquakes. These three characteristics are compared in Figure A-2, (a) through (c). Ground motion amplitudes from earthquakes are often two to three orders of magnitude greater than for blasting when measured at structures. The duration of earthquake motion can last well over 30 seconds while ground motions from a typical rock blast can last two to three seconds. The frequency at the peak ground motions is often below 1 Hz for earthquakes while for construction blasting it is typically above 20 Hz. Earthquakes may be damaging to structures because they carry high amplitudes of ground motions over long durations at very low frequencies. However, rock blasting motions (amplitude, duration and frequency) can be controlled so that structure cracking and damages do not occur.

### **Development of Safe Blasting Standards**

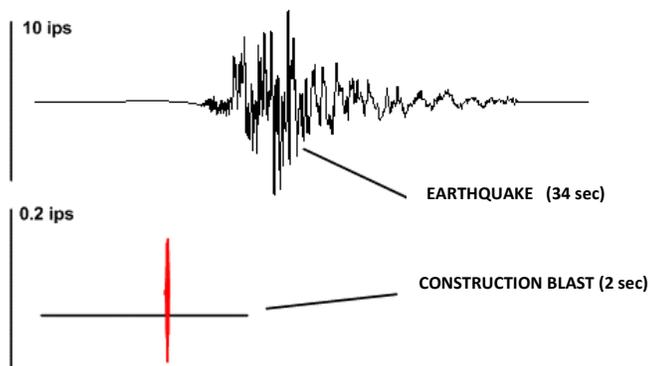
The evolution of rock blasting research and the effects of blasting on residential structures began in the 1940s and culminated in 1981 with the development of safe blasting vibration criteria to prevent cracking in residential-type structures. The leading research agency, the US Bureau of Mines (USBM), along with other consultants, studied the propagation and attenuation of vibrations with distance, residential structure motions, and the amplitudes of ground motions that resulted in the smallest hairline cracking in structure walls. Other study elements included how to classify blast-induced cracking (threshold or cosmetic, minor and major) and best methods used to measure ground vibrations. Only in the early years of research was site geology considered to play a role in blast vibrations.

The USBM completed blasting research in the 1980s at the time the agency closed. Since that time, other researchers, including Aimone-Martin Associates, have continued research in structure response to blasting. All research since 1980 has supported the USBM findings and recommendations for safe blasting.



(a)

**TIME DURATION COMPARISON**



(b)

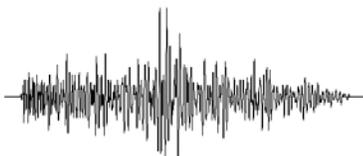
**LOMA PRIETA EARTHQUAKE - YERBA BUENA ISLAND, CA  
October 17, 1989**

30 sec time history: 5.7 in/s 0.25 Hz



**CONSTRUCTION TRENCH BLAST**

3 sec time history: 0.18 in/s 24 Hz



(c)

Figure A-2 Time histories of an earthquake in comparison with a construction blast showing difference in peak amplitudes (a), time duration of ground motions (b), and peak frequencies (c).

**Bulletin 656** (Nicholls, et al, 1971): Much of the USBM early blasting research started in the mid-1940s and was performed at hundreds of blast sites with highly varied geologies, including different rock types and variable thicknesses of overlying soils, using a wide range of blasting methods. Bulletin 656 summarize research work on structure response to blast vibrations conducted over the previous 10-year period. In the research the authors conclude that 2.0 in/s peak ground vibration was a safe limit to prevent damage to structures.

Geology and rock type were noted to affect vibration amplitudes “within limits”. However, the document conclusions clearly state that the effects of soil thickness and underlying rock type could not be determined over the 10-year measurements period. Ground motion amplitudes were similar irrespective of geology. The influence of overburden (soil type) did not show any differences in ground vibrations amplitudes while the frequencies of ground motions were influenced by overburden.

Field vibration studies conducted by Aimone-Martin Associates (AMA) since 1985 to present agree with Bulletin 656 findings. AMA has found that the statistical variance in ground motion amplitudes as a function of distance is similar among various site geologies. In other words, the statistical spread of measurements for any one geology is the same as the spread for all geologies combined and no clear trend can be correlated to specific rock or soil types.

