

# **EXECUTIVE SUMMARY**

## **Blasting Attenuation Study Structure Response Study**

**Crystal Ridge, MacDonald Ranch and MacDonald Highlands**

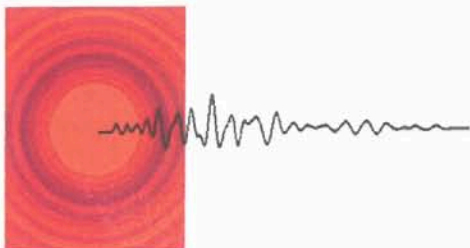
**For the**

**City of Henderson  
240 Water St.  
Henderson, Nevada**

**Prepared by**

**Dr. Catherine T. Aimone-Martin  
President**

**May 27, 2005**



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## **BLASTING ATTENUATION STUDY**

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

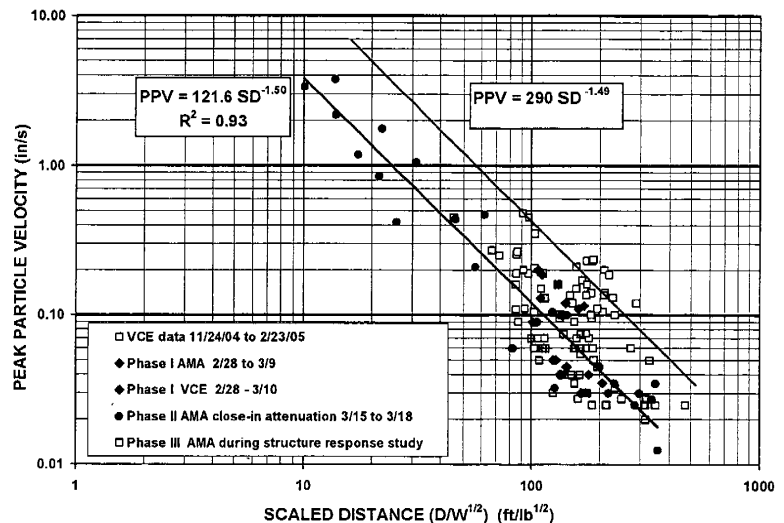
- evaluate seismograph measurements and data from blasting operators and vibration consultants, VCE, of Las Vegas, Nevada,
- validate measurements recorded by VCE,
- evaluate geological influences that may be contributing to unusual ground vibrations in various directions from blasting operations, and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

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 at coal mines. The 100% confidence line for all data, including data recorded during the Structure Response Study, was

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



Conclusions drawn from this study are as follows:

- 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 more control on blasting was exercised since that inceptions of scientific studies and elevated oversight by the City.
- Post-blast record keeping of blasting and vibration information was lacking in key information upon the 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.
- 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.

## **STRUCTURE RESPONSE STUDY**

The response of two residential structures, one in Sun City MacDonald Ranch and one in MacDonald Highlands, to blasting vibrations was conducted from 3/15/05 to 4/15/05. Structures were instrumented with single-axis velocity geophones to measure whole structure and mid-wall vibratory motions during blasting

events. Displacement-type gages were used to measure movement of a pre-existing stucco exterior wall crack during blasting, construction, and wind events. A single tri-axial geophone and air pressure sensor were employed exterior to the dwellings to record ground motions and airblast. Data analyses for blast-induced and other motions were conducted to:

- compare vibration time histories in terms of velocity and calculated displacements within structures relative to ground excitations and air overpressures,
- evaluate response frequencies to determine natural frequencies and damping characteristics,
- determine structure response amplification of ground motions,
- compute differential displacements at corner motions to estimate global shear and in-plane tension wall strains,
- compute bending strains in walls, and
- compare crack movements subjected to blasting, variations in temperature and humidity and wind gusts.

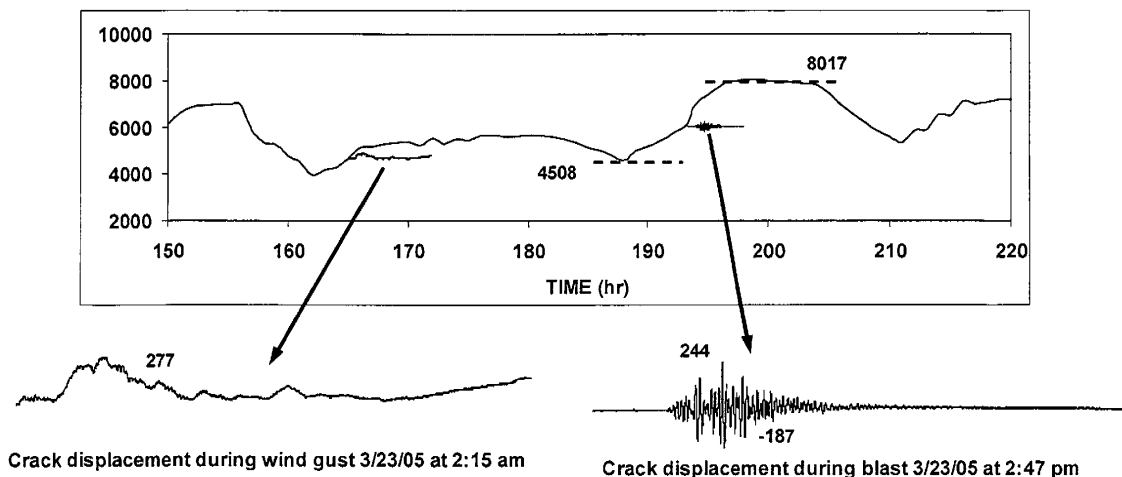
Blasting over the time period of this study did not provide sufficient energy in the ground and into the structures to compute structure damping, natural frequency, and amplification except in the case of the blast on 3/23/05 at 2:47 pm for the structure on Bighorn. The computed 9 Hz natural frequency and damping of 5.4% are within the typical range for residential structures. Structure amplifications of blast excitations were 1.23 and 1.2 for southwest and southeast wall motions and below the average of 2 for typical residential structures.

The blast on 3/23/05 generated maximum in-plane tensile and mid-wall bending strains of 27.8 and 9.4 micro-strains, respectively, in the southwest wall at the dwelling on Bighorn. For the dwelling on High Mesa, the maximum calculated in-plane tensile and mid-wall bending strains were 5.78 and 4.33 micro-strains, respectively, in the northeast wall during the blast on 4/13/05. These computed strains were far below the range of tensile failure strains in gypsum core of interior drywall (300 to 500 micro-strains) and modern stuccos, reinforced with polymeric fiber (exceeding 1,000 micro-strains). At low levels of blasting recorded throughout this study, the induced strains never exceeded the elastic limit of the wall materials and no permanent deformation could have occurred. Hence, cracking both in interior drywalls and exterior stucco is not caused by blasting activities at the excitation levels recorded during this project.

Peak blast-induced dynamic crack displacements ranged from 45.6 to 243.5 micro-inch and 42.6 to 113.6 micro-inch for the structures on Bighorn and High Mesa, respectively. The largest overall weather-induced changes in crack width over the project duration were 8212 and 5403 micro-inch for the structures at High Mesa and Bighorn, respectively.

Daily weather-induced changes in crack width over a 4-day period are compared below with dynamic crack motions for the most significant blast on 3/23/05 (right, for 0.45 in/sec peak ground motion) and high wind gusts (left, for 34 mph winds) for the structure on Bighorn. The maximum daily change of 3509 micro-inch exceeds the largest change in zero-to-peak crack width during blasting (244 micro-inch) while the wind gust zero-to-peak opening (277 micro-inch) was greater than that for the largest blast.

It is therefore concluded that large weather-induced changes in crack width is the greatest contributing factor to crack extension and widening over time. The influence of wind pressures against walls during a typical storm produced crack width changes greater than those produced by blasting when ground vibrations were near the 0.5 in/sec regulatory limit. Hence, the influence of blasting vibrations on crack width changes is negligible compared with the influence of climate and less than the influence of wind gusts. It is highly unlikely that blasting is the source of structure cracking.



Conclusions drawn from this study are as follows:

- There is a 100% probability that blasting at the current regulatory limit does *not* contribute to cracking in structures.
- Structure response data clearly demonstrated that large variations in ambient temperature and humidity produce wall strains up to 72 times greater than those created by blasting at the current regulatory limit of 0.5 in/sec peak ground velocity.
- Structures motions and wall strains produced by wind gusts on the order of 31 to 34 miles per hour were 10% greater than those produced from blasting at the current regulatory limit.
- Ground vibrations from construction activities near structures, ranging from 0.03 to 0.07 in/sec., and resulting wall strains were on the same order as those produced by blasting.
- Airblast or air-born pressures from blasting were negligible and the effects were not detected in structure response motions.

## **AUTHOR BIOGRAPHY**

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.

# **Blasting Attenuation Study**

## **Crystal Ridge, MacDonald Ranch and MacDonald Highlands**

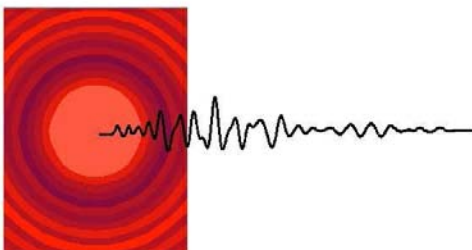
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## INTRODUCTION

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.

## DESCRIPTION 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<sup>3</sup>, 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 than 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. from 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

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

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

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

$$PPV = a * SD^{-b} \quad (3)$$

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

$$SPL = 20 \log \frac{P}{P_o} \quad (4)$$

where P<sub>o</sub> is a reference or standard pressures equal to 2.9 (10<sup>-9</sup>) 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 (geomorphology), 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 influenced 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 trend 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 through 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 trend 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<sup>1/2</sup> 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<sup>1/2</sup> 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, dominant 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  $\text{ft/lb}^{1/2}$ .

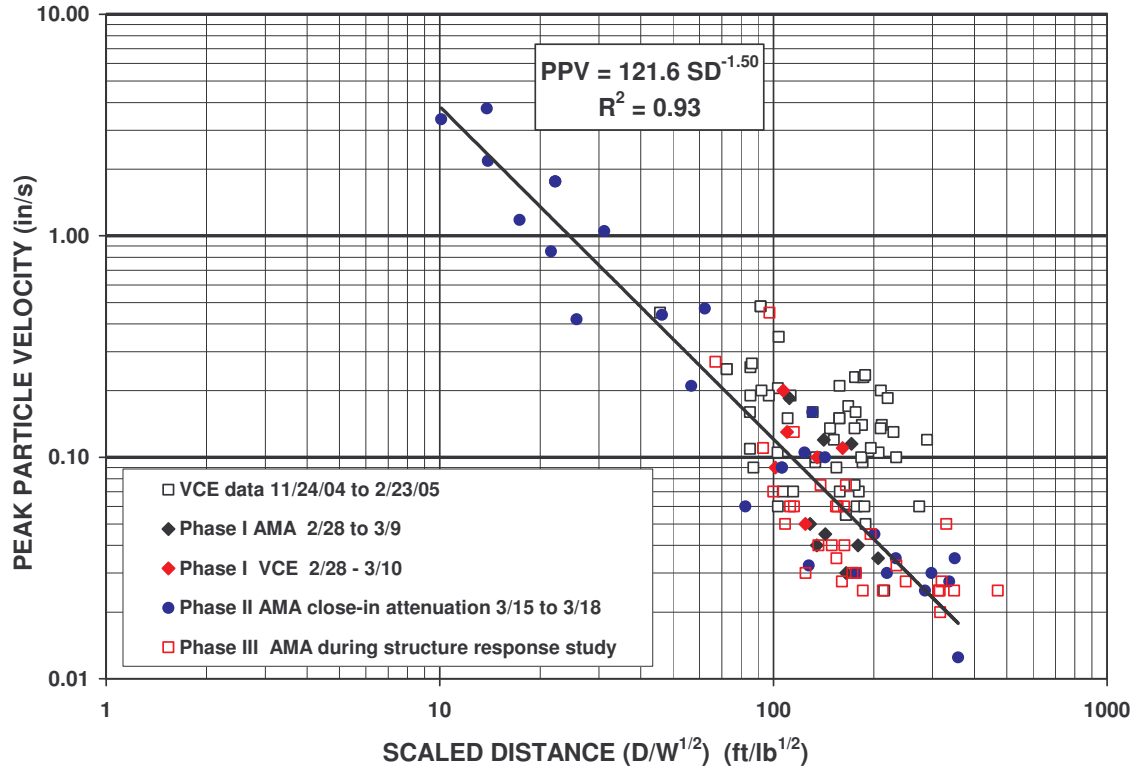


Figure 3 Peak particle velocity versus scaled distance

### 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

$$PPV = 121.6SD^{-1.50} \quad (5)$$

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 than  $10 \text{ ft/lb}^{1/2}$ ) 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 established 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

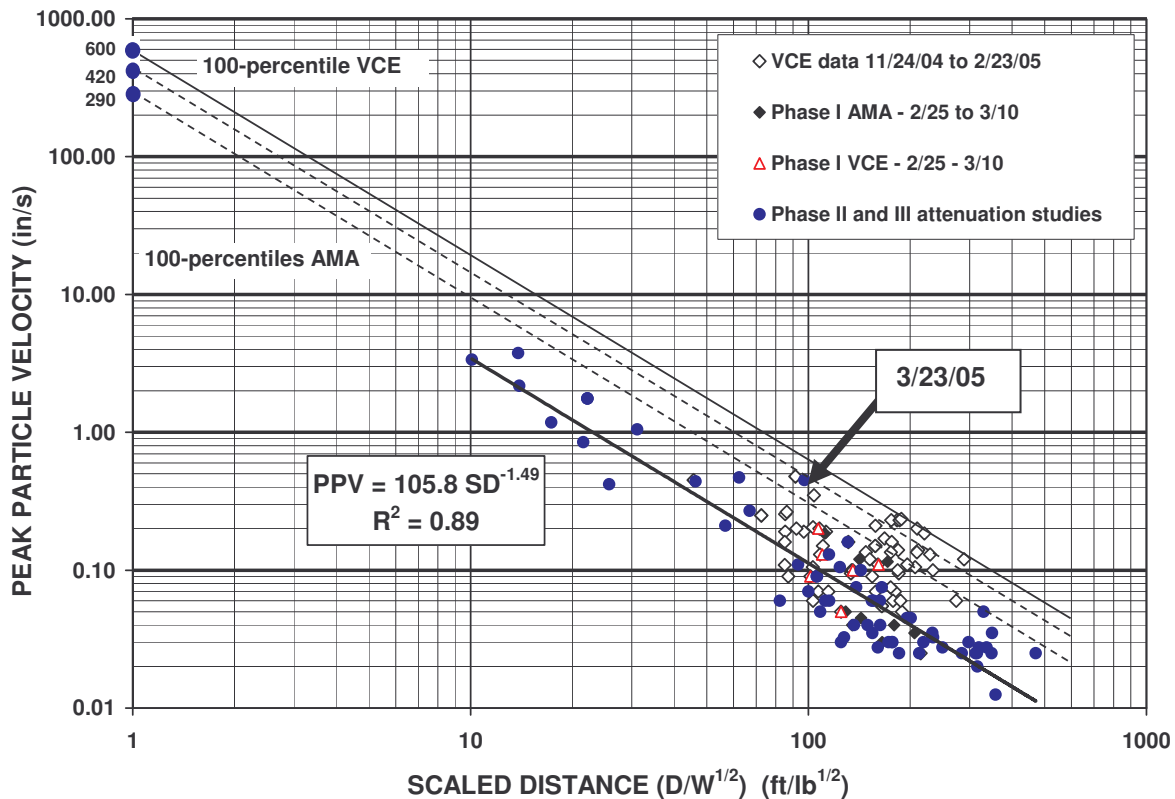


Figure 4 100-percentile attenuation lines for AMA data, Phases II and II combined and early data provided by VCE

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<sup>1/2</sup>, 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

$$PPV = 290SD^{-1.49} \quad (6)$$

### *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<sup>2</sup> 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).

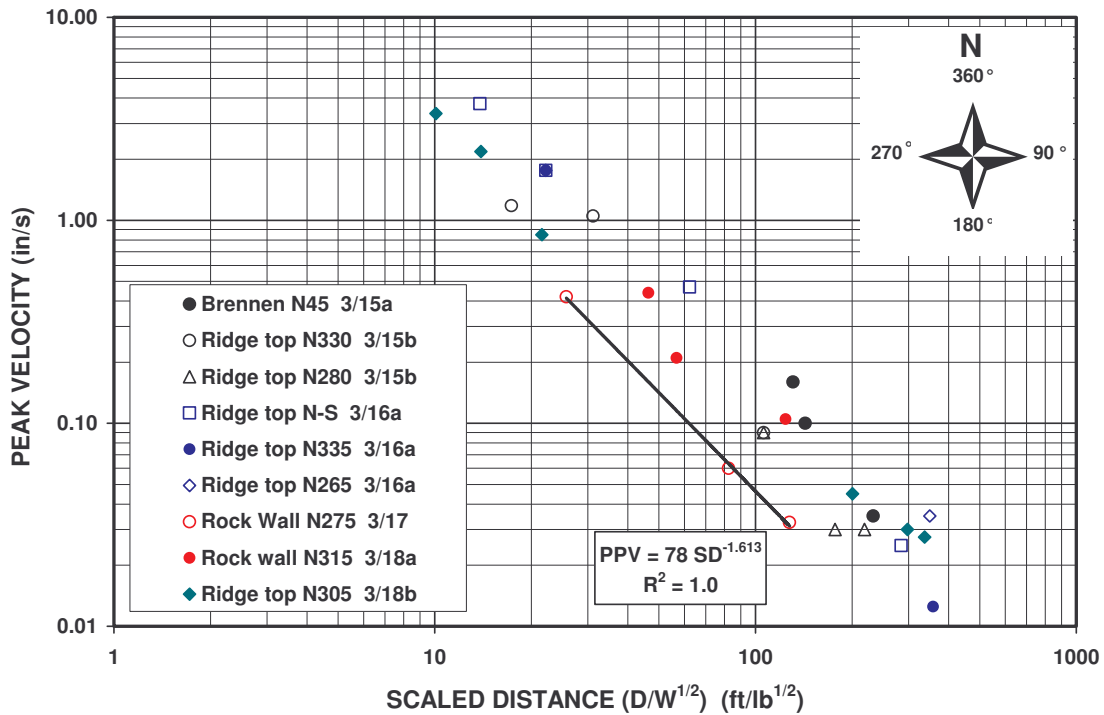


Figure 5 Attenuation line data plotted as PPV versus scaled distance for Phase II blasts

Table 2 Summary of fitting parameters for attenuation array blast data

Azimuth direction (degrees from North)	Y-intercept Energy Factor (a) (in/sec)	Attenuation slope (b)	Correlation Coefficient $R^2$
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, coincidentally 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<sup>1/2</sup>. Plotted within the graph is the federal

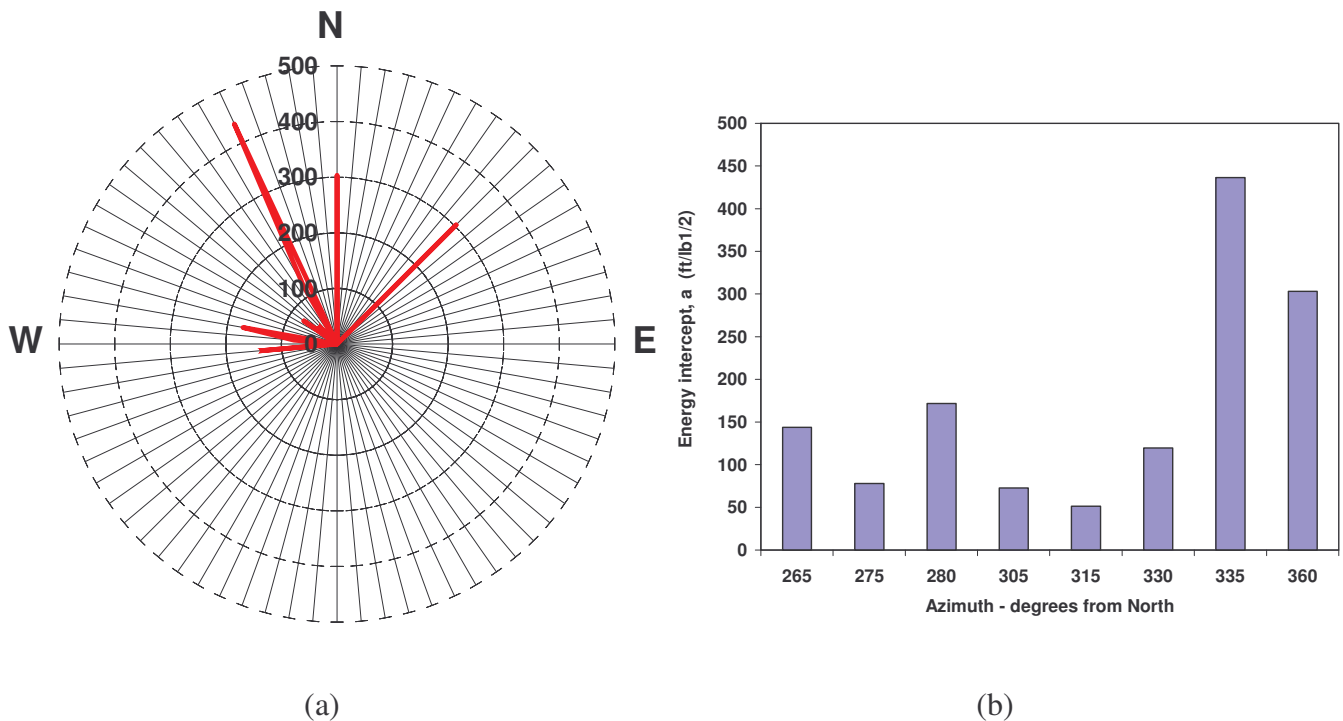


Figure 6 Variation of energy factor (y-intercept) values as a function of azimuth for (a) a circular distribution and (b) a conventional histogram