AMA, as well as other researchers, have found that surface soils through which vibrations travel can influence the frequency characteristics of ground motions as distance increases from the blast site. The resulting peak frequency measured at structures is important to the perception of ground motions by inhabitants. Low ground motion frequencies are more readily perceived by persons in comparison with high frequency motions even at very low amplitudes of ground vibrations. As a result, high frequency, high PPV ground motions are often not noticed by inhabitants while low frequency, low amplitude vibrations can be perceived as damaging and very annoying to persons inside dwellings. As such, site geology can influence frequency but has little measurable effect on vibration amplitude.

**Report of Investigation (RI) 8507** (Siskind, et al, 1980): In 1980, the USBM published RI 8507 summarizing blast-induced motions in 76 residential structures subjected to ground vibrations from 219 production blasts. The focus of this study was to find the lowest ground vibrations inducing wall cracking. During this study, ground vibrations at structures ranged from 0.2 to 10 in/s. This important publication set the final USBM recommendations for safe surface blasting vibrations that are currently referenced and adopted as regulation in many locations throughout the U.S.

Categories of crack intensity were defined for typical construction materials in order of increasing material strength and presented in Table 10 of RI 8507. Categories of cracking included threshold or cosmetic (cracking of plaster or drywall or the weakest material in structures), minor (cracking in mortar materials) and major (cracking in concrete slabs). It was shown that increasing amplitudes of PPV were required to crack materials of increasing strength.

During this study, the USBM did not find any cracking in any materials in the 76 structures and observed only a tape joint separation between two drywall boards at 0.79 in/s even though ground vibrations outside structures ranged up to 10 in/s. Because of this fact, researchers included ground vibration measurements associated with crack observations reported by other researchers to establish a conservative lower limit to safe blasting that protected the weakest materials in residential structures. The culmination of this study that included non-USBM crack observations by others established the safe blasting criteria shown in Figure A-3. Recommended limits for minor and major cracking in materials stronger than drywall are included in this Figure and were derived from laboratory simulated blasting studies. These laboratory studies are further described below.

**Report of Investigation (RI) 8896** (Stagg, M.S. et al., 1984): In 1984, the USBM published RI 8896 in which long-term fatigue or repeated effects of continued blasting was studied in a newly constructed residential structure. The structure was subjected to 587 blasts over a 2-year period with ground motions measured at the foundation ranging from 0.1 to 6.94 in/s. The study incorporated

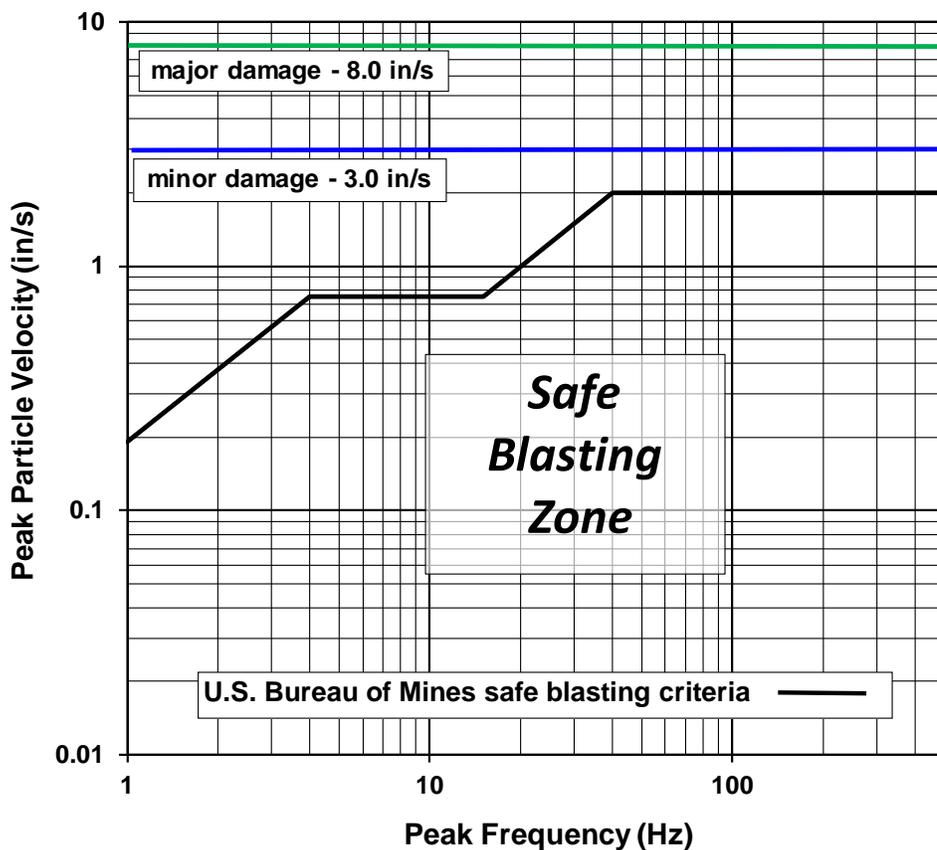


Figure A-3 Safe blasting criteria recommended by the U.S. Bureau of Mines in 1980 and widely adopted for blasting in the U.S.; the black line presents threshold or cosmetic cracking bounds

environmental effects (i.e., variations in temperature and humidity) on the appearance of new cracks and addressed amplification of ground motions in upper structure walls to ensure maximum wall strains from blasting were addressed.

The study concluded that no new blast-related crack occurred during the 2 years and a minor extension of an existing crack in drywall occurred at 0.88 in/s. All other cracking was related to fluctuations in temperature and humidity along with natural aging of new construction materials.

RI 8896 marked the second large-scale effort by the USBM to establish the lowest limits of ground vibrations leading to threshold or cosmetic cracking without success. As a result, the USBM embarked on several laboratory-based studies at universities and national testing labs to determine the dynamic strain limits to cracking in drywall and mortar materials. These strains were equated to ground vibrations that produced similar strains in structure walls during field blasting. The laboratory studies verified that threshold cracking related to environmental factors could not be distinguished from wall cracking possibly related to blast vibrations. The smallest ground vibration (measured in PPV) that produced equivalent environmental strains in walls resulting in cosmetic cracking was 1.2 in/s. In other words, wall strain effects of temperature and humidity variations on drywall movement was the same as wall strain from a PPV of 1.2 in/s.

Mortar between red brick and concrete masonry units (CMU) cracked at ground motion equivalents of strain of 2.6 in/s and 2.9 in/s, respectively, at low frequencies near natural frequencies of structures (10 Hz and less). At higher frequencies above 10 Hz, mortar cracked at 7.2 in/s equivalent strain. This is because higher amplitudes of ground motion are required to crack walls at high frequencies.

Over the time of lab studies, a large-scale mechanical shaker was placed in the study home attic after blasting ceased to shake the whole structure until the first drywall crack appeared. This study was intended to evaluate material fatigue from repeated shaking (or simulated blasting) and was performed at low frequencies below 10 Hz at an amplitude of 1.0 in/s. The number of vibratory cycles producing the first drywall crack was documented and equated to the total number of blasts simulated with 5 predominant cycles per blast.

The first new crack in drywall occurred after 361,500 cycles of shaking at 1.0 in/s. The USBM equated these cycles to 72,300 total blasts with 5 or less peak cycles each at 1 in/s. Assuming 400 blasts per year (typical of a mine), it was concluded it would take 180 years of repeated blasts at 1.0 in/s until the first blast-related fatigue crack would appear.

**Office of Surface Mining Research:** Since RI 8896, AMA was contracted with the Office of Surface Mines to perform similar studies in 38 residential structure types not addressed in USBM studies (Aimone-Martin, et al, 2003). In this research, no new structure wall cracks were observed for PPV amplitudes up to 1.3 in/s at 18 blasting sites and over 95 blasts.

Since 2003, AMA has determined amplification and natural frequencies and computed wall strains for over 86 structures in 12 states near mining and construction blast sites. All measurements agreed with measurements obtained by the USBM and no cracking has been observed within the safe blasting zone in Figure A-3

### Adoption of Safe Blasting Standards for the City of Henderson

The culmination of the USBM studies have repeatedly shown that peak particle velocity (PPV) of ground motion and the frequency at the PPV correlate best with cracking potential in structures but only at very high PPV amplitudes. The frequency-based safe blasting standards proposed by the USBM in 1980, shown by the solid black line in Figure A-4, limit the maximum ground velocity as a function of frequency at the PPV. Blasting below this line is safe and cannot possibly cause any cracking in structures. To date, blast-induced cracking has never been observed for ground vibrations below this safe limit.