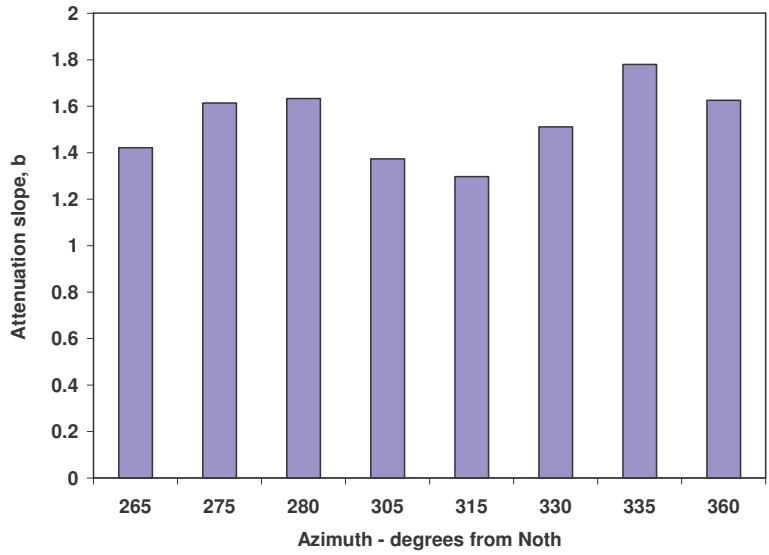


Figure 7 Variation of attenuation slope values as a function of azimuth

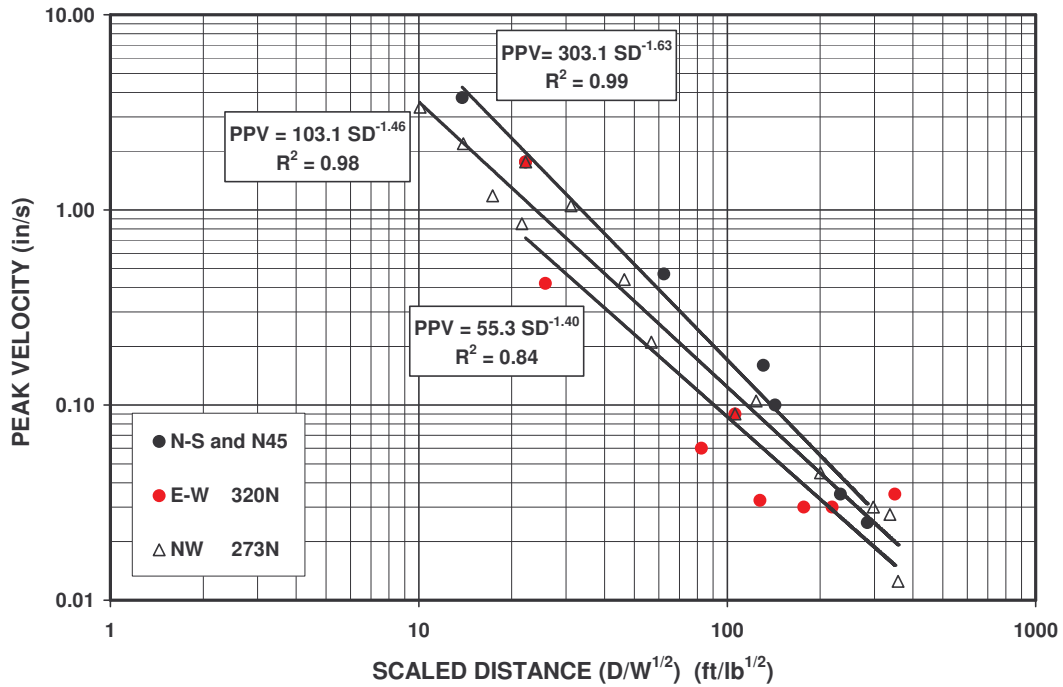


Figure 8 Variation of attenuation fits with three predominate topographic trends



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

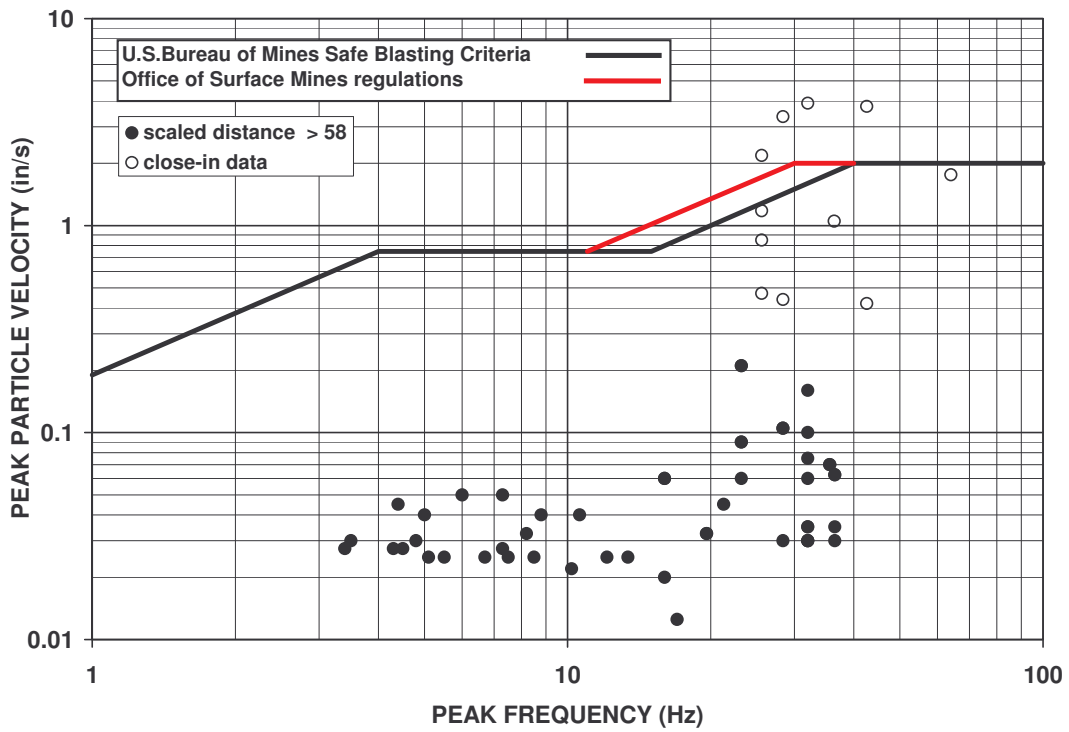


Figure 10 PPV versus frequency at the peak velocity for close-in adapt and far-field data  
( $SD > 58 \text{ ft/lbs}^{1/2}$ )

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  $100 \text{ ft/lbs}^{1/2}$ , 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.

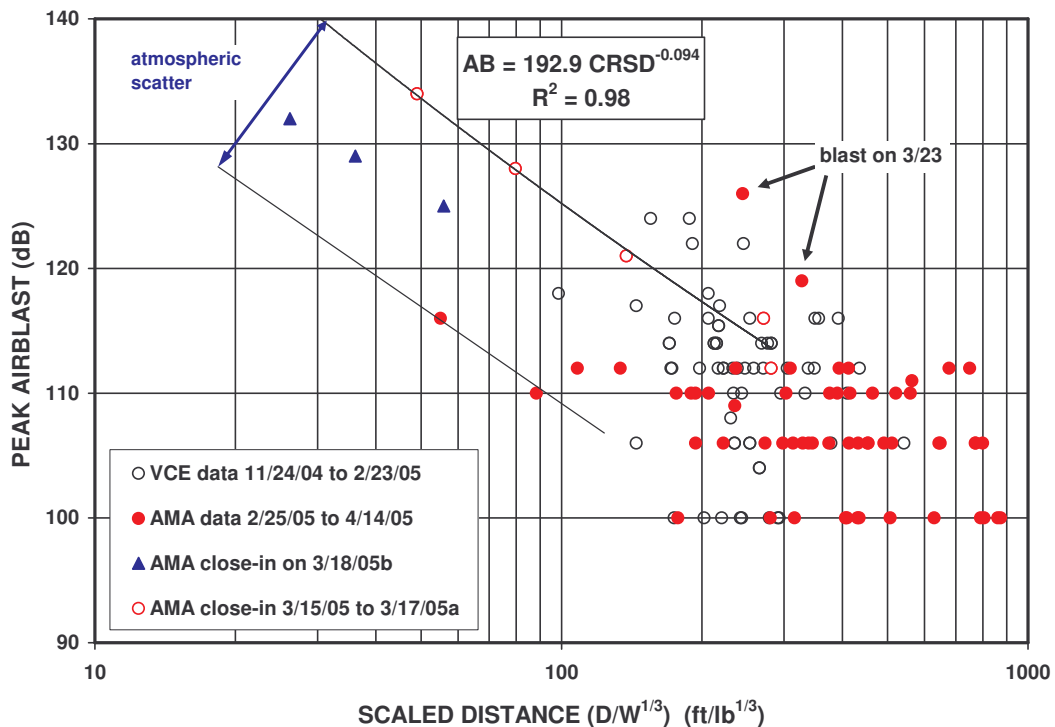


Figure 11 Peak airblast versus cube-root scaled distance



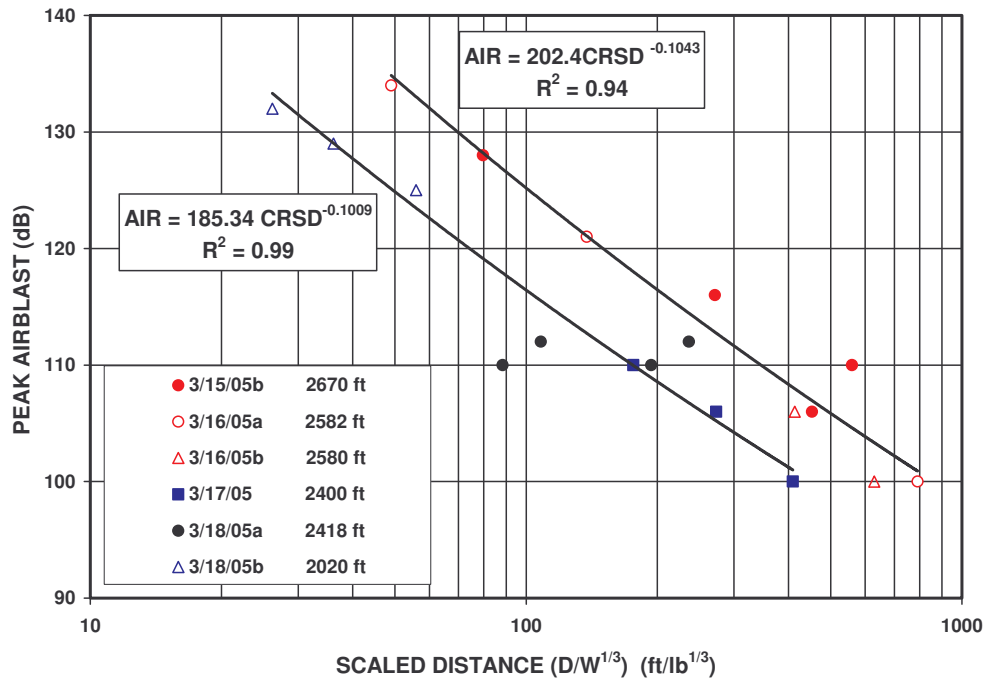


Figure 12 Peak airblast versus cube-root scaled distance for data plotted by blast data during the Phase II study

The attenuation line through the upper array

$$AIR = 192.9CRSD^{-0.094} \quad (7)$$

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<sup>1/3</sup> 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<sup>1/2</sup> 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 more control 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.

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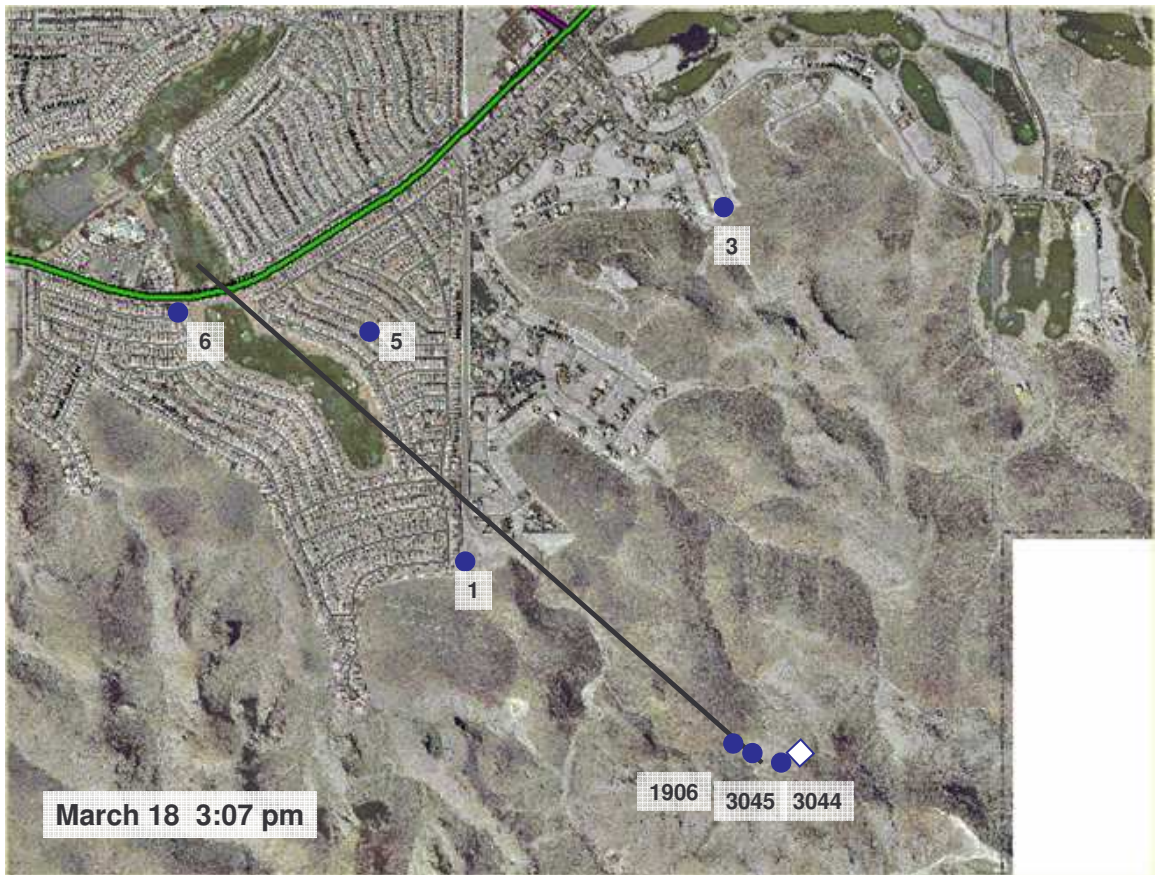
APPENDIX A

Phase II Seismograph Layout Maps











APPENDIX B

Summary of Seismograph Data

Table B-1 Summary of Seismograph Data

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 <sup>1/2</sup> )	(ft/lbs <sup>1/3</sup> )	(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 Highlands	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
				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	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 <sup>1/3</sup> )	(ft/lbs <sup>1/3</sup> )	(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	Seismograph GPS	Seismograph Location	unit S/N	Distance to blast (ft)	Charge Mass W <sub>max</sub> (lbs)	Scaled Distance SD (ft/lbs <sup>1/2</sup> )	Scaled Distance SD (ft/lbs <sup>1/3</sup> )	Peak Velocity PPV (in/sec)	Peak Frequency F <sub>peak</sub> (Hz)	Dominant Frequency FFT (Hz)	Airblast (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			
3/29/05	2:01	Crystal Ridge E. of crusher	35° 59.702 115° 03.273	36 59.629 115 04.099	1875 Cypress Mesa	2490	1302	170	99.9	235.1	0.07			109
				36 00.263 115 04.465	2148 Tiger Links	785	6791	742	249.3	750.2	0.0275	4.3	3.25	112
				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
3/30/05	3:41	in back	35° 59.650 115° 03.211	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
				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			
3/31/05	10:30	Crystal Ridge N. of crusher	35° 59.747 115° 03.256	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			
				36 00.263 115 04.465	2148 Tiger Links	785	6733	192	485.9	1167.1	nt			
				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			
3/31/05	2:25	Crystal Ridge E. of crusher	35° 59.747 115° 03.478	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			
				36 00.263 115 04.465	2148 Tiger Links	785	5786	25	1157.2	1978.9	nt			
				36 00.234 115 04.080	572 Carmel Mesa	1769	4188	25	837.6	1432.3	nt			
4/1/05	11:42	Crystal Ridge S. of crusher	35° 59.584 115° 03.377	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
				36 00.263 115 04.465	2148 Tiger Links	785	6764	200	478.3	1156.6	nt			
4/1/05	11:42	Crystal Ridge S. of crusher	35° 59.584 115° 03.377	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	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 <sup>1/2</sup> )	(ft/lbs <sup>1/3</sup> )	(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	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 <sup>1/2</sup> )	(ft/lbs <sup>1/3</sup> )	(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	Seismograph GPS	Seismograph Location	unit S/N	Distance to blast	Charge Mass W <sub>max</sub>	Scaled Distance SD	Scaled Distance SD	Peak Velocity PPV	Peak Frequency F <sub>peak</sub>	Dominant Frequency FFT	Airblast
							(ft)	(lbs)	(ft/lbs <sup>1/2</sup> )	(ft/lbs <sup>1/3</sup> )	(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

# **Structure Response Study**

## **Crystal Ridge, MacDonald Ranch, and MacDonald Highlands**

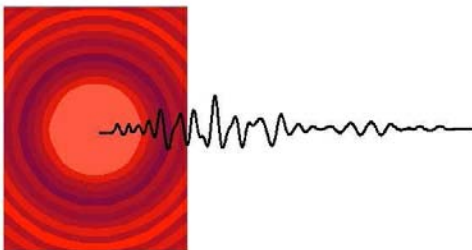
**For the**

**City of Henderson  
240 Water St.  
Henderson, Nevada**

**Prepared by**

**Dr. Catherine T. Aimone-Martin  
President**

**May 27, 2005**



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## **AUTHOR BIOGRAPHY**

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

The response of two residential structures to blasting vibrations was conducted in Henderson, NV from March 15 to April 15, 2005. The location and identification of the residential structures are shown in Figure 1. Structure 'A' is located at the corner of High Mesa Drive and Cyprus Mesa Drive in Sun City MacDonald Ranch. Structure 'B' is located on Bighorn in MacDonald Highlands. Both structures are wood-framed with stucco exteriors. Structure 'B' is a single-story, slab-on-grade dwelling and the two-story structure 'A' is constructed into the hillside.

Structures were instrumented with single-axis velocity geophones to measure whole structure and mid-wall vibratory motions during blasting events. Displacement-type gages were used to measure the motions of an existing exterior wall crack. A single tri-axial geophone, buried in the ground, and an air pressure sensor were employed exterior to the dwellings to record ground motions and airblast. Data analyses for blast-induced motions were conducted to:

- compare vibration time histories in terms of velocity and calculated displacements within structures relative to ground excitations and air overpressures
- evaluate response frequencies to determine natural frequencies and damping characteristics
- determine structure response amplification of ground motions
- compute differential displacements at corner motions to estimate global shear and in-plane tension wall strains, and
- compute bending strains in walls

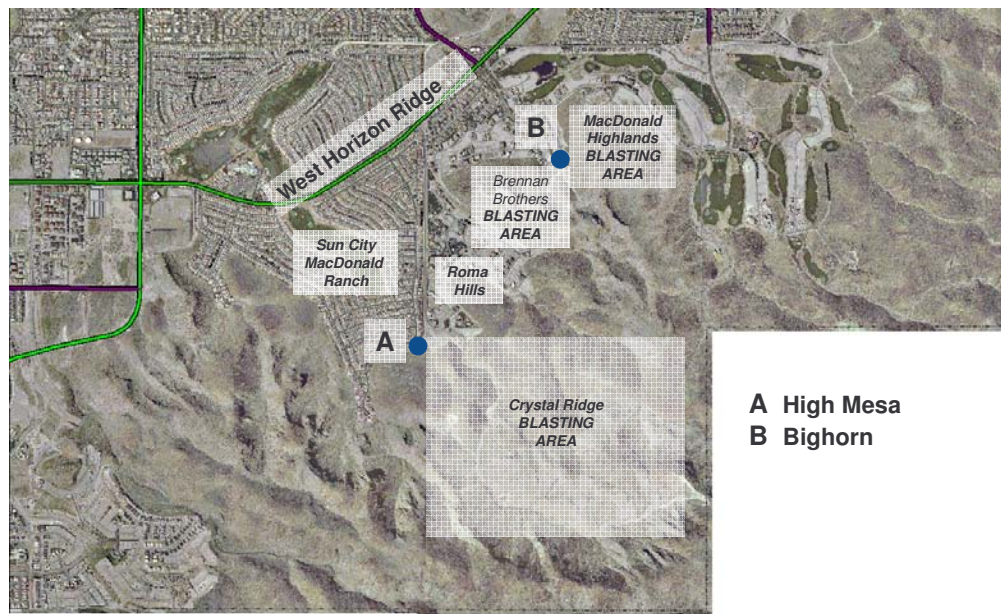


Figure 1 Location map showing blast sites and structures used for instrumentation  
Corner and mid-wall motions from blasting were compared with motions induced by external

forces such as wind and construction activities taking place adjacent to residential structures. In addition, wall crack responses (e.g., crack opening and closing) to environmental changes, wind, construction and blasting vibrations were measured.

The large volume of supporting data summaries and plot are found in the Appendices organized as follows:

#### Appendix

- A Blasting seismograph records for structure at High Mesa
- B Blasting seismograph records for structure at Bighorn
- C Seismograph records during construction activities and wind for structures at Bighorn and High Mesa
- D Summary of seismograph data
- E Displacement time histories and strain calculations
- F Crack displacement time histories for High Mesa structure
- G Crack displacement time histories for Bighorn structure

## PROCEDURES

### *Vibration and Airblast Instrumentation*

Figures 2 and 3 show the exterior instrumentation locations at the two structures. The locations of the single component velocity transducers placed in the upper (S2) corner, lower (S1) corner, and at the mid-wall (MW) are indicated. LARCOR™ multi-component seismographs were used to digitally record four channels of seismic data. The exterior (master) unit consisted of a tri-axial geophone and an airblast microphone. The geophones, buried 4 in. in depth, were oriented so that the radial, R, component was parallel with the longest axes of the house. This orientation is based upon recording motions that are parallel to one of the house's translation axes rather than the traditional direction relative to the vibration source. The airblast microphone was installed 4 to 6 in. above the ground surface and used to record the pressure pulses transmitted through the air during blasting.

Both the S1 and S2 seismographs were connected to clusters of three single axis transducers in the upper and lower exterior corners closest to the blasting activity and at the mid-wall of the adjoined walls as shown in Figures 2 and 3. The three seismographs were connected in series, with the exterior seismograph acting as the master (triggering) unit and all other systems as slave units generically shown in Figure 4. These transducers were affixed to the walls using hot glue to minimize damage during removal. The three corner transducers measured whole structure motions in the horizontal radial, transverse, and vertical directions. The mid-wall transducers measured horizontal motions during wall flexure or bending.

### *Existing Crack Gage Instrumentation*

To measure the effect of blasting and climate conditions (temperature and humidity) on changes in the width of existing exterior cracks, Kaman™ eddy-current gages were installed, as shown in Figures 2 and 3, and data was collected using a SOMAT™ field computer. A schematic

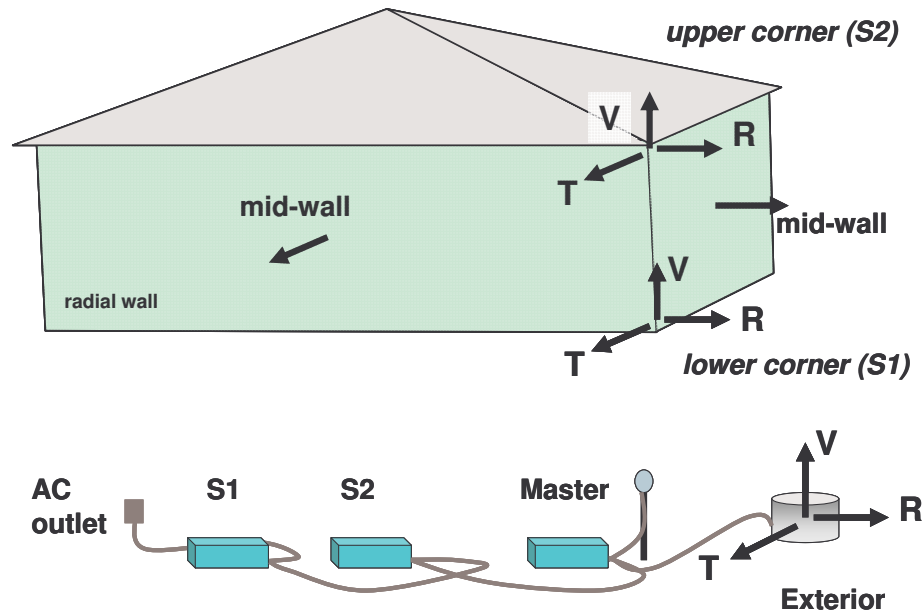


Figure 4 Position of transducers and serial connection of seismographs used to measure time-correlated structure response

of the data acquisition system is given in Figure 5. Each Kaman gage consisted of mounting brackets, one of which served as a target plate, and an active element. Gages were mounted in brackets affixed to the stucco exterior over an existing crack (crack gage) and on an un-cracked surface (null gage) at both structures. The crack gage was installed with each mounting bracket placed on either side of the crack. One bracket held the active element against the target plate (second bracket) at a sufficient gap distance to allow the gage to function properly.

Operation of eddy-current gages relies on the property of electrical induction. The sensor consists of a coil of wire driven by a high frequency current that generates a magnetic field around the coil. If a non-magnetic conductive target material is introduced into the coil field, eddy-currents are induced in the surface of the target material. These currents generate a secondary magnetic field in the target, inducing a secondary voltage in the sensor coil (active element), resulting in a decrease in the inductive reactance in the coil. This type of system is also known as variable impedance because of the significance of the impedance variations in defining its complex nature (Hitz and Welsby, 1997).

The three seismographs and field computer were connected in series, with the exterior seismograph acting as the master (triggering) unit and all other systems as slave units. Upon triggering, the master seismograph delivered a 1 volt pulse via the serial cable to activate and begin recording dynamic data during blasting events. This produced seismograph and dynamic crack/null gage records were time-correlated that is critical for analysis of structural and crack response.

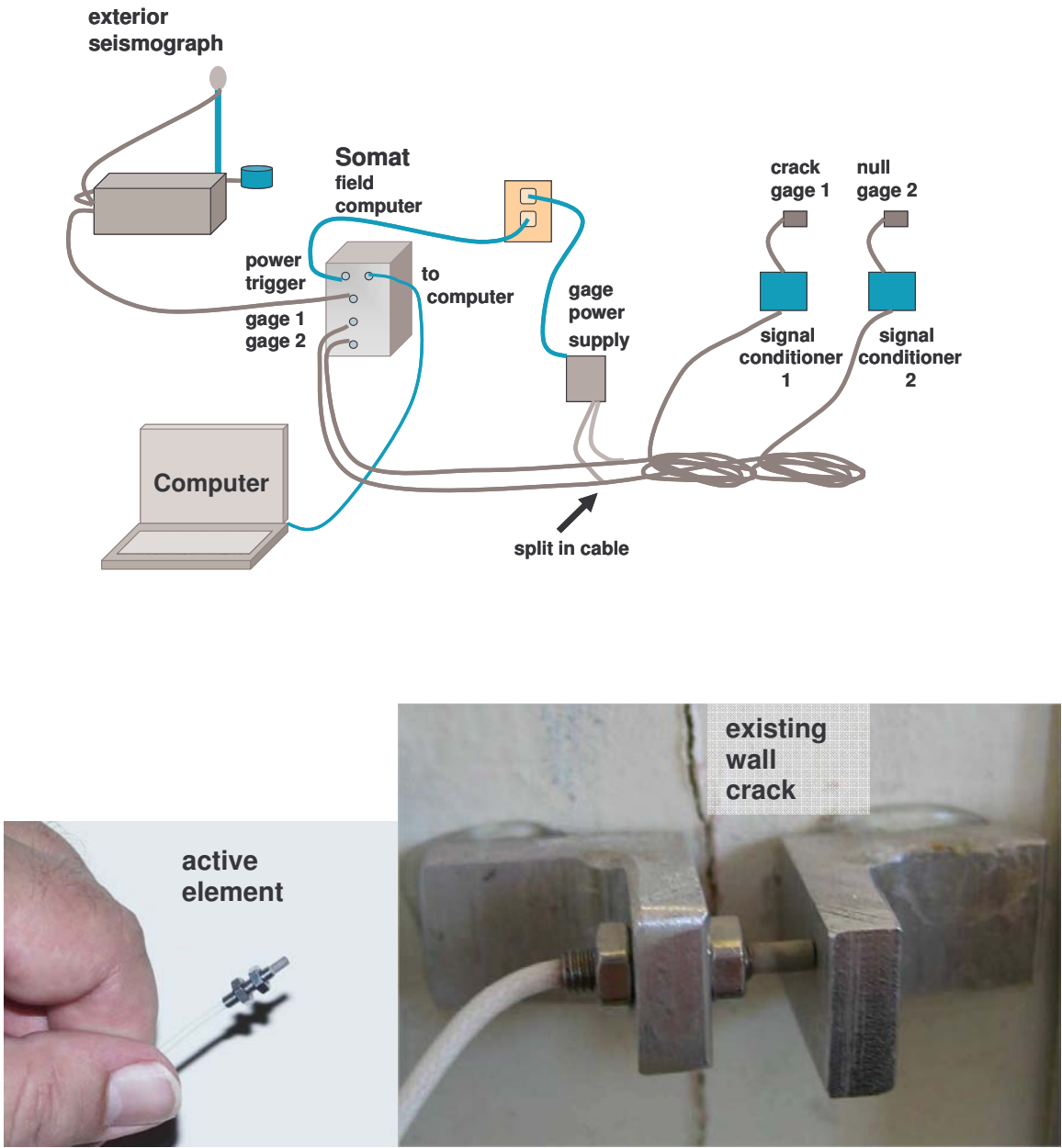


Figure 5 Displacement gage system used to measure opening and closing of an existing wall crack (above) and close-up of mounted crack gage (below)

The master and slave seismographs each had a range of available settings for recording data. These settings include:

- trigger levels for the master unit set to 0.03 in. per second (ips) for ground velocity, and 125 decibels (dB) for airblast
- sample rate set at 512 samples per second
- a sampling duration of 9 (one-story house on High Mesa) to 12 seconds (the two-story house on Bighorn)

These settings ensured the full data record was preserved with sufficient resolution.

The Kaman gage system was programmed to sample crack opening and closing every hour in response to diurnal environmental changes. In the dynamic or ‘burst’ mode, data was acquired every 0.001 seconds. Temperature and relative humidity were recorded using a SUPCO™ data logger. A sample interval of 10 minutes was used.

The operating parameters of the Kaman gages are as follows:

- displacement monitoring range of 0.02 inches.
- output voltage range  $\pm 5$  volts.
- resolution of 3.94 micro-inch. (.00000394 in.)
- frequency response of 10,000 Hertz (Hz).

*Throughout this report, readers are reminded that the velocity unit of inches per second (ips) is one only of convenience. Neither the ground nor the structures move in inches over time but rather milli-inches per milli-second. Structure damage in the form of cosmetic or threshold wall cracks do not result from high structure velocities, but rather high differential displacements in walls leading to high strains or strains that exceed the failure strain of the materials comprising the walls. Therefore the analysis herein emphasizes structure and wall strains as an indicator of potential damage to structures.*

### *Data Analysis*

Velocity data were analyzed using White 2000™ software to plot velocity and displacement time histories and integrate velocity time histories. Two frequencies, or wave cycles (oscillations) per second, are of interest and were analyzed. The peak frequency is that frequency associated with the maximum velocity amplitude over the full time-history of motion. It is used to demonstrate compliance with frequency-based regulations. The predominant frequency, evaluated using Fast Fourier Transform (FFT) analysis, dominates over the entire time history. The FFT frequency carried the largest percentage of ground motion energy and is important when evaluating structure response.

Crack gage data were downloaded from the SOMAT™ field computer and analyzed using SOMAT WINTCS v.2.0.1 and SOMAT™ DataXplorer v. 3 softwares. Crack displacement time histories were filtered using Data Filter, (Mercer, 2002) a spectrum filtering program to remove system noise and enhance the data signal-to-noise ratio.

## RESULTS

Seismograph reports are given in Appendices A through C. Appendix D contains summary tables of all velocity and airblast values for the various seismographs. Data are given by blast date and include peak velocity values and frequencies for the three components of ground motion and for the single component interior geophones. Information on the blasts such as distance from the structure to each blast and the explosive charge weights per delay have been previously given in the report “Blasting Attenuation Study” (Aimone-Martin, 2005).

### *Ground Motion and Airblast*

Figures 6 and 7 are plots of scaled distance factor plotted against peak ground motions and airblast, respectively. Data recorded during the structure response study at the two dwellings are compared with data collected during the attenuation study. The attenuation study included very close-in measurements (up to 40 ft. from the blasts) to better define attenuation slopes taking into account both distance from the blast and the explosive charge weights used in design. Scaled distance factors are applied to ground motions and airblast, given by the following:

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

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

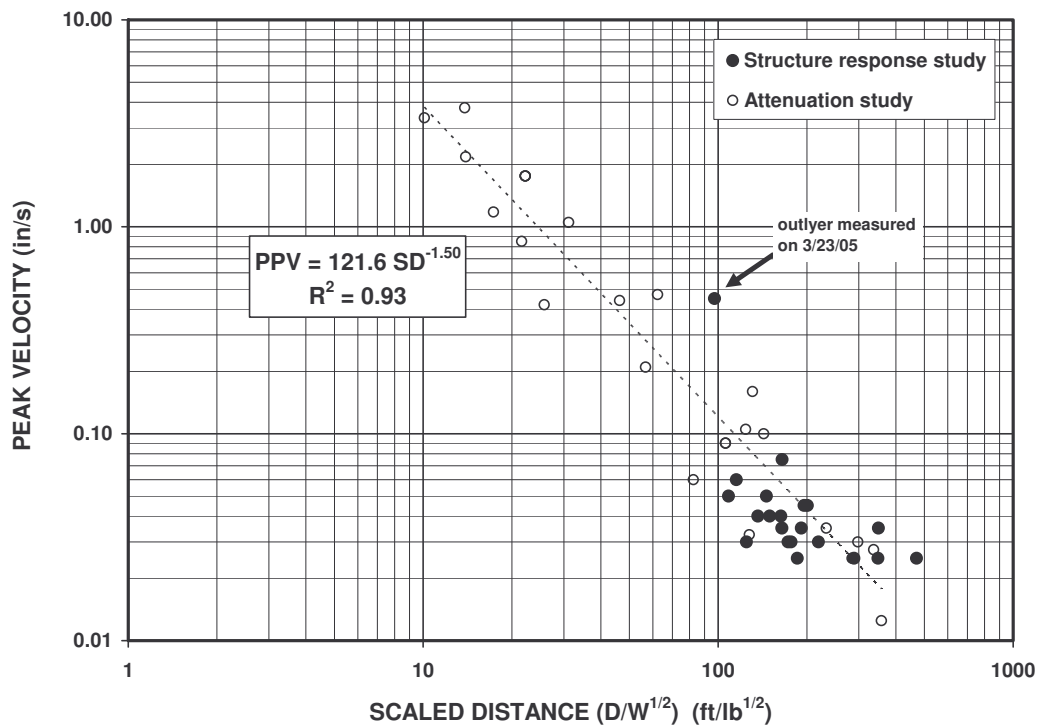


Figure 6 Peak particle velocity in the ground versus scaled distance for structure response study compared with data recorded during attenuation study

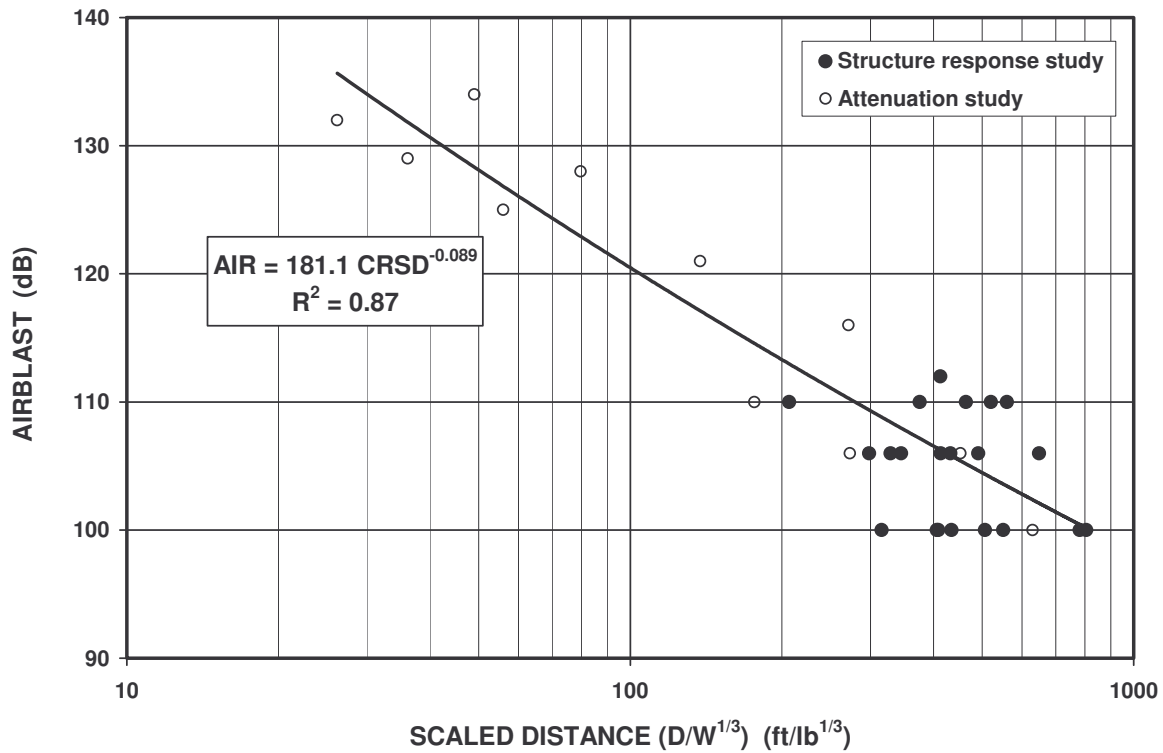


Figure 7 Peak airblast versus cube-root scaled distance for structure response study compared with data recorded during attenuation study

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 case of airblast, air pressures correlate best with the cube-root of the charge weight.

Values for PPV and airblast during this study plot below the current limits (0.5 ips and 120 dB). The outlier data point for the 3/23/05 blast at 2:47 pm in Figure 6 was discussed in the attenuation study and may be the results of errors associated with explosive charge weight reported.

Figure 8 is a plot of the peak particle velocities (PPV) and frequency of ground motion at the PPV. The data for ground motions at the two structures are plotted within the safe blasting criteria recommended by the U.S. Bureau of Mines and surface coal mining regulatory limits, as enforced by the Office of Surface Mining (OSM). All data recorded during this study fell well within the safe blasting criteria for which no damage to structures can occur with a 100% confidence. This safe criteria is based on over 40 years of research and crack observations that have never been scientifically challenged.



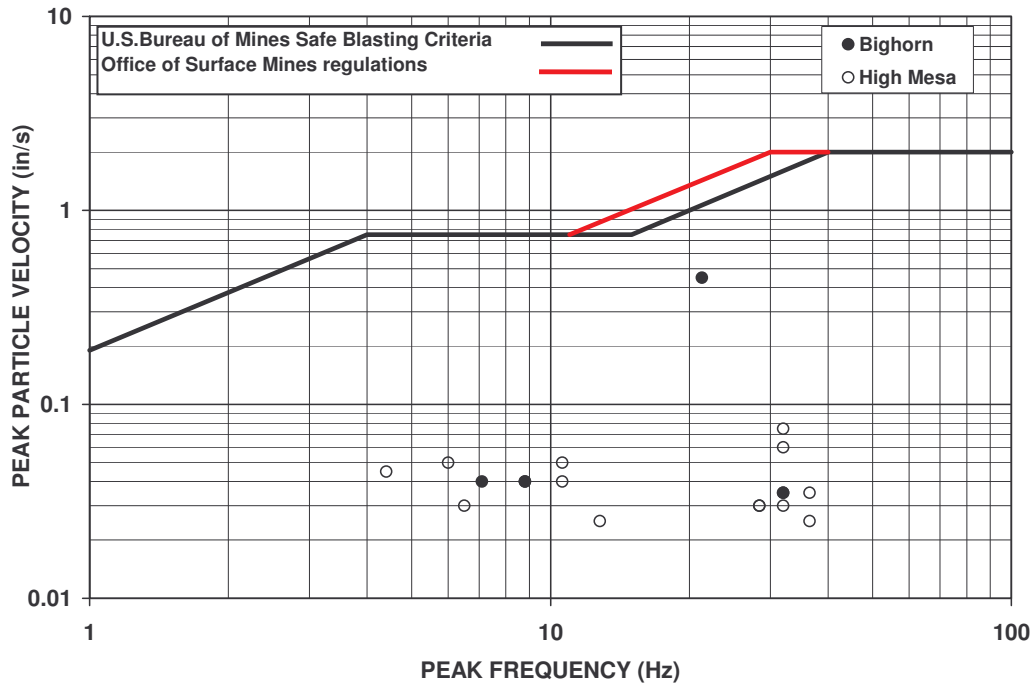


Figure 8 Peak particle velocity versus frequency at the peak velocity

With the exception of the blast on 3/23/05 at 2:47 pm, horizontal ground velocities recorded at the structures were very low, ranging from 0.025 inches per second (ips) to 0.075 ips. The peak ground and FFT frequencies ranged from 3.3 Hertz (Hz) to 42.6 Hz. The average low frequencies at the High Mesa and Bighorn sites were 6.6 and 3.8 Hz, respectively. These values illustrate geological differences between the two general directions (north and west) of the blast sites to the structures. These differences are highlighted in the Attenuation Study report.

#### *Comparison of Structure Response with Ground Motions and Airblast*

It is often useful to visually compare the response of a structure (upper and lower corners and mid-wall) with ground motion and airblast excitations driving structure motions. Representative velocity time histories for the blasts generating the greatest dynamic crack response were selected for the two structures and illustrated herein. These blasts dates are

- 3/23/05b for the structure at Bighorn
- 3/16/05b for the structure at High Mesa

Figures 9 (a) and (b) and 10 (a) and (b) show time histories comparing the ground motions and airblast with structure motions for the Bighorn and High Mesa structures, respectively. The lower corners (S1) for each structure compare closely with the ground velocities for the two horizontal components (Figures (a) for each wall direction as shown), indicating good coupling of the structures with the foundations. The difference between S2 and

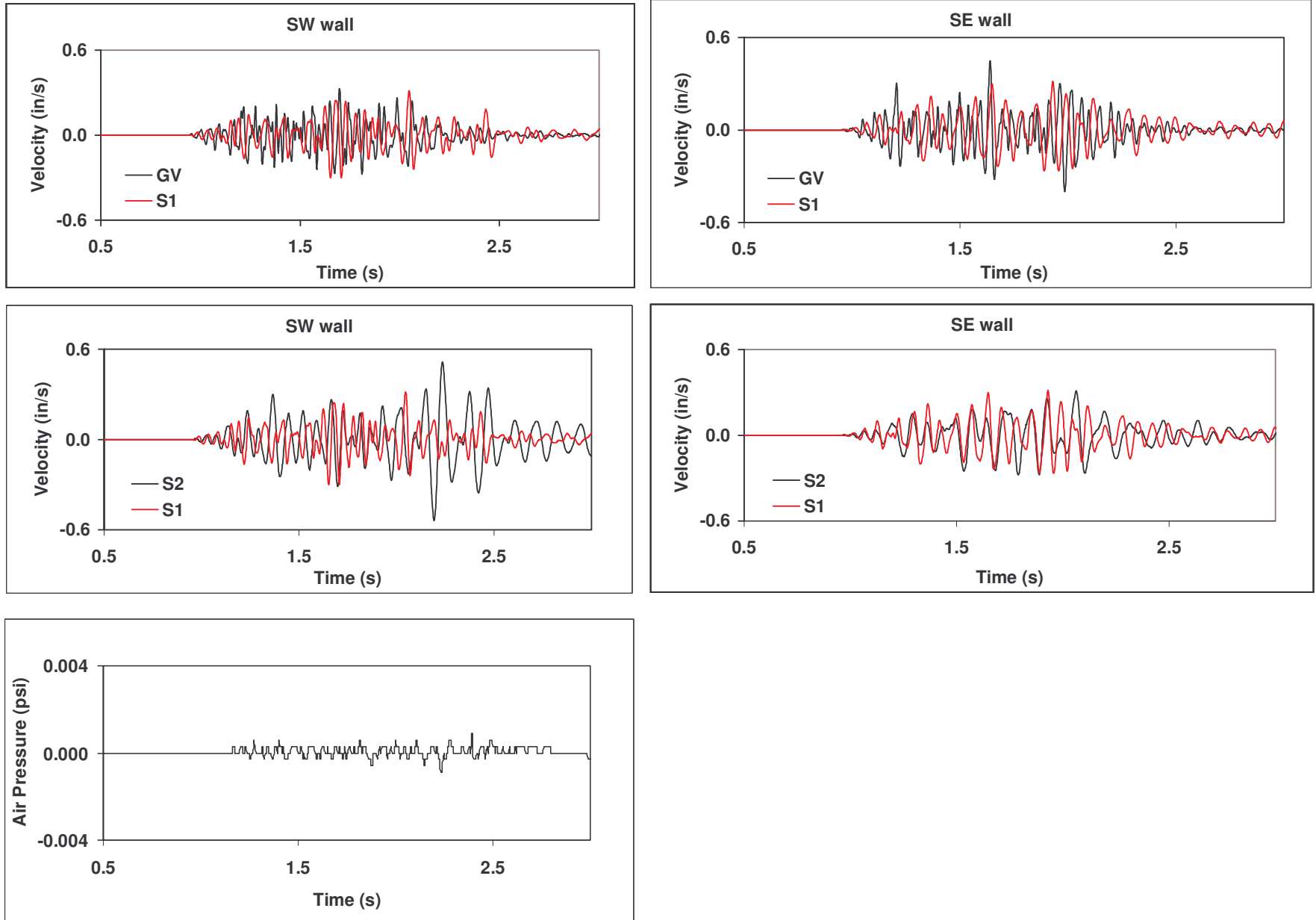


Figure 9 (a) Time histories comparisons of southwest and southeast ground velocity (GV), lower corner (S1), upper corner (S2), and airblast for structures on Bighorn

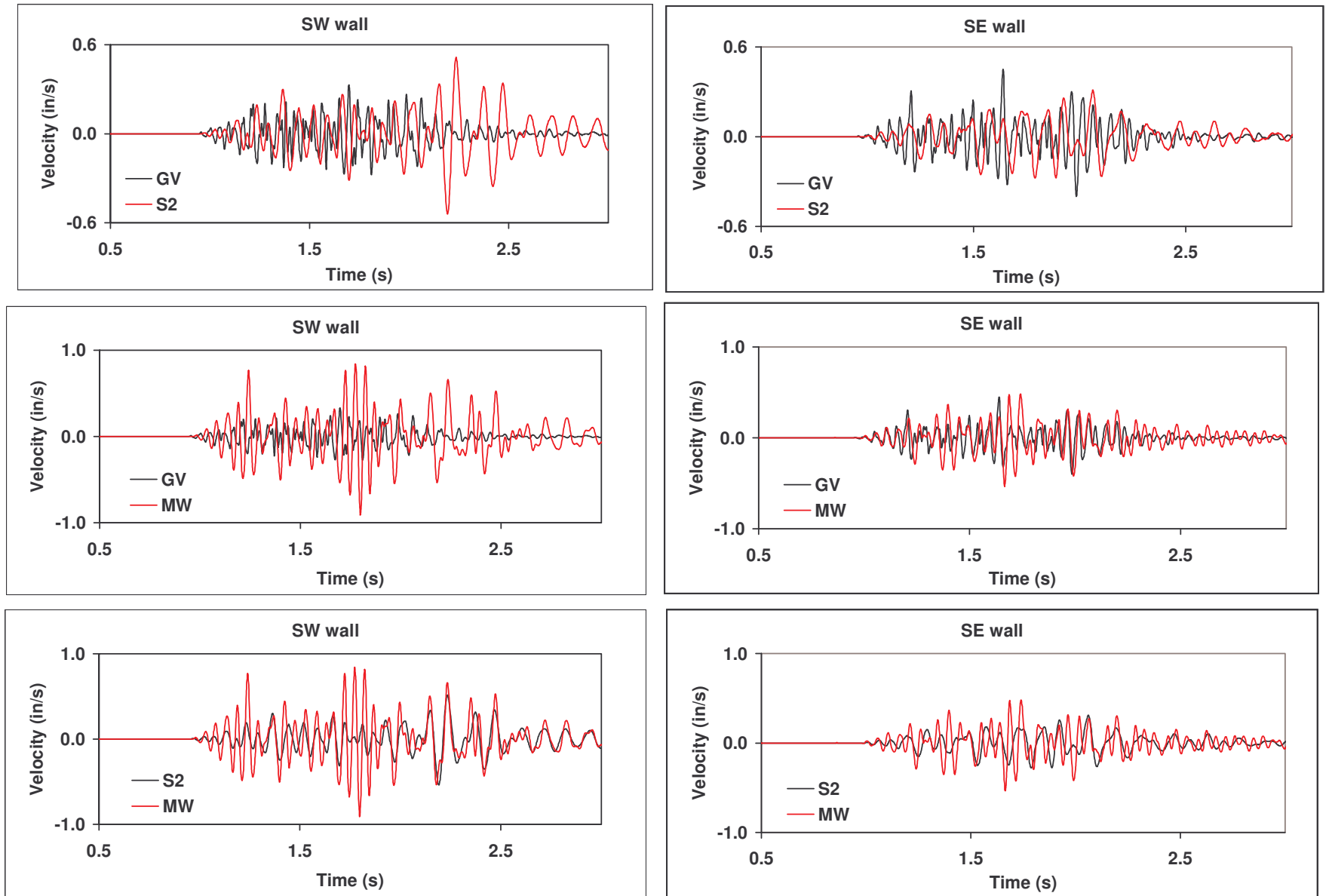


Figure 9 (b) Time histories comparisons of southwest and southeast ground velocity (GV), lower corner (S1), upper corner (S2), and mid-walls (MW) for structures on Bighorn