The City of Henderson published a blasting guideline in 1993 that limited the maximum particle velocity (single component) of 0.5 inches per second, measured at the closest occupied structure. This was modified in the 2005/2006 blasting regulations to the limit shown in Figure A-4.

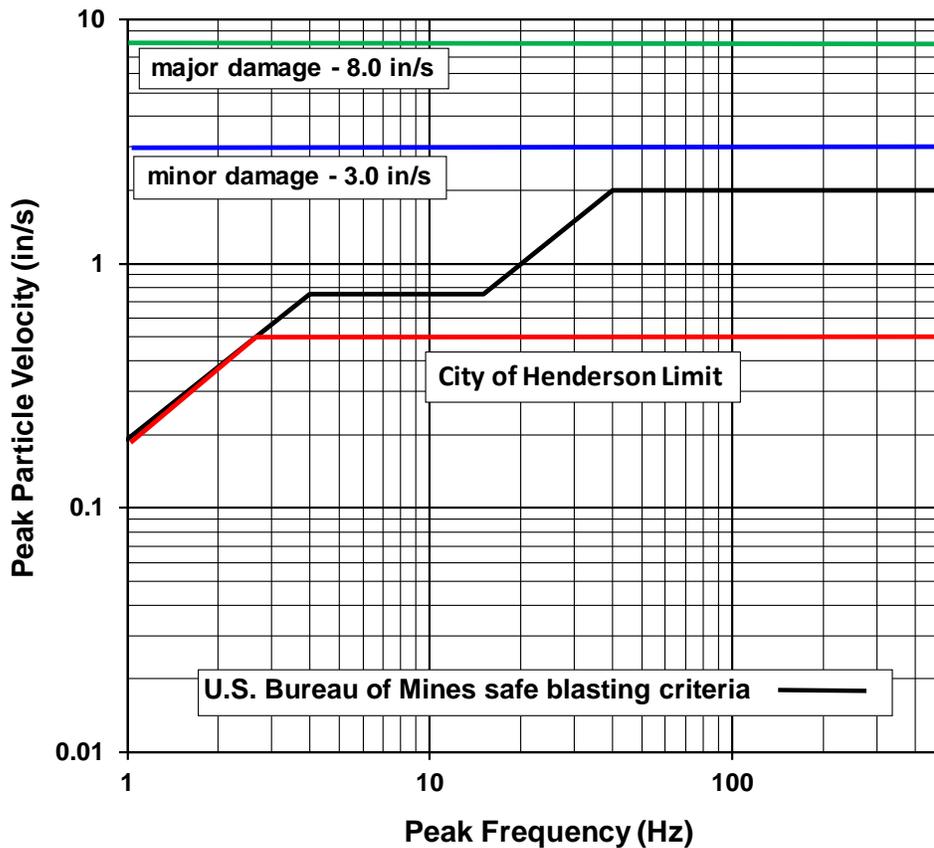


Figure A-4 Vibration limits imposed in the City of Henderson

## How Structures Respond to Vibrations

Structure response studies using special instrumentation in one- and two-story residential dwellings has been performed for over 35 years. Studies have shown that structure response to blasting is dependent on the predominate frequencies in the ground. Figure A-5 shows a structure subjected to both high frequency (left) and low frequency (right) ground motions. If the wave length is very short relative to the dimensions of the structure, as with high frequencies, the structure does not have time to respond to the blast wave. On the other hand, when the blast wave is long relative to the structure dimensions (at low frequencies), the structure tends to move with the ground motion energy and motions are readily perceived by inhabitants.

Studies have further shown that ground vibrations become noticeable to inhabitants when vibration energy in the ground contains frequencies that match the low natural frequency of the structures. Structure natural frequencies range from 4 to 12 Hz for whole structures (with motions of the upper roof relative to the foundation) and from 18 to 25 Hz for mid-walls. These motions can cause structures to shake for a period of time that can be longer than the ground motion duration resulting in amplification of ground motion in the upper structure. Noise and rattling of loose objects resting on or against walls can result and may startle and alarm persons inside structures. This noise can leave the impression that damage may be occurring even at very low amplitudes of ground motion. However, it is not possible that damages from blasting can occur below the safe blasting criteria.