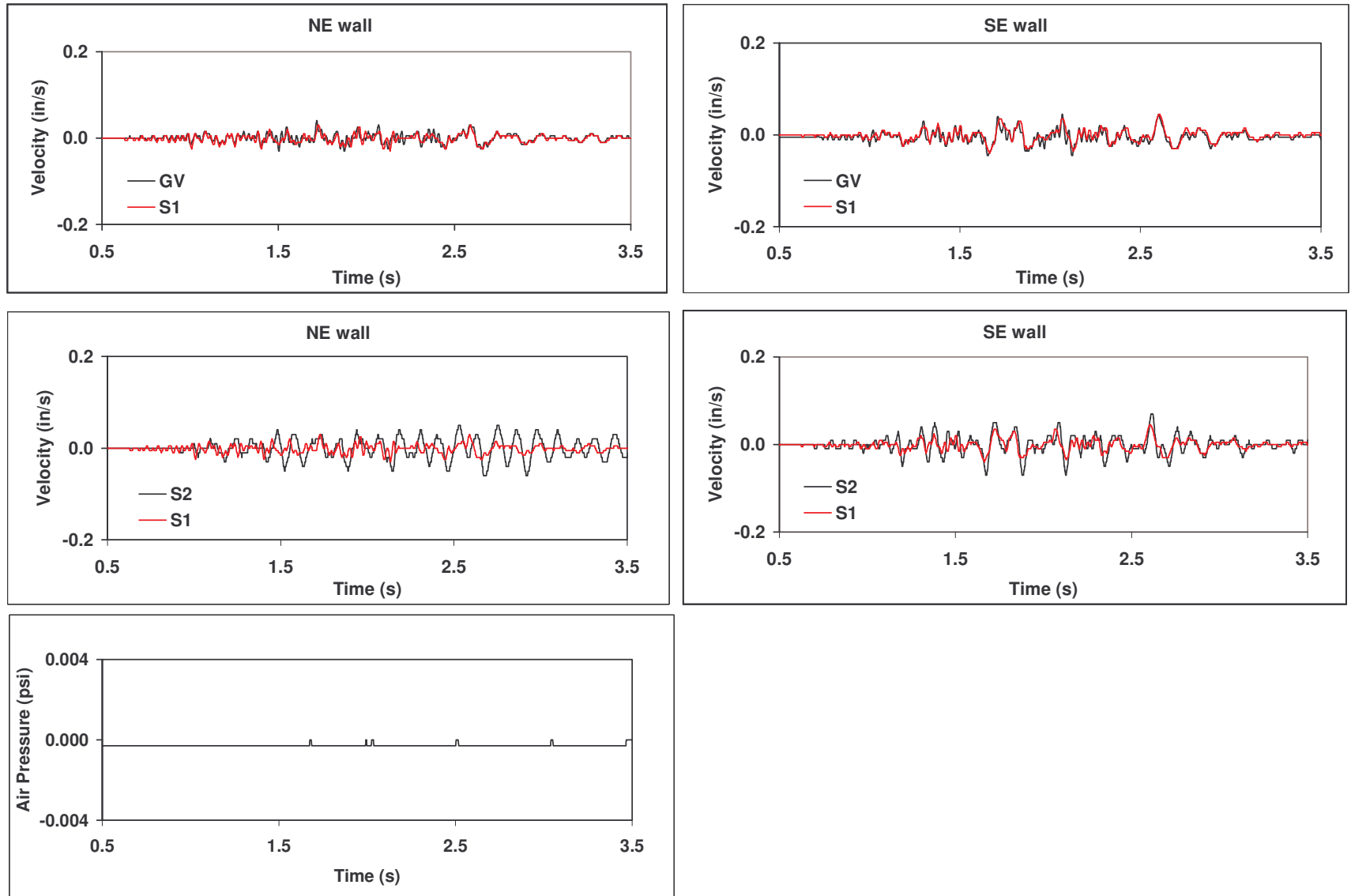


Figure 10 (a) Time histories comparisons of southwest and southeast ground velocity (GV), lower corner (S1), upper corner (S2), and airblast for structures on High Mesa

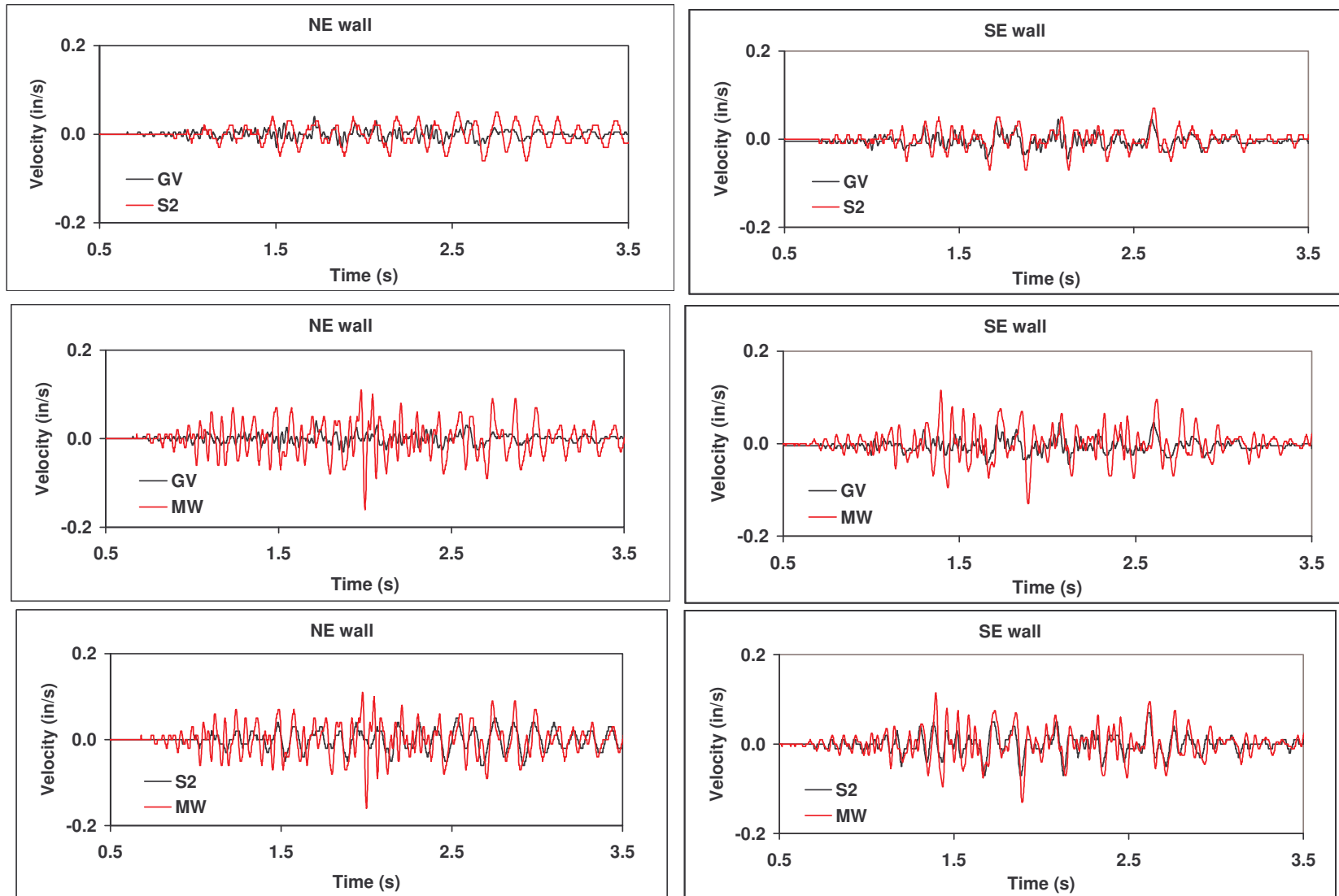


Figure 10 (b) Time histories comparisons of southwest and southeast ground velocity (GV), lower corner (S1), upper corner (S2), and mid-walls (MW) for structures on High Mesa

S2 in row two of Figures 9(a) and 10(a) show the influence of the blasting direction on the upper corner responses (S2), particularly for the 2-story structure on Bighorn, and to a lesser extent for the one-story house on High Mesa. As expected, both S2 responses show considerable low frequency energy that contributes to the perception of blasting. However, the vibration levels are far below those that could lead to damage in these structures.

The influence of airblast is negligible for the High Mesa residence and does not contribute to structure shaking for the Bighorn dwelling. The frequency at the peak 100 dB airblast is 64 Hz and the predominant frequency is 11.4 Hz. Both are above the 9 Hz natural frequency of the structure (discussed below) and energy is not coupled within the walls at this low amplitude.

Shown in Figures 9 (b) and 10 (b), the mid-walls in the direction of the blasting respond with motions larger than the upper corners. In the case of the High Mesa structure, both walls face the blasting whereas for the Bighorn structure, the southwest wall faces the blasts. The mid-wall tends to vibrate far greater than corners as corners are more restrained. Vibrations in mid-walls rarely lead to cracking but rather contribute to interior structure noise, as loose objects hanging on or leaning against walls tend to rattle with the wall motions. This rattling and resulting noise leaves persons inside a structure with the perception that structure damage is taking place. Mid-walls very often carry the same low frequencies and characteristic cycles (phases, or peaks and troughs) as the upper structure (S2), particularly later in the time histories when low frequencies persist. This is apparent in both structures in the SW and NE walls (chief blasting directions), given in the bottom row, left plot.

Time histories for the two structures do not exhibit any unusual characteristics. Both structures respond as expected and within the range of structures of similar construction.

### *Natural Frequency and Damping Ratio*

Natural frequency is the frequency at which structures oscillate freely after excitation energy is removed. If the blasting ground vibration arrives at a structure carrying a predominant frequency component identical to the natural frequency of the structure, blast wave energy above a certain threshold will readily transmit into the structure and start the structure in motion. The natural frequency match will cause the structure to continue to vibrate for a longer time compared with a ground motion carrying frequencies above the structure's natural frequency. Often long duration shaking will cause residents to notice the blast and become fearful that damage may be occurring within the structure. However, damage can only occur if the amplitude of shaking is high, resulting in wall strains that may promote cracking.

Fundamental frequencies of most residential structures range from 4 Hz to 12 Hz. Keeping the ground motion frequencies above this range may help minimize the sensation that the structure is being harmed by long duration vibrations when, in fact, the amplitudes are far below those that would cause cracking.

The natural frequency of a structure can be evaluated during upper structure "free-response", or during upper structure shaking when the ground motions have arrested. The free-response method identifies the upper structure (S2) time history corresponding with zero ground motions where the upper structure response begins to decay slowly to zero. The frequency of this trailing response is often assumed to represent the natural frequency of the structure.

During this decay portion, the structure damping coefficient can be computed. Damping is a natural phenomenon that occurs in all materials when subjected to an impulse force.

Structure motions from excitations (ground velocities) are naturally attenuated during energy dissipation and eventually come to rest. The percentage of critical damping,  $\beta$ , is a measure of structure rigidity and how fast the energy of excitation decays in the structure. Damping is calculated using two successive peaks during the free response decay portion,  $P_1$  and  $P_2$ .

The percentage of critical damping is calculated as follows:

$$\beta = \left( \frac{1}{2\pi} \right) \ln \left( \frac{P_1}{P_2} \right) \quad (3)$$

where

$\beta$  = percentage of critical damping (%)

$P_1$  = amplitude of the first peak (ips)

$P_2$  = amplitude of the next successive peak (ips)

To compute a structure's natural frequency and damping, sufficient energy from ground motions or airblast is required. Previous studies by Aimone, et al. (2003) have shown that ground motion energy well above 0.3 ips and airblast levels above 120 dB, both at predominate frequencies near the structure's natural frequency, are required. Blasting over the time period of this study did not provide sufficient energy to compute damping and natural frequency except in the case of the blast on 3/23/05 at 2:47 pm, as noted for the structure on Bighorn.

Figure 9 is a plot of the free response of the upper structure (S2) radial component of the southwest wall for the blast on 3/23/05. The FFT was computed for the free response portion resulting in a structure natural frequency of 9 Hz and is within the range of all structure types (4 to 12 Hz).

Damping,  $\beta$  was calculated as follows:

$$\beta = \left( \frac{1}{2\pi} \right) \ln \left( \frac{0.21}{0.15} \right)$$

and  $\beta = 0.054$  or 5.4% and is within the range for typical residential structures (3.5 to 13% of critical, Dowding, 1996). Therefore, the dynamic characteristics of the structure on Bighorn are within typical ranges.

#### *Upper structure amplification of ground velocities*

Amplification is a comparative measure of the maximum structure response to ground vibration at the same point in time in terms of velocity. It is similar to the term "dynamic amplification factor" used by seismologists to describe the effects of earthquakes on structures.

Amplification occurs when motion at S2 becomes larger than the motion at S1 and GV. Amplification factor (AF) was defined for blasting vibrations by the U.S. Bureau of Mines (Siskind, et al., 1980) as the ratio of the peak upper structure velocity ( $S2_{peak}$ ) divided by the preceding ground velocity (GV) of the same phase, positive or negative, that most likely drove the structure, or

$$AF = \left( \frac{S2_{peak}}{GV} \right) \quad (4)$$

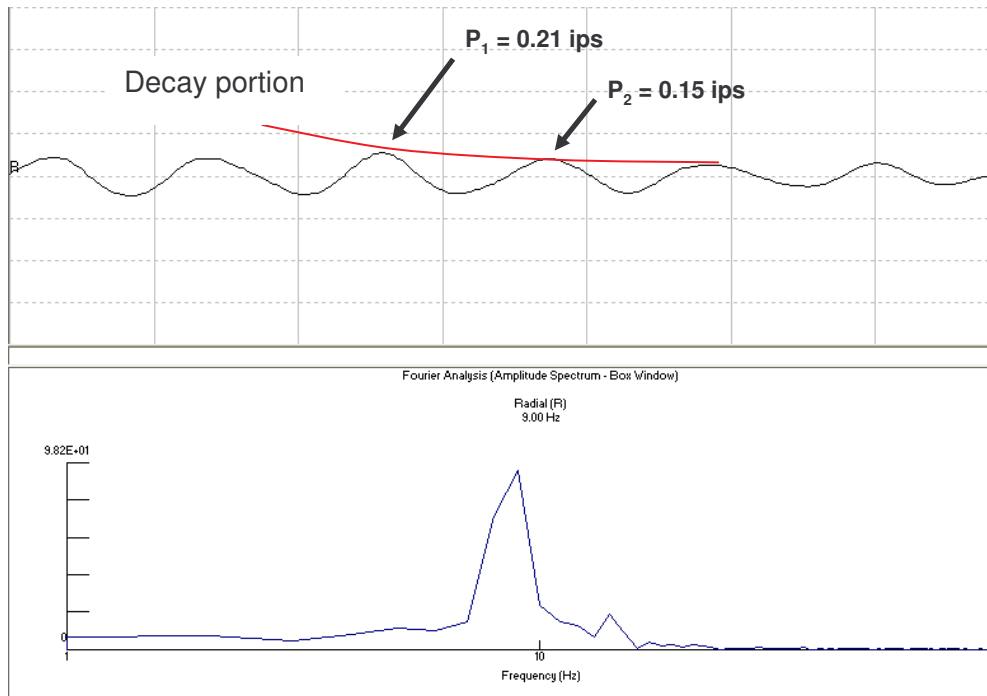


Figure 9 Upper structure radial component (SW wall) free response time history (above) and the FFT for the free response showing the predominant frequency (below)

AF was originally used by the U.S. Bureau of Mines as an indicator of the likelihood of cracking in structures. It was determined by Siskind (1980) and Aimone-Martin, et al., (2003) that typical one- and two-story residential structures will respond to blasting with AF ranging from less than 1.0 for very stiff structures, to 4, averaging 2 to 4. However, no direct correlation with crack observations have been reported for AF in excess of 5 that have typically been measured in 2-story and taller structures.

To calculate AF, the time-correlated waveforms for the ground (GV) and the upper structure corner (S2) for the same horizontal component were compared. The blast on 3/23/05 at 2:47 pm was the only blast to possess sufficient energy enabling computing AF for the structure on Bighorn. For all other blasts, ground vibration energy was generally within the seismograph system electronic 'noise'. Amplitudes were not sufficiently high to provide a reliable comparison. The small amplifications visually noted in time histories resulted from the influence of low ground motion frequency components.

AFs (T and R components) were computed for the 3/23/05 blast as follows for the structure at Bighorn using time-correlated velocities and equation (4):

	Upper structure (S2) peak	Ground velocity (GV)	AF
R	0.54 ips	0.23 ips	2.3
T	0.31 ips	0.26 ips	1.2



The maximum amplification factor of 2.3 falls within the lower end of the average range established by the U.S. Bureau of Mines and others for wood framed dwellings. Such low amplification factors will not contribute to situations of wall cracking at vibration levels below 0.5 ips peak ground motion.

### *Strains Calculated for Structure Walls*

The magnitude of induced strains in structure components determines the likelihood of cosmetic cracking in residences. Global shear strains may be estimated from differential structure motions calculated from the difference in displacements at the upper, S2, and lower, S1, in direction parallel to the plane of the wall of interest. Velocity time histories at S1 and S2 are first integrated to obtain displacement time histories, then the largest time correlated difference between corner responses (S2 minus S1) is found. Plots of the differential and component displacements time histories for all blast events are found in Appendix E.

Global shear strain is determined by the following:

$$\gamma_{\max} = \left( \frac{\delta_{\max}}{L} \right) \quad (5)$$

where

$\gamma_{\max}$  = global shear strain (micro-strains or  $10^{-6}$ )  
 $\delta_{\max}$  = maximum differential displacement, S2 – S1 (in.)  
 L = height of the wall subjected to strain (in.)

In-plane tensile strain important in the assessment of wall cracking potential,  $\epsilon_{L\max}$ , is calculated from global shear strain by the equation:

$$\epsilon_{L\max} = \gamma_{\max}(\sin\theta)(\cos\theta) \quad (6)$$

where  $\theta$  is the interior angle of the longest diagonal of the wall subjected to strain with reference to a horizontal. Theta,  $\theta$ , is calculated by taking the inverse tangent of the ratio of wall height to wall length.

Bending strains in walls were also computed. Walls of structures, which approximate flexible plates, tend to flex in a direction perpendicular to the plane of the wall with maximum displacements in the first mode of response at the middle of the wall. Such wall flexure is directly related to the bending strain induced in the walls and were modeled as a beam fixed at both ends, at the foundation (S1) and at the roof (S2). It has been determined that the foundation is well coupled to the ground, or “fixed”. However, the roof can be modeled with varying degrees of “fixity”, ranging from relatively unconstrained to highly fixed. Bending strain is most conservatively estimated with the fixed-fixed analogy because this model predicts the highest strains in walls per unit of maximum relative displacement. These out-of-plane bending strains can be calculated as:

$$\epsilon = \left( \frac{6d\Delta \delta_{\max}}{L^2} \right) \quad (7)$$

where

$\epsilon$  = bending strain in walls (micro-strains or  $10^{-6}$ )

d = the distance from the neutral axis to the wall surface, or one half the thickness of the wall subjected to strain (in.)

Appendix E contains displacement time histories used to compute strains and show the results of these strain calculations. The results of strain calculations for both structures are summarized in Tables 1 and 2. No data (nd) was available for the Bighorn structure for the blasts on 3/16/05 as the seismographs triggered constantly from nearby heavy construction activity early on 3/17/05 and all data was overwritten. Hence, data could not be downloaded. The exterior (triggering) geophone was moved farther east and away from the construction activity on 3/17/05 to prevent this problem for subsequent blasts.

The peak strains shown in the tables do not necessarily correspond with the maximum ground velocities. In fact, very little response data can be correlated with exterior ground motion excitations with even a modest degree of reliability or confidence. This is because the ground velocities were very low and near the detectable limits of the seismographs. Integrating low velocity time histories to compute displacements can produce some data scatter. What variations are noted in the low strain values result from this scatter and most likely are influenced by slight variations in ground motion frequencies.

Table 1 Calculated strains for all blasts that trigger exterior seismographs at the structure on Bighorn in comparison with ground motion velocity components and peak crack displacements

Shot Date	Time	Maximum differential wall displacement, S2-S1 (in)		Maximum shear strain (micro-strain)		Maximum in-plane tensile strain (micro-strain)		Maximum bending strain (micro-strain)		Maximum ground velocity (in/s) <sup>(1)</sup>		Maximum Crack Displacement (micro-in)
		SW wall	SE wall	SW wall	SE wall	SW wall	SE wall	SW wall	SE wall	Radial	Transverse	
3/15/05a	10:00	0.00137	0.00104	10.78	8.16	4.58	3.95	2.50	1.30	0.025	0.035	48
3/15/05b	3:48	nt										
3/16/05a	1:58	nd										51.6
3/16/05b	3:17	nd										45.7
3/17/2005	3:05	nt										
3/18/05a	11:00	nt										
3/18/05b	3:07	nt										
03/21/05	11:07	0.001036	0.00075	8.13	5.88	3.45	2.85	3.04	2.71	0.040	0.045	61.7
03/22/05	12:35	0.005292	0.012646	41.51	99.18	17.64	47.99	5.39	7.75	0.040	0.040	45.6
3/23/05a	12:09	nt										
3/23/05b	2:47	0.008346	0.006358	65.46	49.87	27.82	24.13	9.45	5.51	0.330	0.450	243.5
03/24/05	1:17	nt										
03/25/05	10:58	nt										
3/29/05	2:01	nt										
3/30/05	3:41	nt										
3/31/05	10:30	nt										
3/31/05	2:25	nt										
4/1/05	11:42	nt										
4/5/05	10:08	nt										
4/6/05	12:39	nt										
4/7/05	12:33	nt										
4/8/05	11:15	nt										
4/12/05	2:21	nt										
4/13/05	3:40	nt										
4/14/05	4:00	0.003402	0.00681	26.68	53.41	11.34	25.84	3.88	4.47	0.035	0.040	46.4
nt - no trigger; ground motion below seismograph trigger level												
nd - no data												
(1) radial component parallel with SW wall; transverse component parallel with the SE wall												

Table 2 Calculated strains for all blasts that trigger exterior seismographs at the structure on High Mesa in comparison with ground motion velocity components and peak crack displacements

Shot Date	Time	Maximum differential wall displacement, S2-S1 (in)		Maximum shear strain (micro/strain)		Maximum in-plane tensile strain (micro-strain)		Maximum bending strain (micro-strain)		Maximum ground velocity (in/s) <sup>(4)</sup>		Maximum Crack Displacement (micro-in)
		NE wall	SE wall	NE wall	SE wall	NE wall	SE wall	NE wall	SE wall	Radial	Transverse	
3/15/05a	10:00	nt										
3/15/05b	3:48	0.00022	0.00016	3.06	2.31	1.07	0.74	0.75	0.72	0.030	0.025	nd
3/16/05a	1:58	0.00017	0.0001	2.04	1.85	0.71	0.59	0.51	0.60	0.035	0.025	42.6
3/16/05b	3:17	0.00093	0.00053	8.61	4.91	3.02	1.56	2.52	2.96	0.045	0.045	113.6
3/17/2005	3:05	0.00032	0.00021	2.96	1.94	1.04	0.62	0.68	0.90	0.035	0.025	46.7
3/18/05a	11:00	0.0002	0.00026	1.85	2.41	0.65	0.77	0.85	0.80	0.025	0.015	68.8
3/18/05b	3:07	0.00038	0.00032	3.52	2.96	1.23	0.94	1.20	2.08	0.035	0.025	49.8
03/21/05	11:07	(1)										(3)
03/22/05	12:35	(1)										(3)
03/23/05	11:00	nt										
03/23/05	2:47	nt										
03/24/05	1:17	nt										
03/25/05	10:58	(1)										(3)
3/29/05	2:01	(1)										(3)
3/30/05	3:41	nt										
3/31/05	10:30	nt										
3/31/05	2:25	nt										
4/1/05	11:42	nt										
4/5/05	10:08	nt										
4/6/05	12:39	nt										
4/7/05	12:33	nt										
4/8/05	11:15	0.00132	(2)	12.22	(2)	4.28	(2)	3.69	3.40	0.075	0.070	nd
4/12/05	2:21	0.00068	0.00052	6.30	4.81	2.21	1.53	1.50	1.27	0.025	0.020	44.4
4/13/05	3:40	0.00178	0.00062	16.48	5.74	5.78	1.83	4.33	2.67	0.030	0.025	67.2
4/14/05	4:00	0.00165	0.0009	15.28	8.33	5.35	2.66	4.32	2.80	0.030	0.035	95.5

(1) unable to download S1

(2) S2 Transverse component fell from SW wall during wind storm

(3) Somat crack gage computer being repaired

(4) radial component parallel with NE wall; transverse component parallel with the SE wall

nt - no trigger; ground motion below seismograph trigger level

nd - no data

For the dwelling on Bighorn, the maximum recorded corner differential displacement (S2 – S1) was 0.008346 in. in the SW wall driven by ground motions in the T direction (or parallel with the SW wall) during the blast on 3/23/05 at 2:47 pm. The maximum in-plane tensile and mid-wall bending strains calculated were 27.8 and 9.4 micro-strains, respectively, both in the southwest wall.

For the dwelling on High Mesa, the maximum recorded whole structure differential displacement was 0.00178 in. in the NE wall during the blast on 4/13/05. The maximum in-plane tensile and mid-wall bending strains calculated were 5.78 and 4.33 micro-strains, respectively, both in the northeast wall.

According to Dowding (1985), the range of failure strains in the gypsum core of drywall is 300 to 500 micro-strains. Literature shows that the tensile strains for modern stuccos, reinforced with polymeric fiber, the failure strains are in excess of 1,000 micro-strains. Using the maximum observed tensile strain of 27.8, the minimum factor of safety against cracking is 10.7 for the interior drywall, 36 for stucco, and well above the safe limits of cracking. At such low levels of blasting, the induced strains never exceeded the elastic limit of the wall materials. Hence, no permanent deformation could have occurred and cracking both in interior drywalls and exterior stucco are not caused by blasting activities at the levels recorded during this project.

### *Crack Response to Blasting Vibrations*

The dynamic response of an existing exterior crack in stucco was measured at each structure during blasting events. Crack displacement time histories are given in Appendix F. Tables 1 and 2 show the peak crack displacement measured during blasting. The peak dynamic crack displacements ranged from 45.6 to 243.5 micro-inch for the horizontal crack on the southeast wall of the structure on Bighorn. Peak crack displacement for the diagonal crack on the northeast wall in the structure at High Mesa ranged from 42.6 to 113.6 micro-inch.

### *Long-Term or Environmental and Weather Induced Crack Response*

The width of existing wall cracks is highly sensitive to changes in ambient temperature and humidity. Many of the existing exterior cracks in stucco are attributed to blasting. However, it is often the case that the dynamic response of cracks to blasting is small compared with the static, or slow, opening and closing of existing cracks with diurnal (or 24-hour) fluctuations in temperature and humidity. To show this comparison, long-term changes in crack widths were measured and recorded on an hourly basis throughout the project. Changes in crack width are plotted against time for each structure in Figures 10 and 11 for the structures on High Mesa and Bighorn, respectively (a positive increase in crack displacement corresponds with opening of the crack). Data gaps shown for the High Mesa residence reflect time periods over which the SOMAT™ field computer collecting data was removed for repair. Corresponding temperature and humidity data was not collected during that time period. Additionally, SOMAT™ data was not collected when it was incorrectly initialized. This missing data did not hamper the analysis and a wide range of climate and crack motion data are available on which to draw conclusions.

In general, crack movement follows the trend in exterior humidity. When humidity increases, the crack opens and this occurs most predominately very early in the mornings well before dawn. During the day as temperature increases and humidity decreases, the crack tends to close. It is this daily cycle that produces high stresses on the crack and in particularly, at the tips or ends of the cracks, causing crack to grow slowly over time under the right conditions.

The large variation in crack width over a one-half day cycle can be clearly observed. The largest measured change over this daily cycle was 6844 and 4583 micro-inch for the structures at High Mesa and Bighorn, respectively. Over the project duration, overall crack width changes were 8212 and 5403 micro-inch for the structures at High Mesa and Bighorn, respectively.

Daily changes in crack width over a 4-day period are compared with the dynamic crack motions for the most significant blast on 3/23/05 at 2:47 pm in Figure 12. The maximum daily change of 3509 micro-inch exceeds the largest change in peak-to-peak crack width during blasting (431 micro-inch, or the difference between the highest and lowest reading about the zero amplitude line).

It is therefore concluded that the large weather-induced changes in crack width is the greatest contributing factor to crack extension and widening over time. Blasting vibration influence on changes in crack widths are negligible compared with the influence of climate. Hence, blasting is unlikely to be the source of stucco cracking.

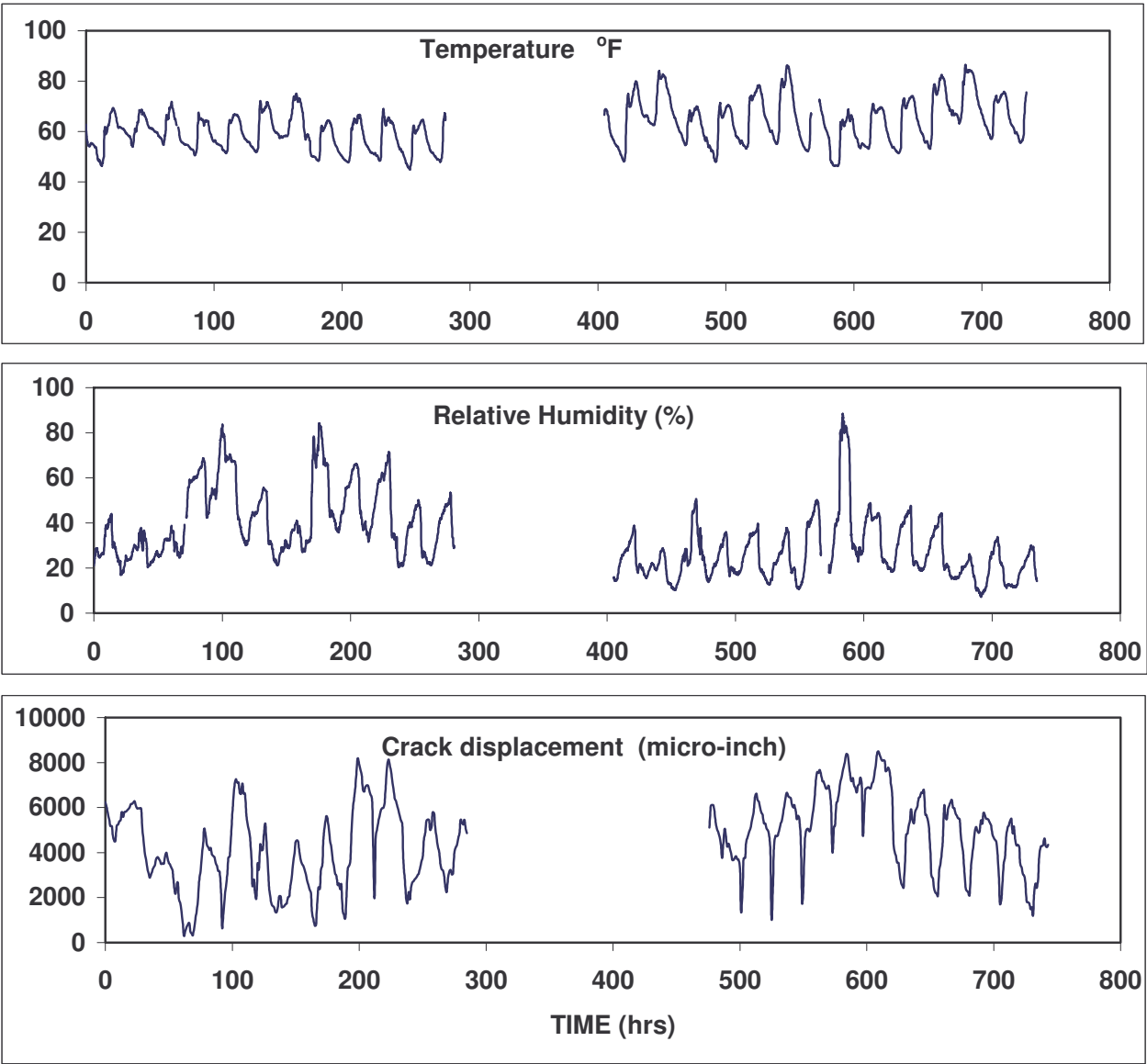


Figure 10 Variations in ambient temperature, humidity and corresponding crack displacement over project duration for structure on High Mesa

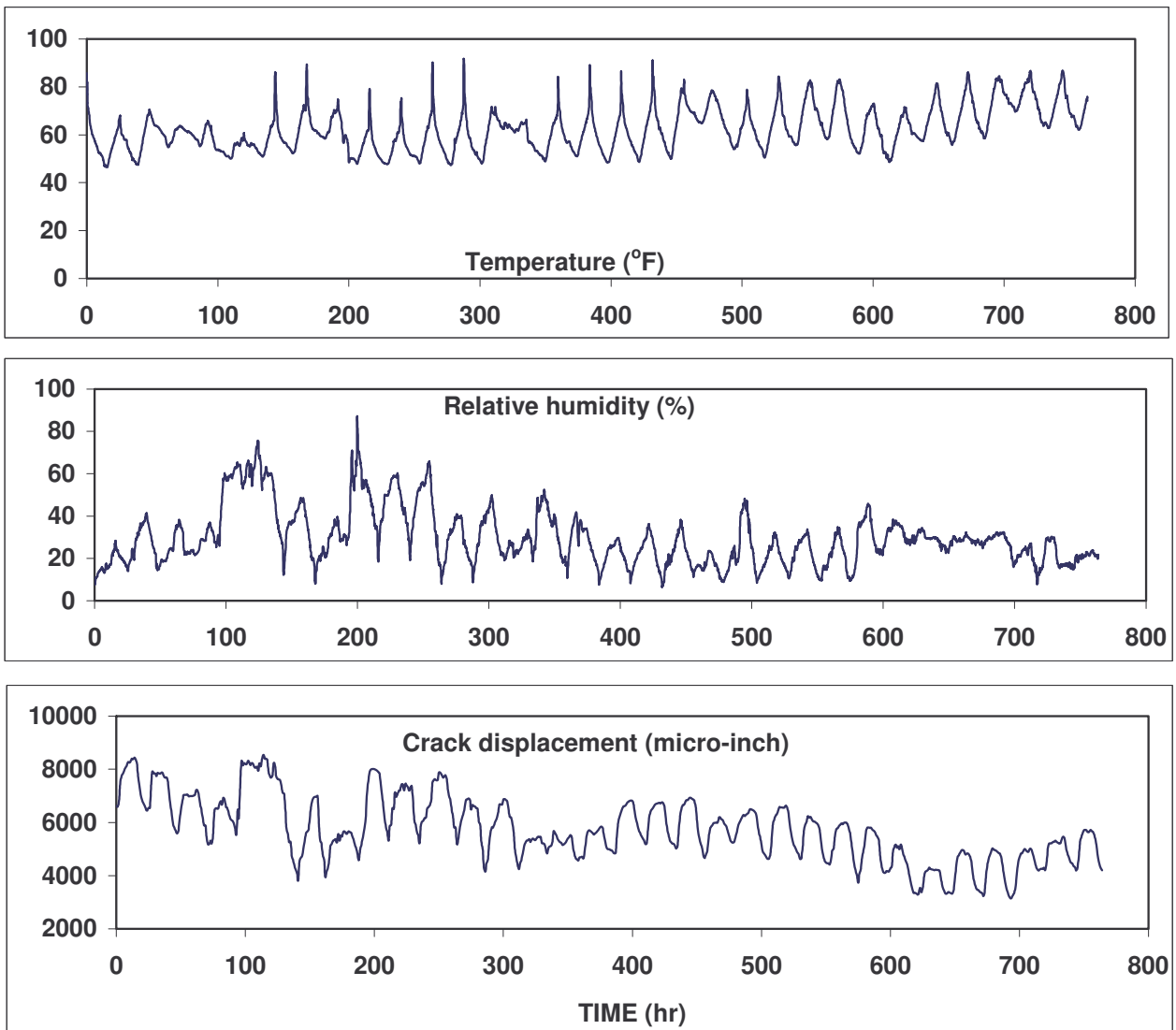


Figure 11 Variations in ambient temperature, humidity and corresponding crack displacement over project duration for structure on Bighorn

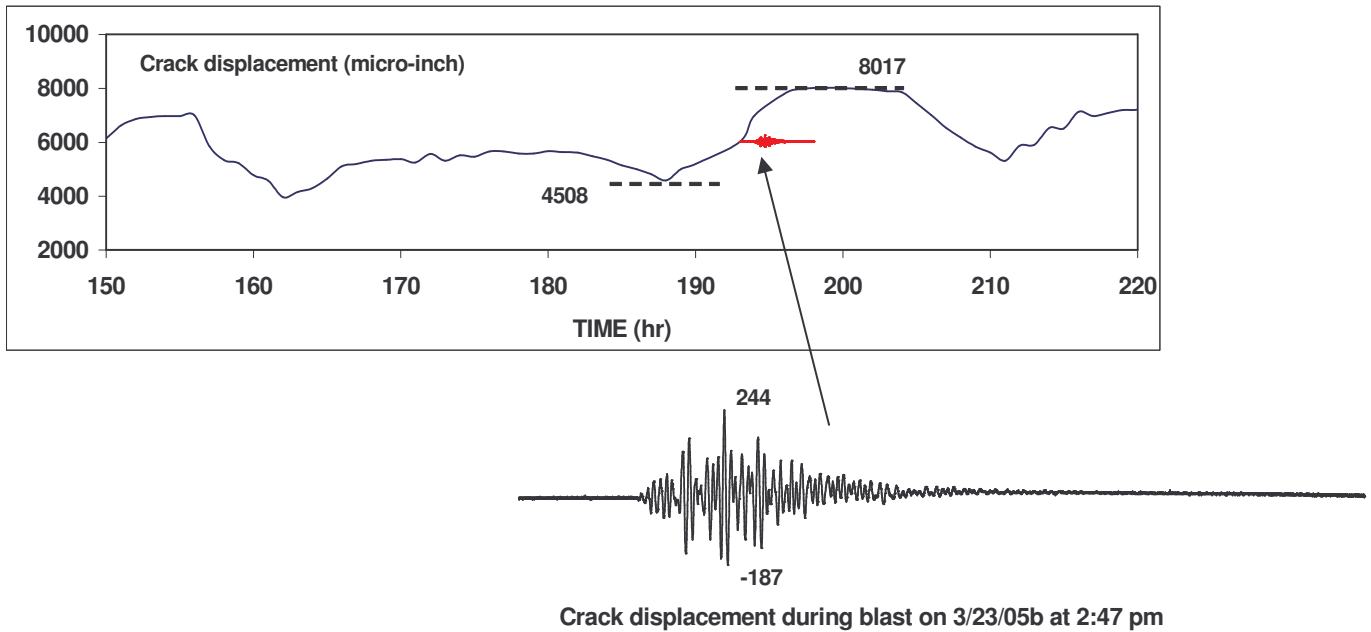


Figure 12 Comparison of dynamic crack displacement time history for blast on 3/23/05 with static crack movement in response to climate over a 4-day period including 3/23/05

### *Crack Response to Construction Vibrations and High Winds*

Throughout the project, structures were subjected to vibrations from nearby construction excavations and other activities. In addition, high winds during storms produced wall and crack displacements of magnitudes similar to or greater than those caused by blasting. The two-story structure on Bighorn was most exposed to winds and construction activities and data from this structure was used to illustrate these comparisons.

Table 3 compares the peak crack responses and ground motions generated during selected construction and blasting events. Seismograph reports for selected construction-triggered events are found in Appendix C. The largest ground motion recorded for construction activities was 0.07 ips, which is 1.6 times greater than all other recorded vibrations created from blasting with the exception of the anomalous blast on 3/23/05 at 2:47 pm.

Figure 13 is a plot of the maximum crack displacement and ground velocity for the component of ground motion driving the crack motions. The blasting data generated slightly higher crack responses than the construction vibrations because blasting energy contains a wide variety of frequencies and more data scatter compared with close-in construction containing more uniform frequencies. The data correlate well both with and without the blast data for 3/23/05.

Table 3 Construction-generated vibrations and crack responses compared with blasting events for structure on Bighorn

Date	Time	Activity	Ground velocity (ips)		Maximum Crack Displacement (micro-in)
			radial	transverse	
3/17/2005	12:19	construction	0.020	0.025	18.7
3/18/2005	7:01		0.015	0.025	19.7
3/23/2005	6:40		0.030	0.015	21.4
4/12/2005	12:15		0.070	0.045	35.3
4/13/2005	10:46		0.045	0.035	31
3/15/05a	10:00	blasting	0.025	0.035	48
03/21/05	11:07		0.040	0.045	61.7
03/22/05	12:35		0.040	0.040	45.6
3/23/05b	2:47		0.330	0.450	243.5
4/14/05	4:00		0.035	0.040	46.4

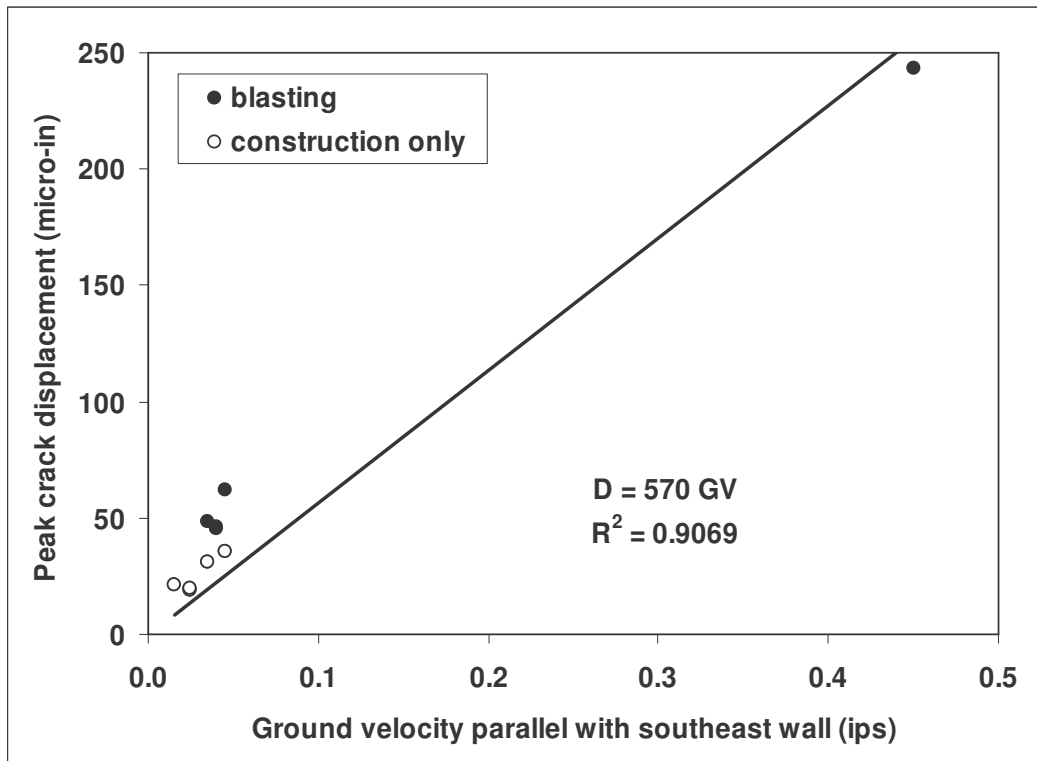


Figure 13 Peak crack displacement versus ground motion in a direction parallel with the wall containing the crack for structure on Bighorn



Wind storm data is summarized in Table 4 showing peak crack displacements and air pressures generated during wind gusts. Air pressure is given in terms of pressure (psi) or sound pressure level equivalent (dB). Selected structure wave forms are given in the seismograph records in Appendix C. Figure 14 is a plot of peak crack displacement correlated with wind pressure and wind speed for measured data. Wind speed may be predicted by the following well-established relationship

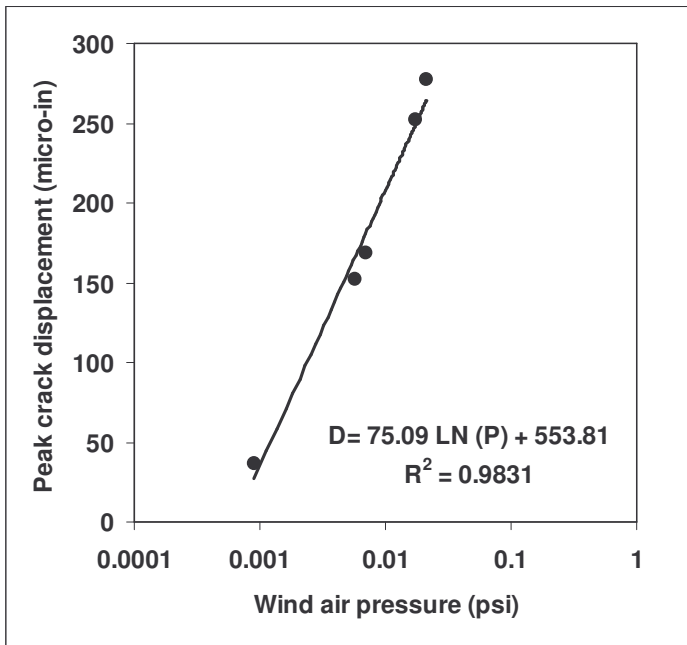
$$\text{Wind speed (mph)} = 1.8728 (10^{-5}) P^2 \quad (8)$$

where P is the air pressure, in psi. The good data fit in Figure 14 results from the consistent crack response to air pressures driving the Bighorn structure southwest wall. The two highest crack displacement measurements shown in Table 4 occurred at 11:54 pm (3/22/05) and 2:15 am (3/23/05) measuring 252.8 and 277.4 micro-inch, respectively. The corresponding wind speeds computed from peak air pressure are 31 and 34 mph. Figure 15 shows a plot of weather pattern data in Henderson for 3/22/05 and 3/23/05. A storm persisted into the night of 3/22/05, generating wind gusts measuring up to 40.3 mph in Henderson.

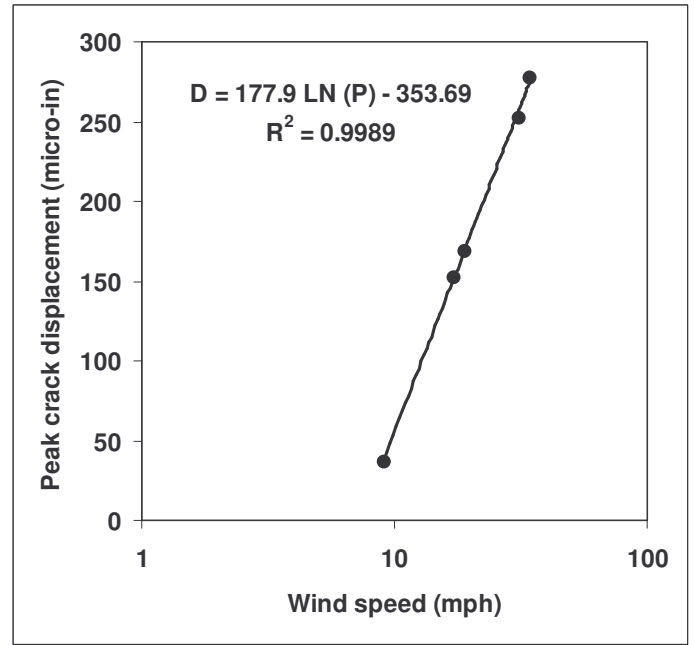
The peak crack displacement for the largest blast on 3/23/05 was 243.5 micro-inch. The wind pressures on the southwest wall of the structure created crack displacements *greater than the largest blast*. It is therefore concluded that the influence of blasting on wall displacements as evidenced by existing crack opening and closing, is less than the influence of high wind pressures for this structure given the range of data provided during this project period.

Table 4 Construction-generated vibrations and crack responses compared with blasting events for structure on Bighorn

Date	Time	Maximum crack displacement	Air pressure	Equivalent airblast	Equivalent windspeed
		(micro-in)	(psi)	(dB)	(mph)
3/17/2005	9:08 PM	152.1	0.0057	125	17
3/17/2005	10:02 PM	169	0.007	127	19
3/22/2005	11:54 PM	252.8	0.0174	136	31
3/23/2005	2:15 AM	277.4	0.0212	137	34
3/23/2005	6:40 AM	37	0.0009	110	9



(a)



(b)

Figure 14 (a) Peak crack displacement during wind gusts versus corresponding wind air pressure (log scale) and (b) versus wind speed.

## CONCLUSIONS

Two residential structures were instrumented to measure upper corner and mid-wall motions and the response for an existing exterior crack during ground vibrations and airblast from rock blasting. The static response of crack opening and closing was also measured during environmental changes of temperature, humidity, and wind. The following are the conclusions of this study:

- All ground vibration data recorded during this study fell well within the safe blasting criteria defined by the U.S. Bureau of Mines in 1980 and widely used in the U.S. rock blasting industry. This safe criteria is based on over 40 years of research and crack observations and has been scientifically supported since 1980 by experts in the field of structure response to rock blasting. There has been no scientific data to date that disputes this criteria.
- Horizontal ground velocities recorded at the structures were very low, ranging from 0.025 inches per second (ips) to 0.075 ips. The peak ground and FFT frequencies ranged from 3.3 Hertz (Hz) to 42.6 Hz.
- Airblast did not contribute to structure vibrations within either dwelling as illustrated in upper corner and mid-wall velocity time histories. During this study, airblast averaged 105.5 dB for the Bighorn dwelling and 104 dB at High Mesa. Peak airblast frequencies were above 11 Hz and energy was not coupled within the walls at this low amplitude.