Engineers design blasts to achieve the highest possible ground motion frequencies to optimize the rock breakage process. However, certain geologies between the blast site and structures will absorb the high frequencies, leaving only the low frequency components. In such cases, blasters adhere to the strict frequency-based vibration criteria given in Figure A-3 to ensure cracking does not occur in structures.

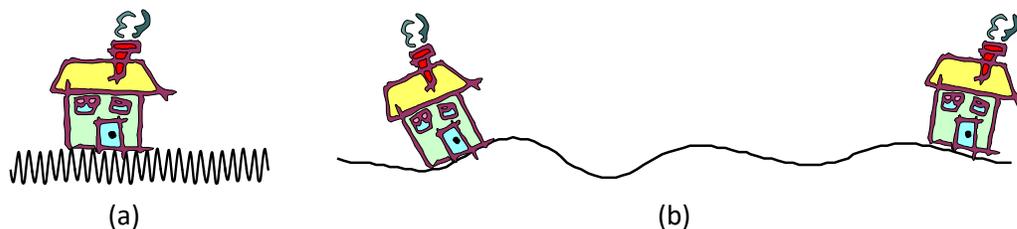


Figure A-5 Response of structure subjected to high (a) and low (b) frequencies of ground motions

## Natural Causes of Structure Cracking

Residents living near blasting operations in Henderson often notice cracking in their home for the first time and associate the cracks with blasting, even though the cracks existed prior to blasting.

Cracking in structures is *normal and expected* over time after construction. Cracks readily form in new construction for many reasons based on subtle, differential soil deflections and natural aging of new

construction materials. Soil deflections up to 0.5 inches are normal. Anything greater than this may be a sign of foundation construction problems. Shrinkage of construction materials such as new concrete, mortar, and wood framing is the largest contributor to cracking in residential structures. "Green" wall studs may shrink 2% to 11% in width upon drying after construction depending on the wood grain orientation with the wall.

After construction, natural atmospheric humidity fluctuations create differential expansion and contraction of wood members acting against other materials such as drywall, glass and metal, resulting in potential wall and joint stresses, separation and cracking, and the common "nail popping" as nail heads naturally deflect outward from the wall. Thermal stresses from daily temperature fluctuation can cause severe material expansion and contraction of stucco, drywall, and concrete that may result in hairline crack formation. These subtle structure movements continue for years and are the main cause of structure distress that leads to on-going cracking.

Older construction may crack for the first time from changes in structure loading or foundation soil conditions as well as every-day human activities. With aging, water pipe joints may leak and saturate the soils beneath structures, causing compaction, consolidation, or even expansion of the soils and may result in cracking of concrete slabs and tile flooring. Storms with high winds prevalent in Nevada may load structure walls, causing cracks to widen and lengthen. Residents running through houses, slamming doors and windows, dropping heavy objects in rooms, and even running a garbage disposal can create wall and structure vibrations that are often as great as or greater than those caused by blasting.

There are hundreds of reasons why cracks appear in construction materials with age, wear and tear, and use of a home. The most common environmental and human factors that lead to cracking in drywall, stucco, masonry, wood, and other materials include the following:

- short-term and long-term changes in temperature and humidity leading to large material strains from expansion and contraction,
- water intrusion through cracks and around foundations from broken water pipes or leaking hose bibs,
- transient wind and earthquake loads,
- soil conditions at time of construction or changes in soils after construction (soft, wet clays, improperly compacted or poorly drained fill, expansive clays, and so forth),
- improper foundation design for the range of anticipated soil or structure loading conditions,
- unsupported upper structure spans,
- inferior or "green" construction materials, and
- normal, everyday household activities.

These forces create strains in construction materials that may exceed those generated in structures from blasting within established safe limits and may often be greater than the failure strain of the weaker material (such as drywall and stucco). Minor cracking in these construction materials is normal and expected. Extensive cracking may be a sign of structural problems and a qualified structural engineer should be consulted.