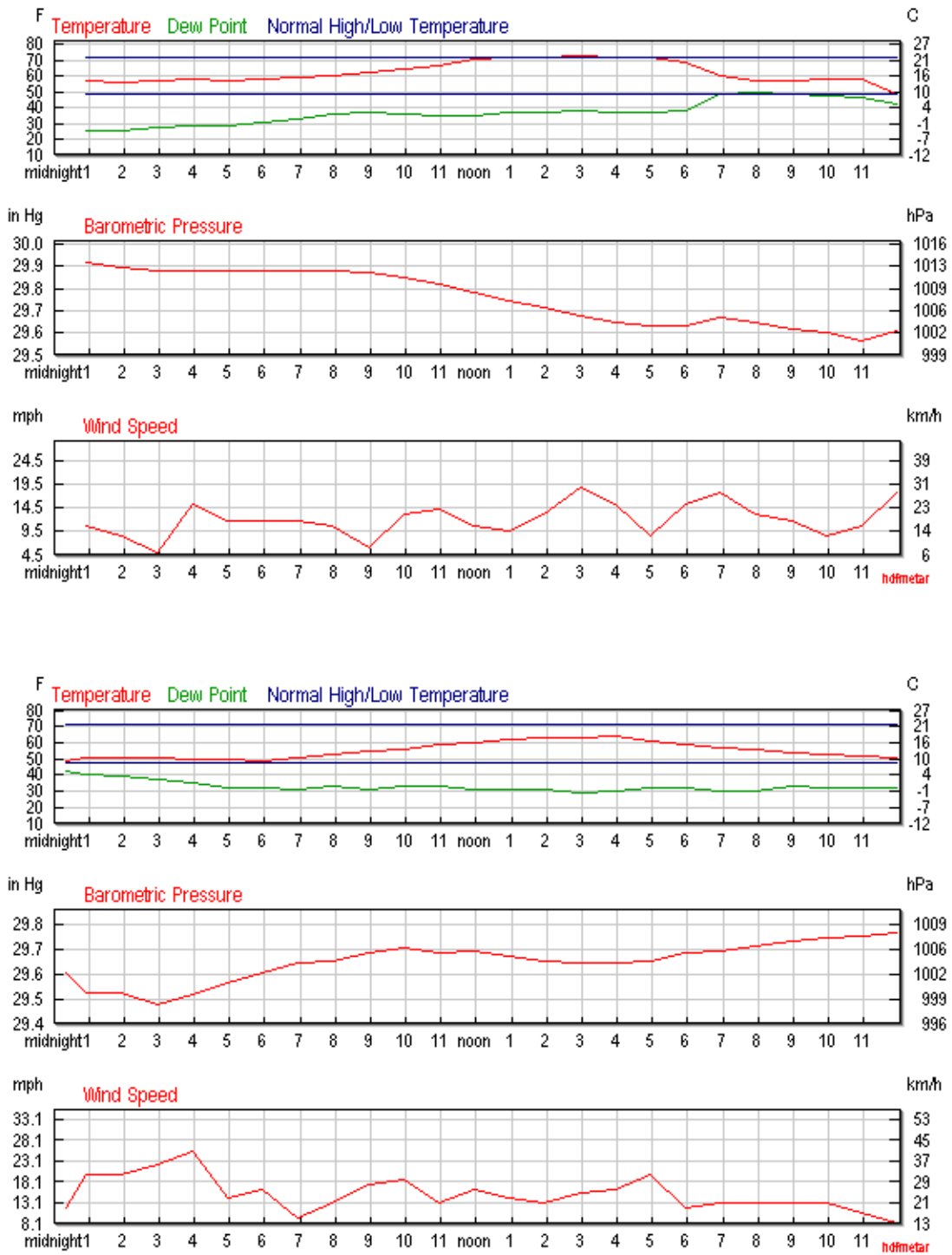


Figure 15 Weather patterns for Henderson, NV during 3/22/05 (above) and 3/23/05 (below)

- Velocity time histories of upper corners and mid-walls for the two structures did not exhibit any unusual characteristics. Both structures responded as expected and within the range of structure responses for similar construction dwellings.
- Blasting over the time period of this study did not provide sufficient energy to allow the computation of structure damping and natural frequency, except in the case of the blast on 3/23/05 at 2:47 pm for the structure on Bighorn. Structure natural frequency and damping were computed to be 9 Hz and 5.4%, respectively, and well within the normal range for all structure types.
- Based on the low ground vibrations and the absence of airblast, it was not possible to compute amplification factors (AF) comparing time-correlated maximum structure responses to ground vibrations for blasts, except for the blast on 3/23/05 at 2:47 pm at the structure on Bighorn. AF values for the R and T components for this blast were 2.3 and 1.2, respectively, and are well within the expected range. For all other blasts there was insufficient blast-generated energy to compute AF.
- The maximum in-plane tensile and mid-wall bending strains calculated for the structure on Bighorn were 27.8 and 9.4 micro-strains, respectively. For the dwelling on High Mesa, the maximum in-plane tensile and mid-wall bending strains calculated were 5.78 and 4.33 micro-strains, respectively.
- The range of failure strains in the gypsum core of drywall is 300 to 500 micro-strains while in polymeric fiber reinforced stuccos, failure strains are in excess of 1,000 micro-strains. Therefore, strains computed from structure motions from blasting during this study were far below those that could possibly cause cracking in walls.
- Peak dynamic crack displacements during blasting ranged from 45.6 to 243.5 micro-inch for the horizontal crack on the southeast wall of the structure on Bighorn for ground motions up to 0.45 ips. Peak crack displacement for the diagonal crack on the northeast wall in the structure at High Mesa ranged from 42.6 to 113.6 micro-inch for ground motions up to 0.045 ips.
- The largest measured changes in the width of the cracks as influenced by variations in temperature and humidity over a 12-hour (half-day) cycle were 6844 and 4583 micro-inch for the structures at High Mesa and Bighorn, respectively. Over the project duration of 764 hours (31 days), overall crack width changes were 8212 and 5403 micro-inch for the structures at High Mesa and Bighorn, respectively. Thus, environmentally-driven crack width changes were 72 and 22 times greater than the zero-to-peak dynamic motions during blasting for the High Mesa and Bighorn structures. Environmental changes have a far greater influence on cracks movements compared with blasting.
- Crack displacements during construction activity (rock impacting, backhoe, vibratory rollers) adjacent to the structure on Bighorn were similar in magnitude to those recorded during blasting with the exception of the anomalous blast on 3/23/05 at 2:47 pm. Hence,

close-in construction and typical blasting activities vibrations have the same influence on structure response as measured by existing crack motions.

- The largest crack displacements measured at the Bighorn residence during a wind storm on 3/22/05 and 3/23/05 were 252.8 and 277.4 micro-inch, respectively. The corresponding wind speeds computed from peak air pressures were 31 and 34 mph. Weather data for Henderson available on the Internet indicated wind gusts measuring up to 40.3 mph. Therefore, high winds during storms in Henderson can produce wall motions greater than those produced by ground vibrations near the regulatory limit of 0.5 ips.
- Blast vibration influence on changes in crack widths were negligible compared with the influence of climate and compared with those produced by high winds. Large weather-induced changes in crack widths are the greatest contributing factor to crack extension and widening over time. Hence, blasting is unlikely to be the source of stucco cracking compared with other daily environmental and weather influences.

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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.

**Appendix A**

**Blasting seismograph records for  
structure at High Mesa**

**High Mesa  
Exterior Master**

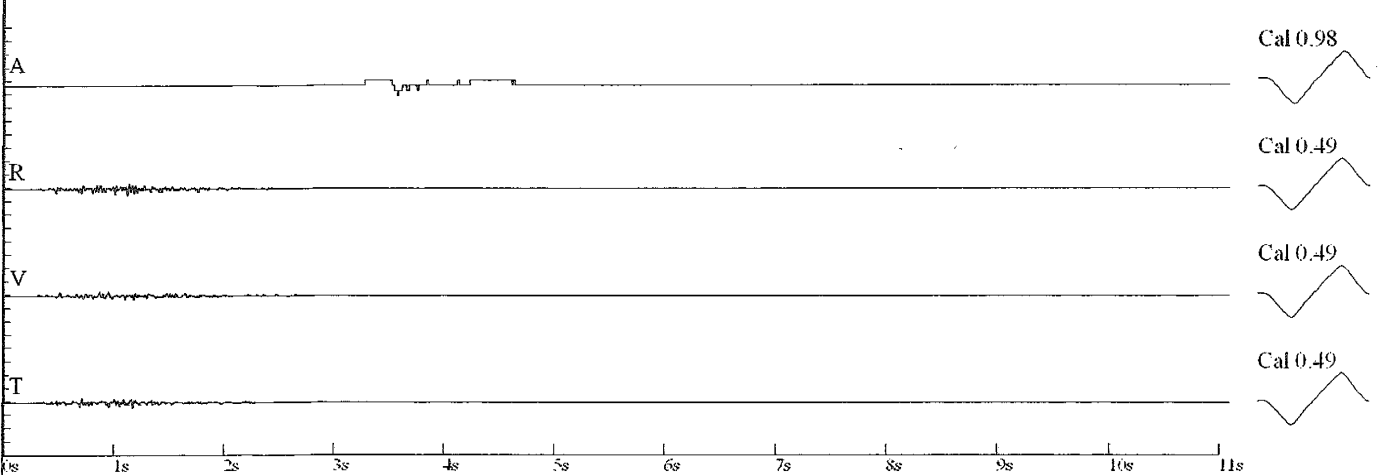
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 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

*Acoustic:* 110 dB @ 1.6 Hz  
 (0.06Mb 0.0009psi 0.0060kPa)  
*Radial:* 0.03in/s 0.762mm/s @ 32.0Hz  
*Vertical:* 0.02in/s 0.508mm/s @ 25.6Hz  
*Transverse:* 0.025in/s 0.635mm/s @ 32.0Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 120dB 0.20Mb (0.050Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



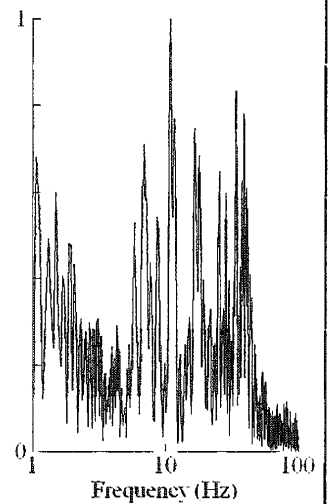
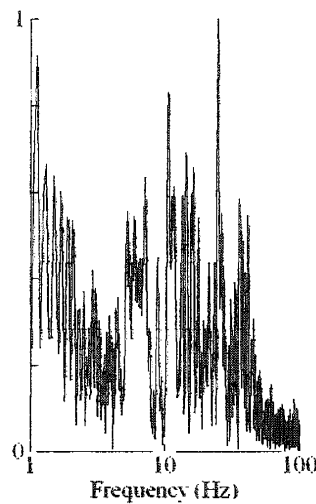
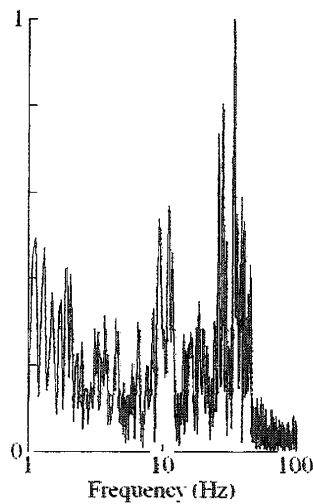
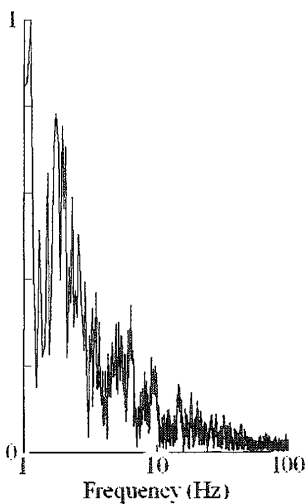
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
1.13 Hz

**Radial**  
34.50 Hz

**Vertical**  
25.06 Hz

**Transverse**  
10.88 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

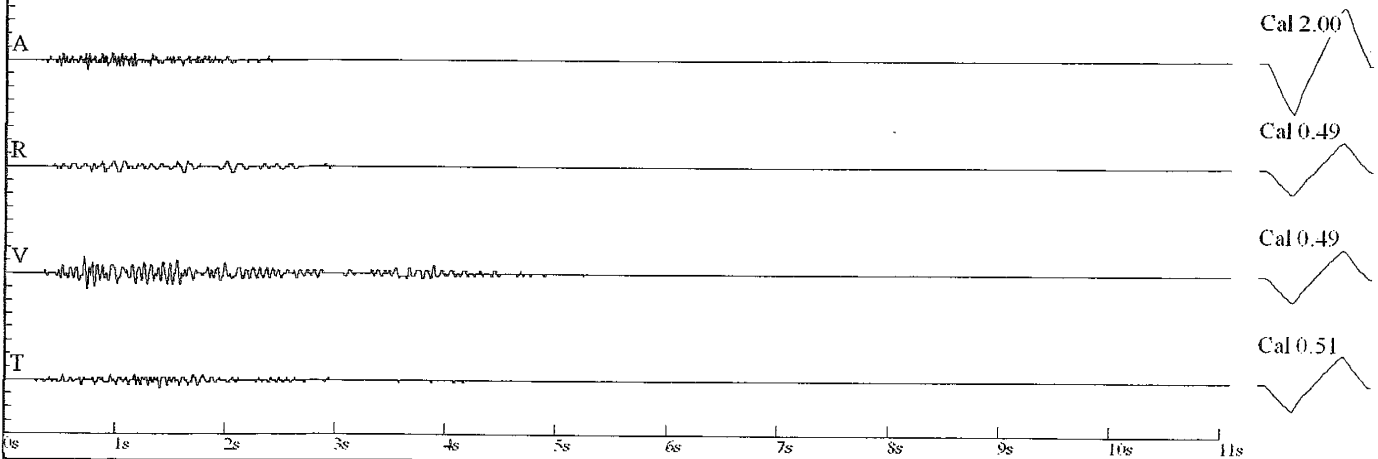
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 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 112 dB @ 0.0 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.02in/s 0.508mm/s @ 0.0Hz  
 Vertical: 0.05in/s 1.27mm/s @ 19.6Hz  
 Transverse: 0.03in/s 0.762mm/s @ 23.2Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
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 Time Line Intervals at: 1.00 s



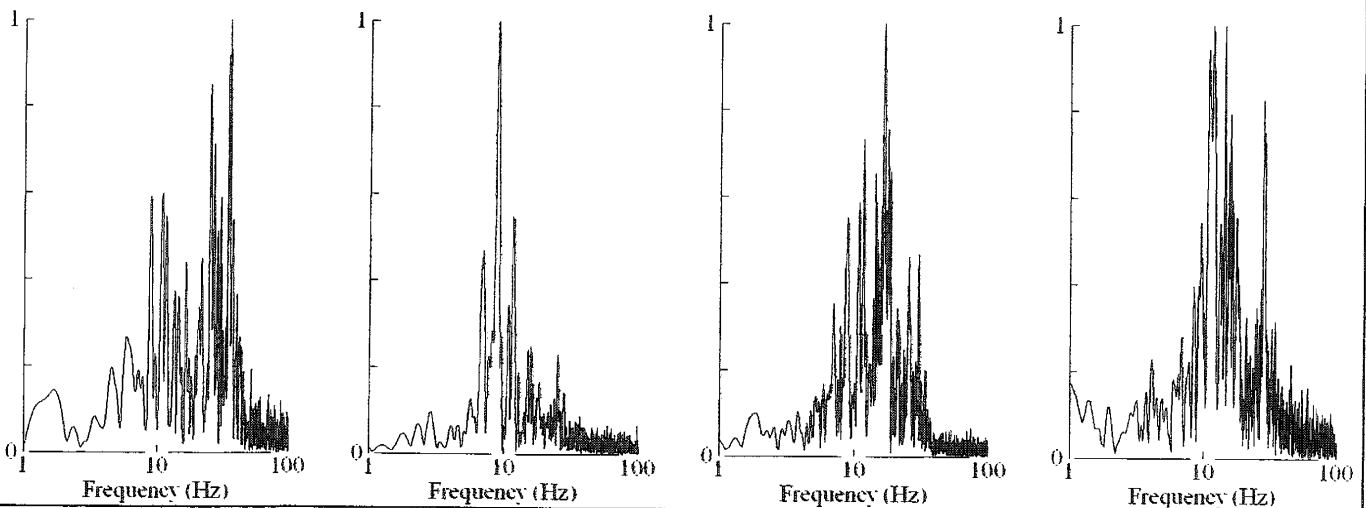
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
34.75 Hz

Radial  
8.88 Hz

Vertical  
16.56 Hz

Transverse  
11.75 Hz





**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

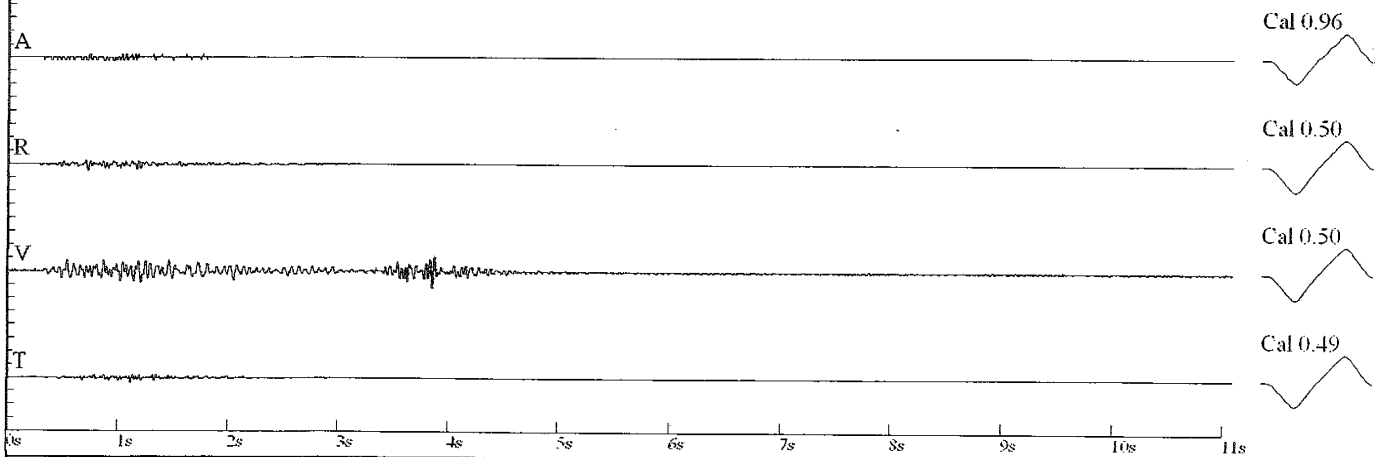
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 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 106 dB ( $\bar{a}$ : 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.02in/s 0.508mm/s ( $\bar{a}$ : 28.4Hz  
 Vertical: **0.065in/s 1.651mm/s ( $\bar{a}$ : 28.4Hz**  
 Transverse: 0.02in/s 0.508mm/s ( $\bar{a}$ : 28.4Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



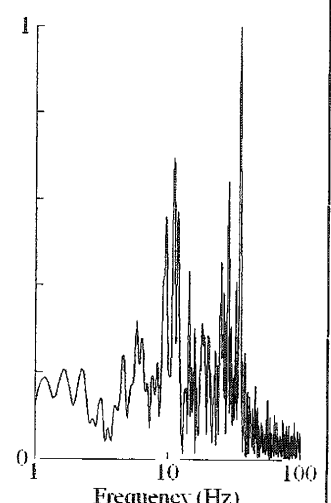
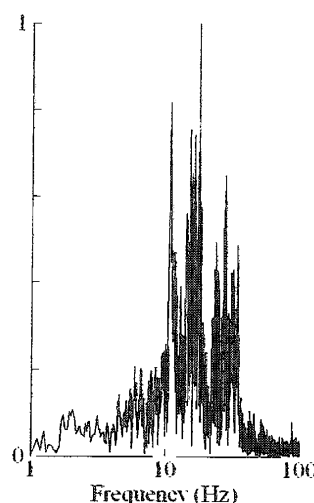
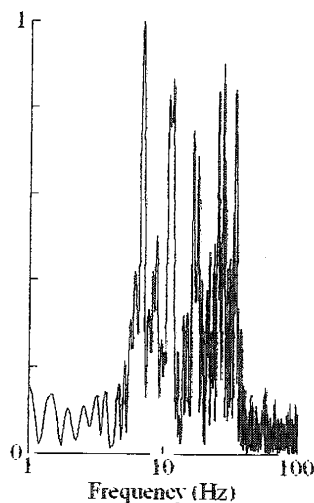
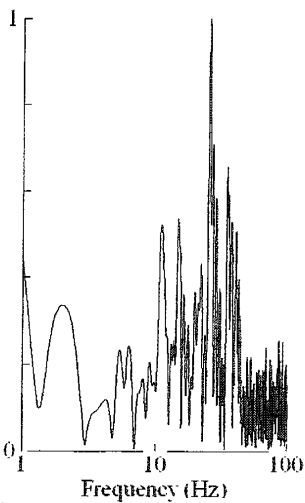
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
 25.00 Hz

Radial  
 6.88 Hz

Vertical  
 17.94 Hz

Transverse  
 34.38 Hz



**High Mesa  
Exterior Master**

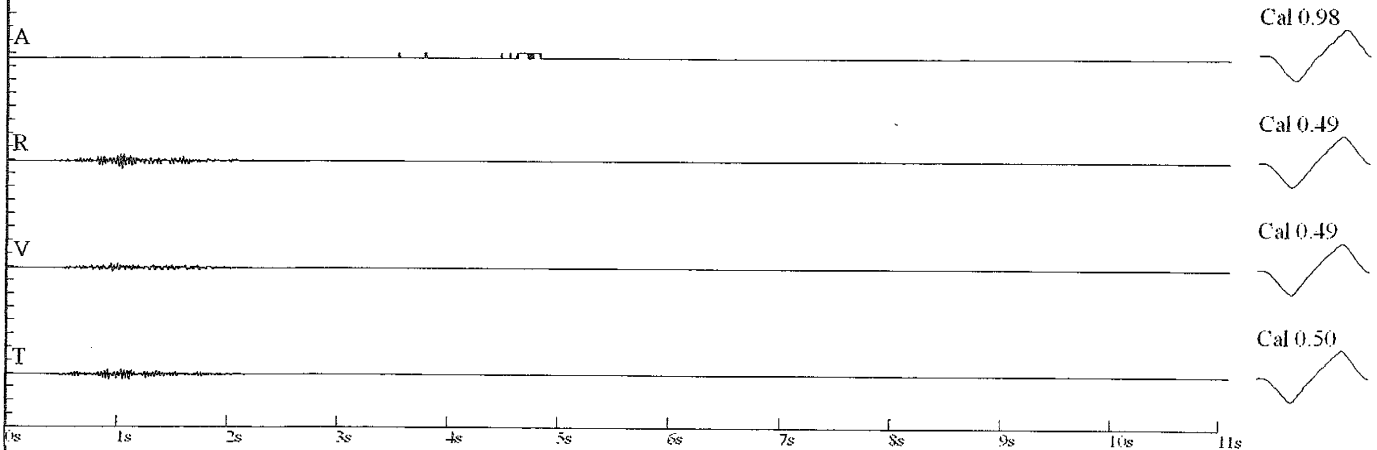
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 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.7

**Amplitudes and Frequencies**

Acoustic: 100 dB  $\hat{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.035in/s 0.889mm/s  $\hat{a}$ : 36.5Hz  
 Vertical: 0.015in/s 0.381mm/s  $\hat{a}$ : 36.5Hz  
 Transverse: 0.025in/s 0.635mm/s  $\hat{a}$ : 32.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



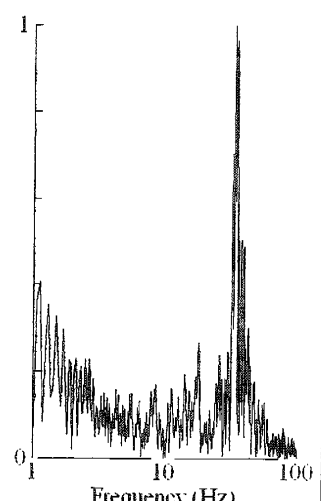
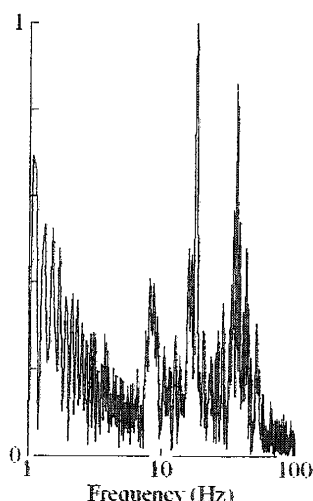
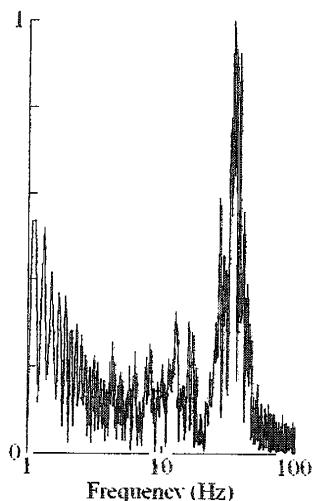
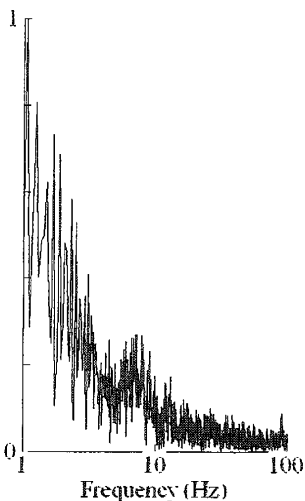
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.06 Hz

Radial  
34.13 Hz

Vertical  
17.94 Hz

Transverse  
33.69 Hz



**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

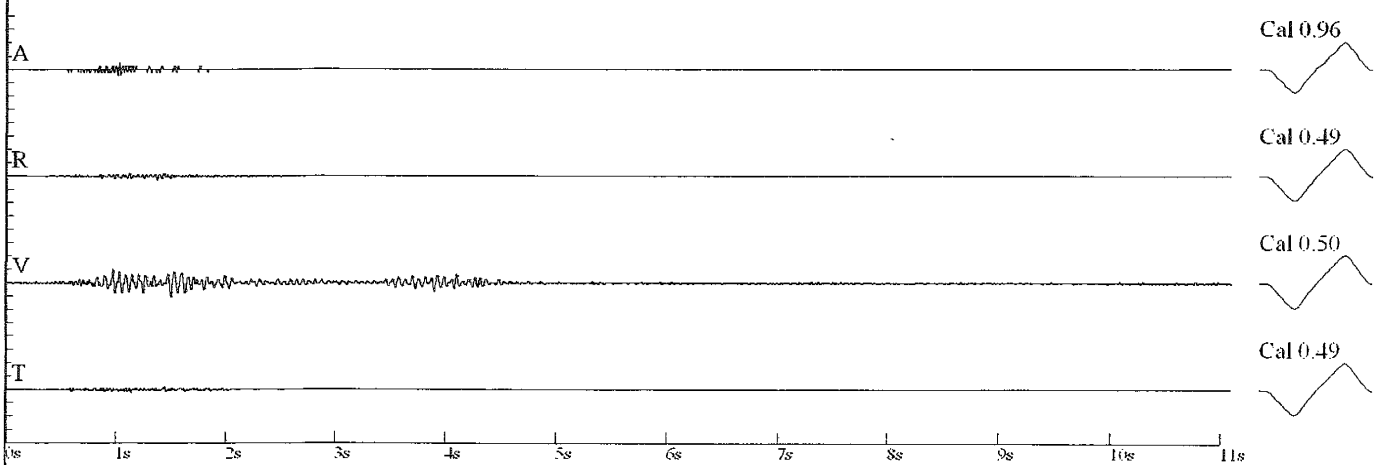
File Name: 00930014.DTB  
 Number: 014  
 Date: 3 16 2005  
 Time: 13:52  
 Serial Number: 930  
 Seismic Trigger: 0.0450 in s 1.1430 mm s  
 Acoustic Trigger: 126 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 112 dB ( $\bar{a}$ : 0.0 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.015in/s 0.381mm/s ( $\bar{a}$ : 28.4Hz  
 Vertical: **0.055in/s 1.397mm/s ( $\bar{a}$ : 21.3Hz**  
 Transverse: 0.015in/s 0.381mm/s ( $\bar{a}$ : 36.5Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



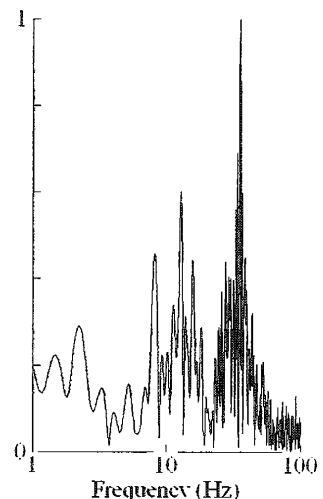
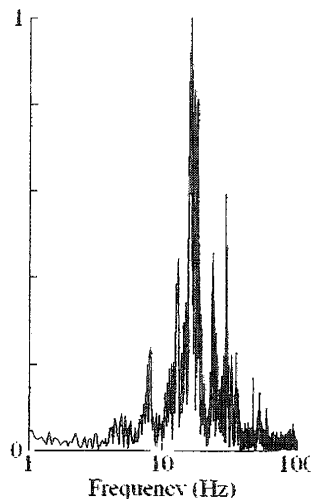
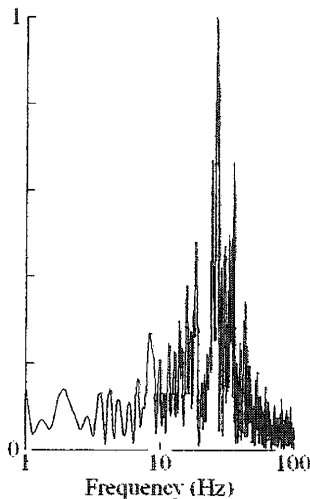
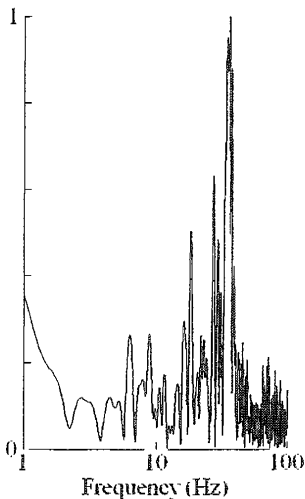
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
 34.88 Hz

Radial  
 26.19 Hz

Vertical  
 16.38 Hz

Transverse  
 35.13 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

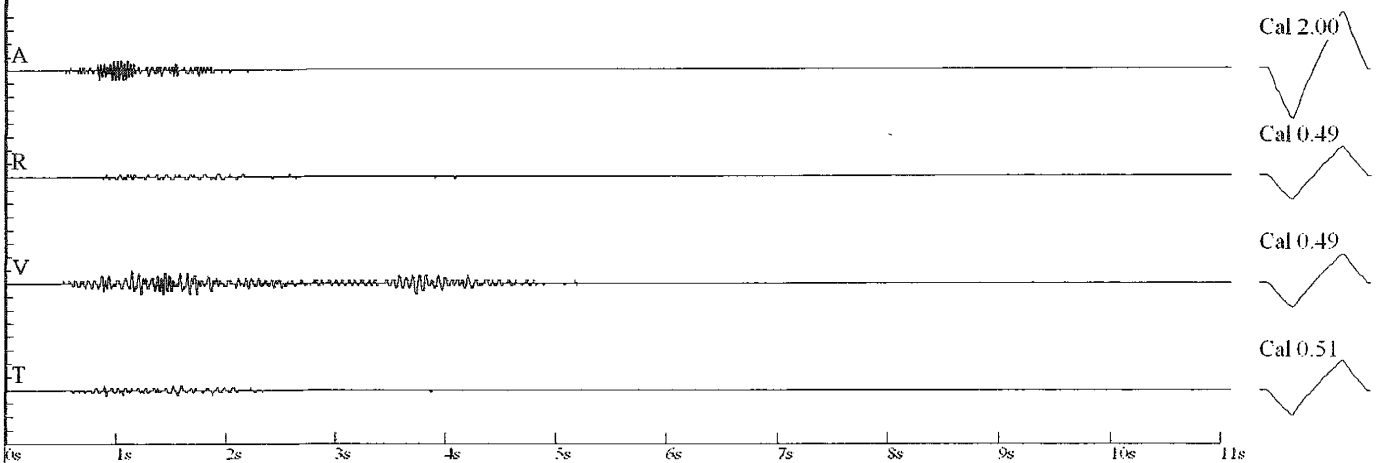
File Name: 02276295.DTB  
 Number: 295  
 Date: 3 16 2005  
 Time: 13:52  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 116 dB ( $\bar{a}$ : 42.6 Hz  
 (0.12Mb 0.0017psi 0.0120kPa)  
 Radial: 0.01in/s 0.254mm/s ( $\bar{a}$ : 0.0Hz  
 Vertical: 0.05in/s 1.27mm/s ( $\bar{a}$ : 25.6Hz  
 Transverse: 0.02in/s 0.508mm/s ( $\bar{a}$ : 0.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



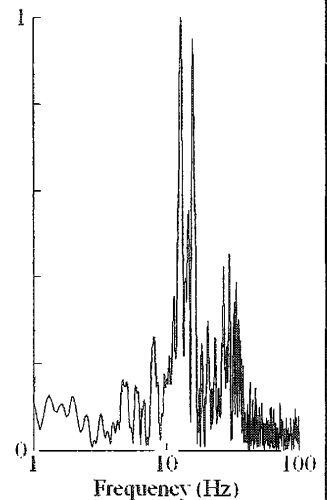
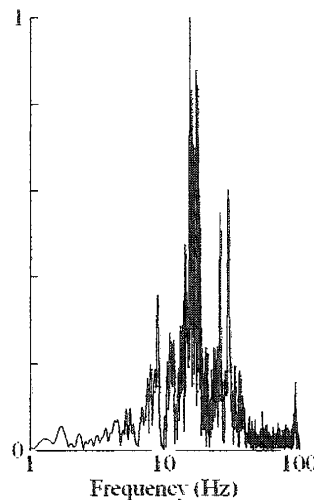
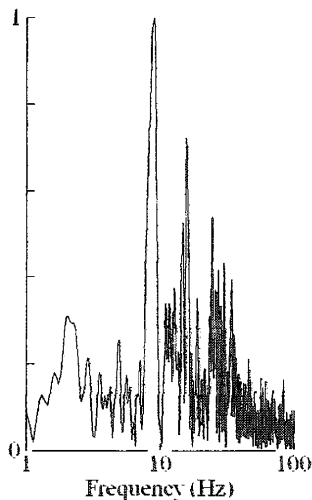
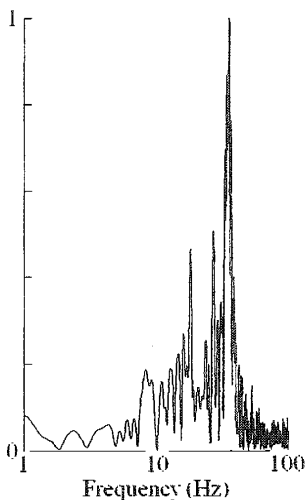
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
 34.81 Hz

Radial  
 9.00 Hz

Vertical  
 15.75 Hz

Transverse  
 12.81 Hz



**High Mesa  
Exterior Master**

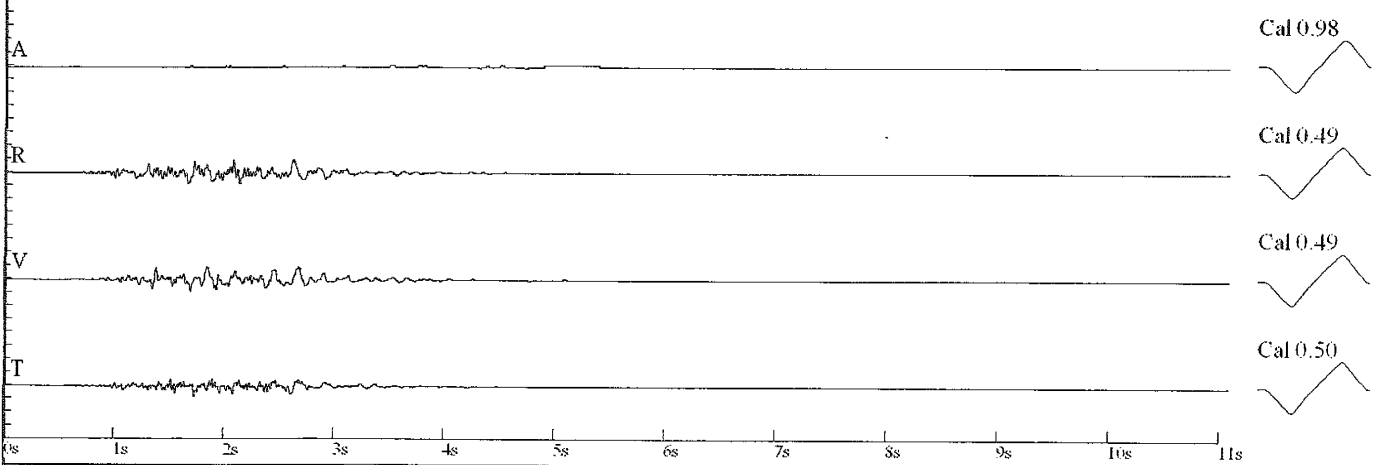
File Name: 01258058.DTB  
 Number: 058  
 Date: 3/16/2005  
 Time: 15:15  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in/s @ 0.6350 mm/s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.045in/s 1.143mm/s @ 21.3Hz  
 Vertical: **0.05in/s 1.27mm/s @ 6.0Hz**  
 Transverse: 0.045in/s 1.143mm/s @ 9.8Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



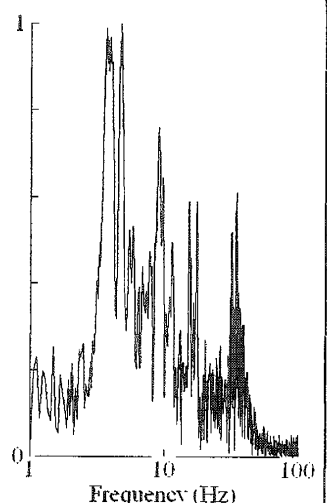
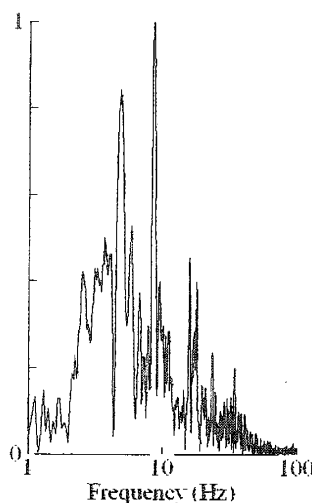
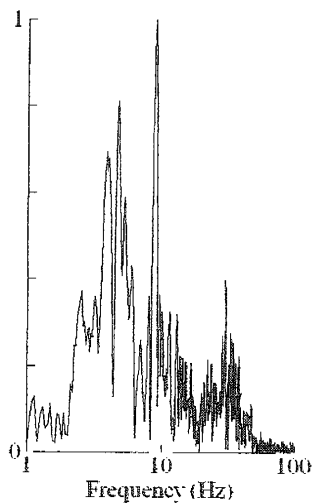
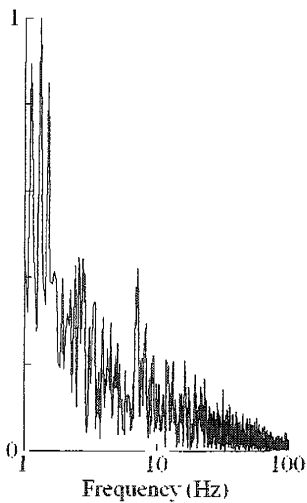
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.31 Hz

Radial  
8.94 Hz

Vertical  
8.56 Hz

Transverse  
4.69 Hz



**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

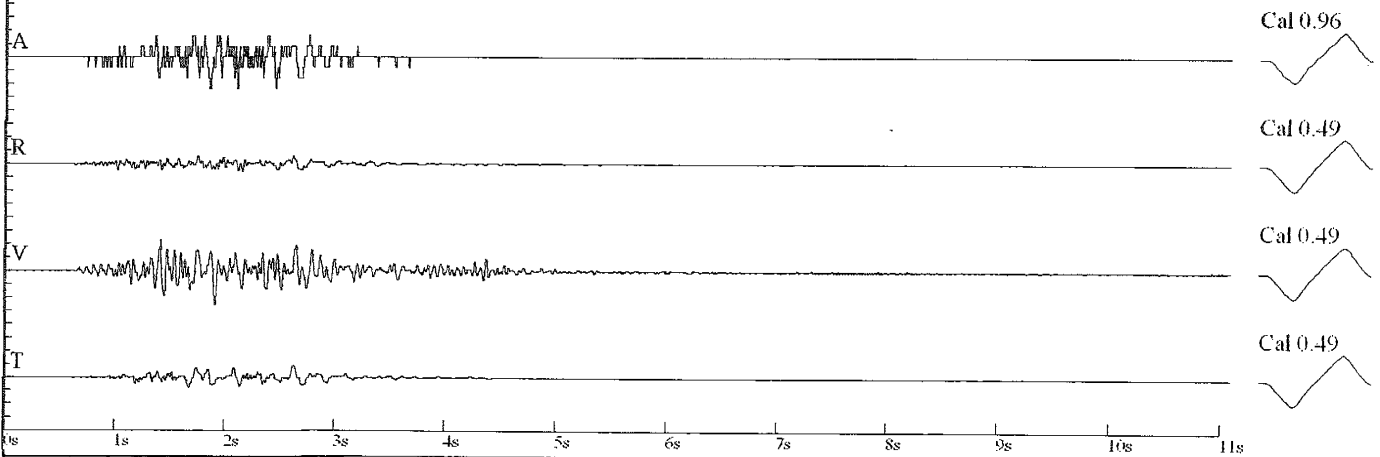
File Name: 00930015.DTB  
 Number: 015  
 Date: 3 16 2005  
 Time: 15:16  
 Serial Number: 930  
 Seismic Trigger: 0.0450 in s 1.1430 mm s  
 Acoustic Trigger: 126 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 116 dB ( $\bar{a}$ : 12.8 Hz  
 (0.12Mb 0.0017psi 0.0120kPa)  
 Radial: 0.03in/s 0.762mm/s ( $\bar{a}$ : 15.0Hz  
 Vertical: 0.13in/s 3.302mm/s @ 12.1Hz  
 Transverse: 0.045in/s 1.143mm/s ( $\bar{a}$ : 8.2Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



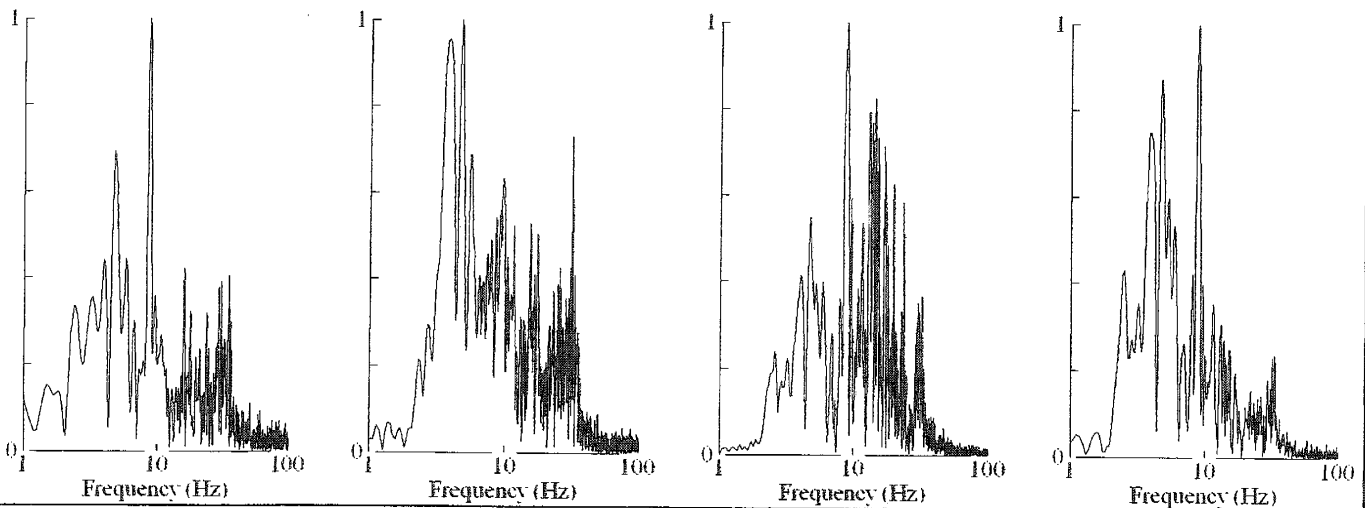
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
8.63 Hz

Radial  
4.69 Hz

Vertical  
8.88 Hz

Transverse  
8.88 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

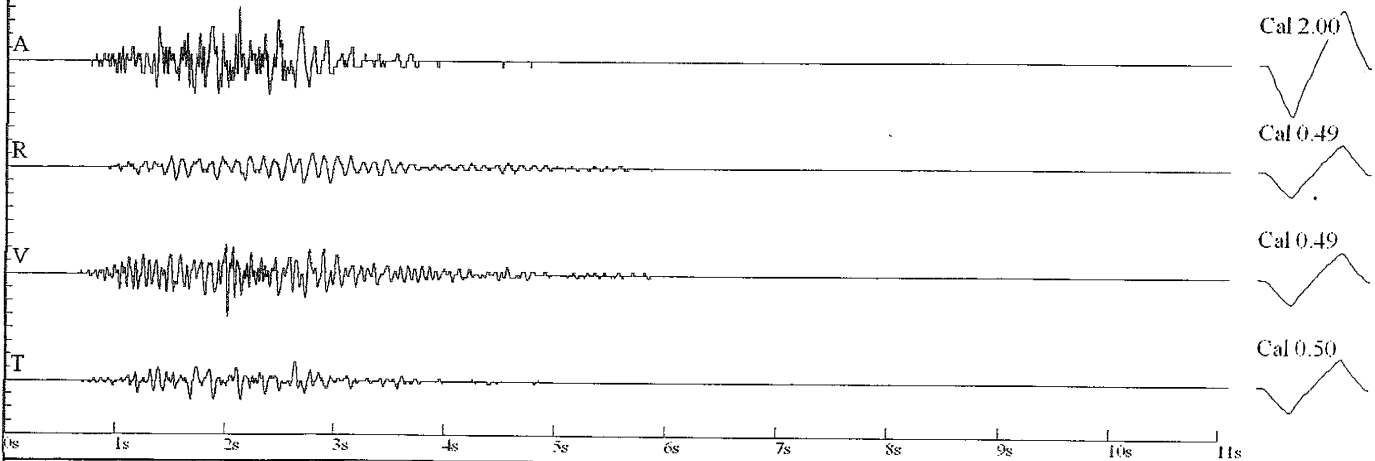
File Name: 02276296.DTB  
 Number: 296  
 Date: 3 16 2005  
 Time: 15:15  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 124 dB ( $\hat{a}$ : 25.6 Hz  
 (0.32Mb 0.0046psi 0.0320kPa)  
*Radial:* 0.06in/s 1.524mm/s ( $\hat{a}$ : 8.8Hz  
*Vertical:* **0.16in/s 4.064mm/s ( $\hat{a}$ : 21.3Hz**  
*Transverse:* 0.07in/s 1.778mm/s ( $\hat{a}$ : 10.6Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 124dB 0.32Mb (0.079Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



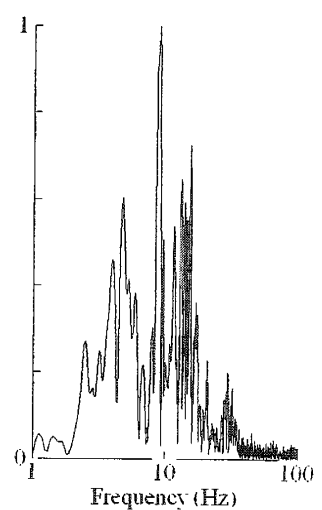
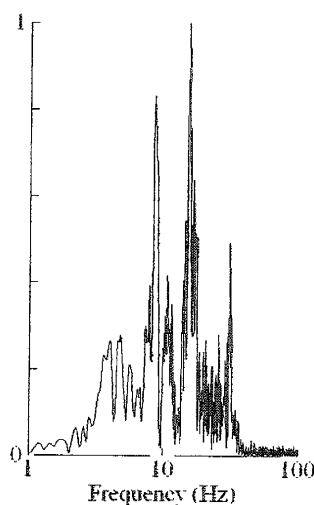
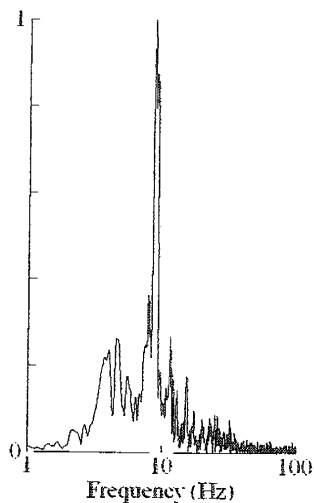
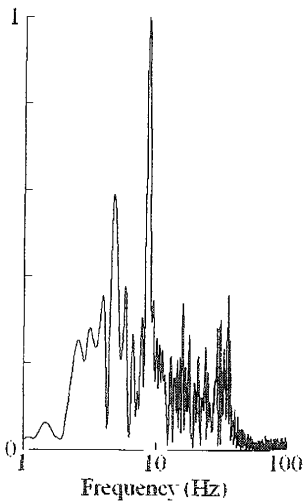
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
8.63 Hz

**Radial**  
8.63 Hz

**Vertical**  
15.50 Hz

**Transverse**  
8.94 Hz



**High Mesa  
Exterior Master**

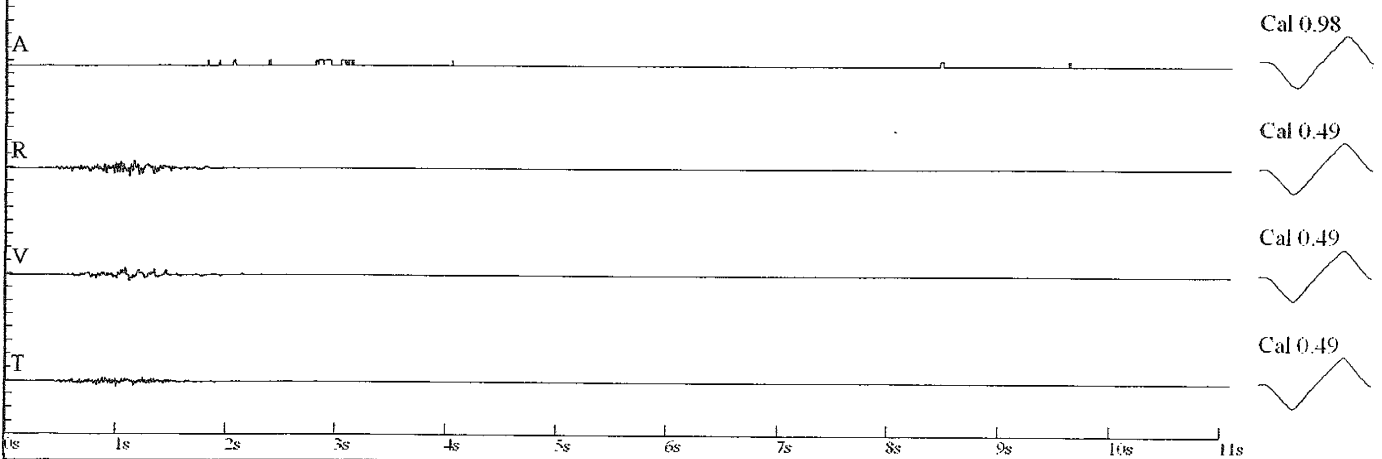
File Name: 01258059.DTB  
 Number: 059  
 Date: 3 17 2005  
 Time: 15:00  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 100 dB ( $\hat{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.035in/s 0.889mm/s ( $\hat{a}$ : 32.0Hz  
 Vertical: 0.03in/s 0.762mm/s ( $\hat{a}$ : 6.7Hz  
 Transverse: 0.025in/s 0.635mm/s ( $\hat{a}$ : 9.4Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



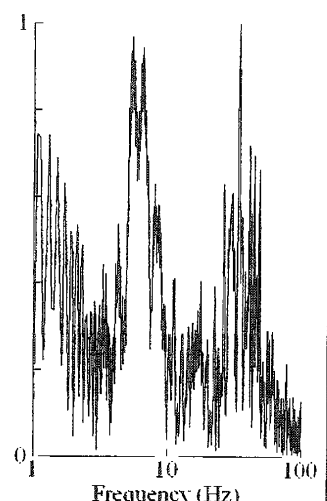
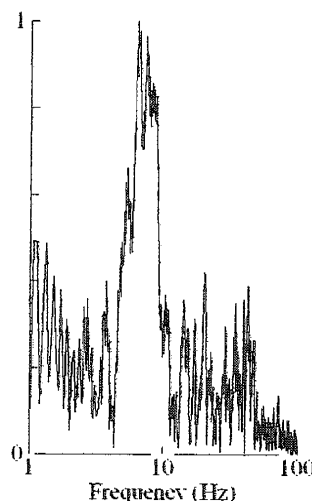
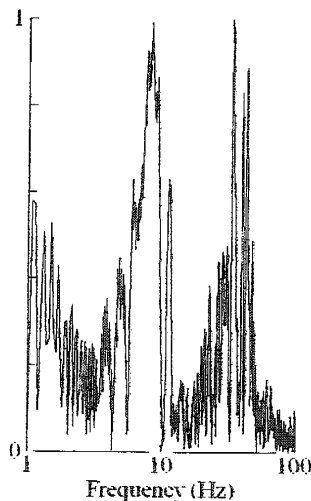
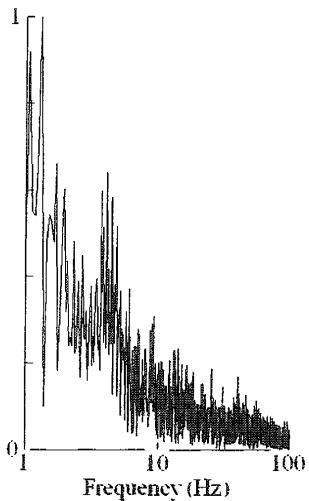
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.31 Hz

Radial  
33.31 Hz

Vertical  
6.31 Hz

Transverse  
33.94 Hz





**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

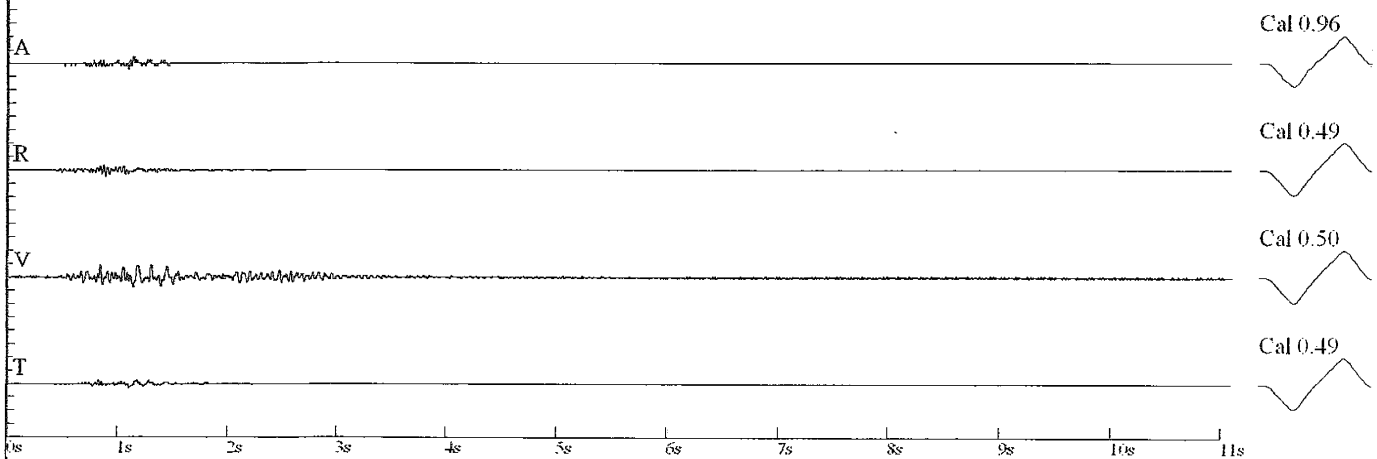
File Name: 00930016.DTB  
 Number: 016  
 Date: 3 17 2005  
 Time: 15:01  
 Serial Number: 930  
 Seismic Trigger: 0.0450 in s 1.1430 mm s  
 Acoustic Trigger: 126 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 112 dB @ 0.0 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.015in/s 0.381mm/s @ 42.6Hz  
 Vertical: 0.045in/s 1.143mm/s @ 21.3Hz  
 Transverse: 0.02in/s 0.508mm/s @ 10.2Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



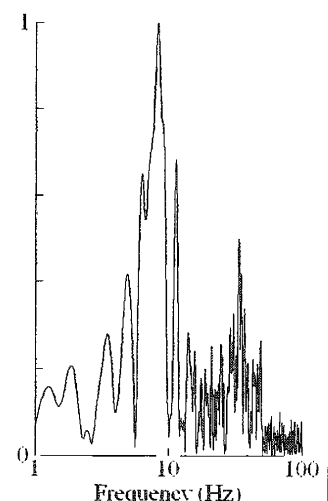
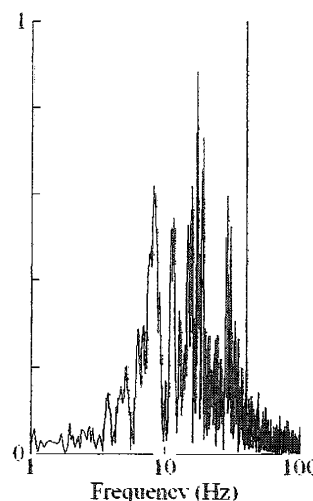
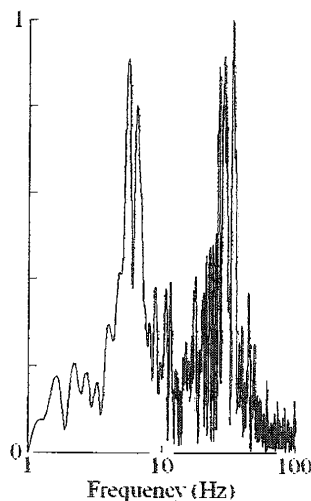
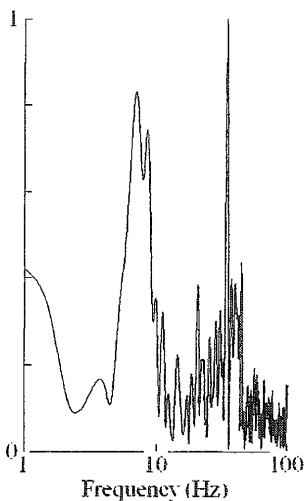
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
33.75 Hz

Radial  
33.44 Hz

Vertical  
40.13 Hz

Transverse  
8.31 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

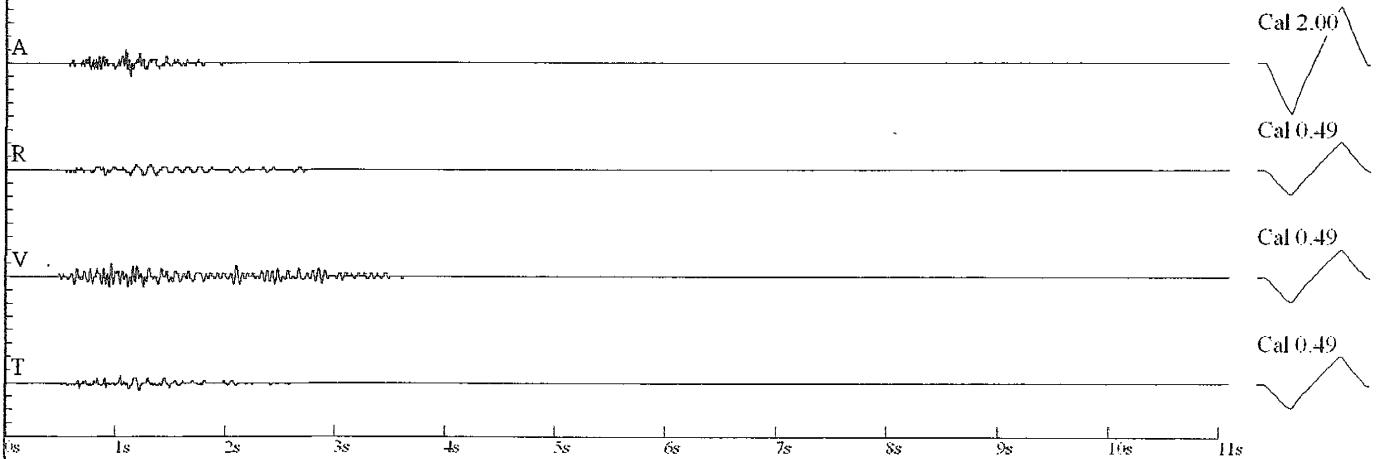
File Name: 02276297.DTB  
 Number: 297  
 Date: 3 17 2005  
 Time: 15:01  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 118 dB  $\bar{a}$ : 36.5 Hz  
 (0.16Mb 0.0023psi 0.0160kPa)  
*Radial:* 0.02in/s 0.508mm/s  $\bar{a}$ : 0.0Hz  
*Vertical:* **0.04in/s 1.016mm/s**  $\bar{a}$ : **32.0Hz**  
*Transverse:* 0.03in/s 0.762mm/s  $\bar{a}$ : 32.0Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



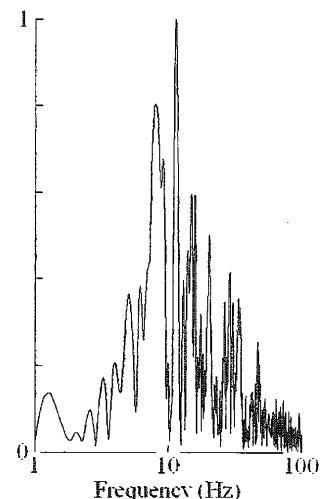
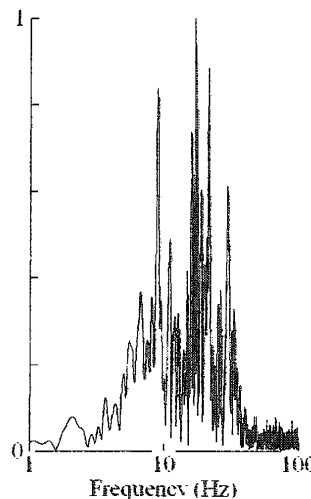
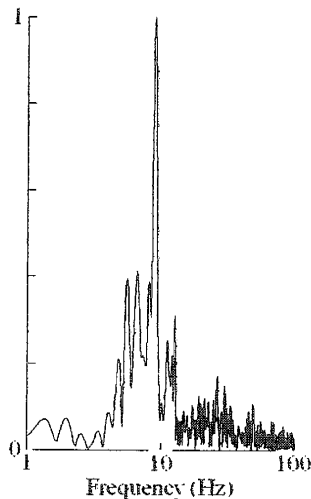
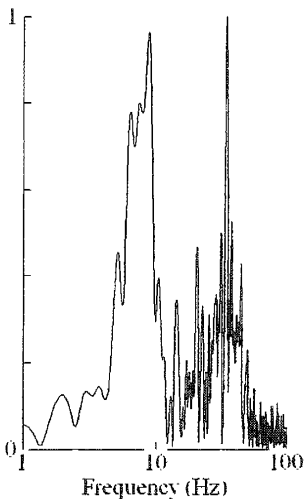
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
**33.50 Hz**

**Radial**  
**8.94 Hz**

**Vertical**  
**17.06 Hz**

**Transverse**  
**11.38 Hz**



**High Mesa  
Exterior Master**

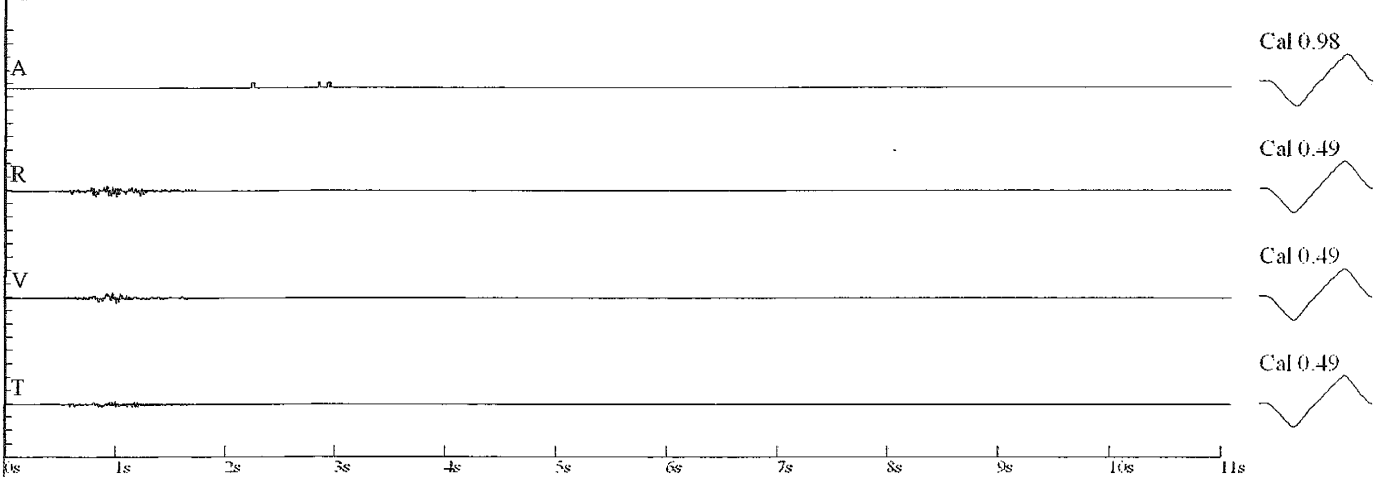
File Name: 01258060.DTB  
 Number: 060  
 Date: 3 18 2005  
 Time: 10:59  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.6

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.025in/s 0.635mm/s @ 36.5Hz  
 Vertical: 0.025in/s 0.635mm/s @ 12.1Hz  
 Transverse: 0.015in/s 0.381mm/s @ 36.5Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



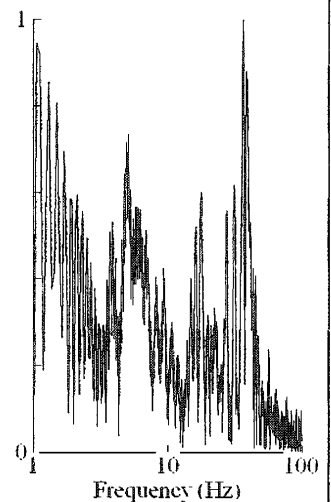
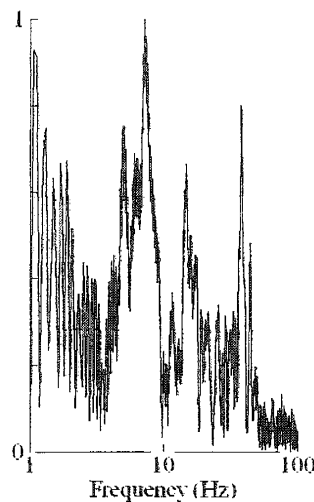
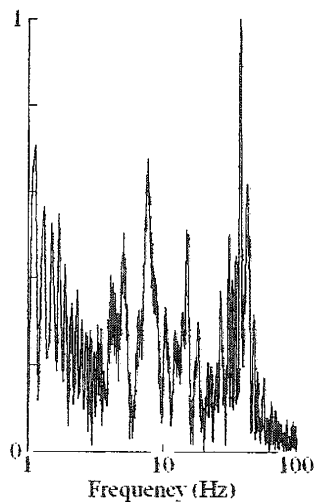
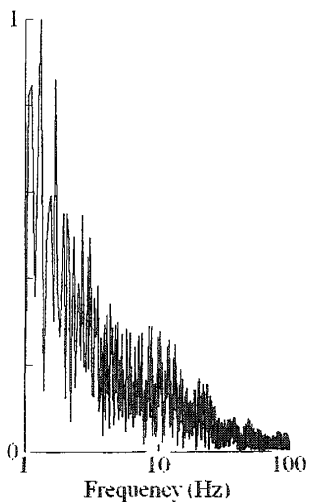
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.31 Hz

Radial  
38.13 Hz

Vertical  
7.31 Hz

Transverse  
36.44 Hz



# High Mesa

## Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

File Name: 00930020.DTB

Number: 020

Date: 3 18 2005

Time: 11:00

Serial Number: 930

Seismic Trigger: 0.0450 in s 1.1430 mm s

Acoustic Trigger: 126 dB

Sample Rate: 512

Record Duration: 10.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.0

### Amplitudes and Frequencies

Acoustic: 106 dB @ 0.0 Hz  
(0.04Mb 0.0006psi 0.0040kPa)

Radial: 0.01in/s 0.254mm/s @ 0.0Hz

Vertical: 0.055in/s 1.397mm/s @ 17.0Hz

Transverse: 0.01in/s 0.254mm/s @ 0.0Hz

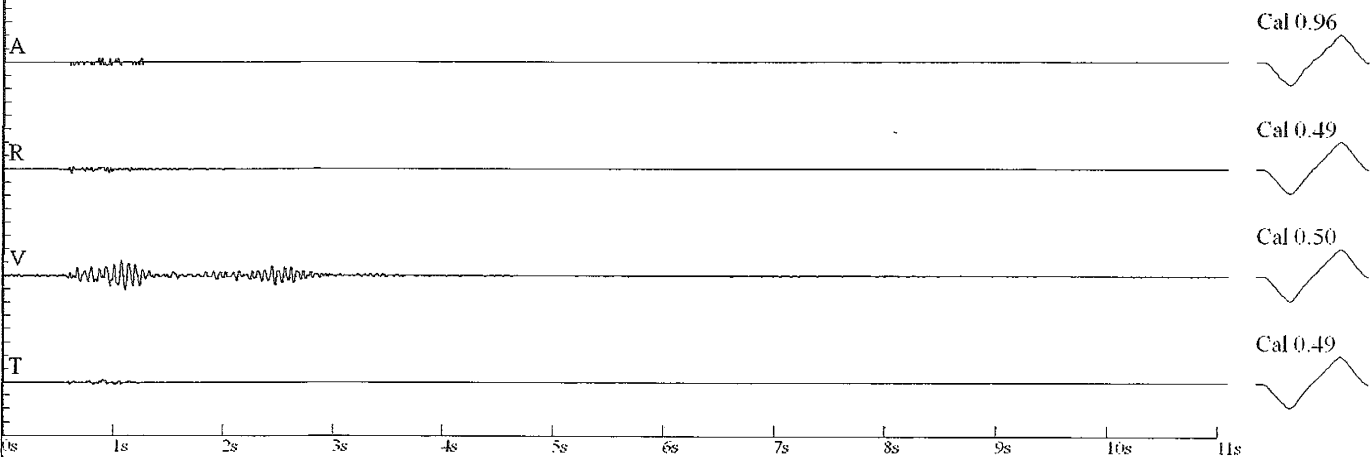
### Graph Information

Duration: 0.000s To: 11.000s

Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)

Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



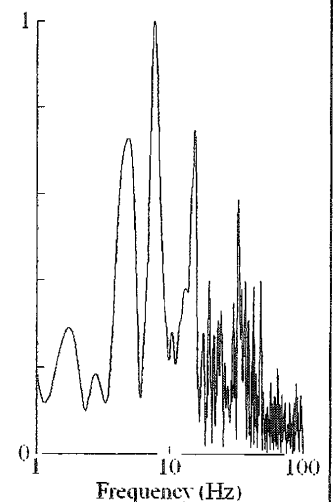
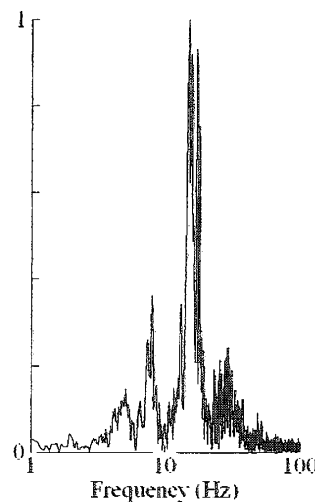
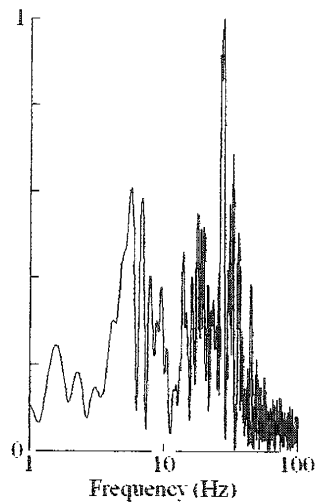
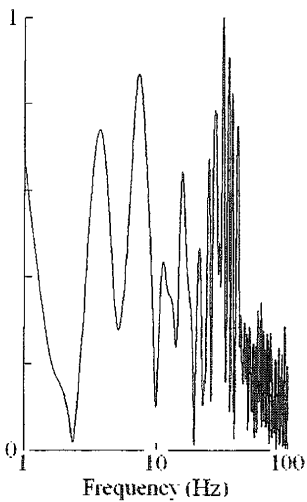
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
31.44 Hz

Radial  
27.81 Hz

Vertical  
14.81 Hz

Transverse  
7.63 Hz



### High Mesa

### Upper corner

V = NE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

File Name: 02276301.DTB

Number: 301

Date: 3 18 2005

Time: 11:00

Serial Number: 2276

Seismic Trigger: 0.0300 in s 0.7620 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 10.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 6.8

### Amplitudes and Frequencies

Acoustic: 112 dB  $\hat{a}$ : 0.0 Hz

(0.08Mb 0.0012psi 0.0080kPa)

Radial: 0.02in/s 0.508mm/s  $\hat{a}$ : 0.0Hz

Vertical: 0.05in/s 1.27mm/s  $\hat{a}$ : 23.2Hz

Transverse: 0.03in/s 0.762mm/s  $\hat{a}$ : 25.6Hz

### Graph Information

Duration: 0.000s To: 11.000s

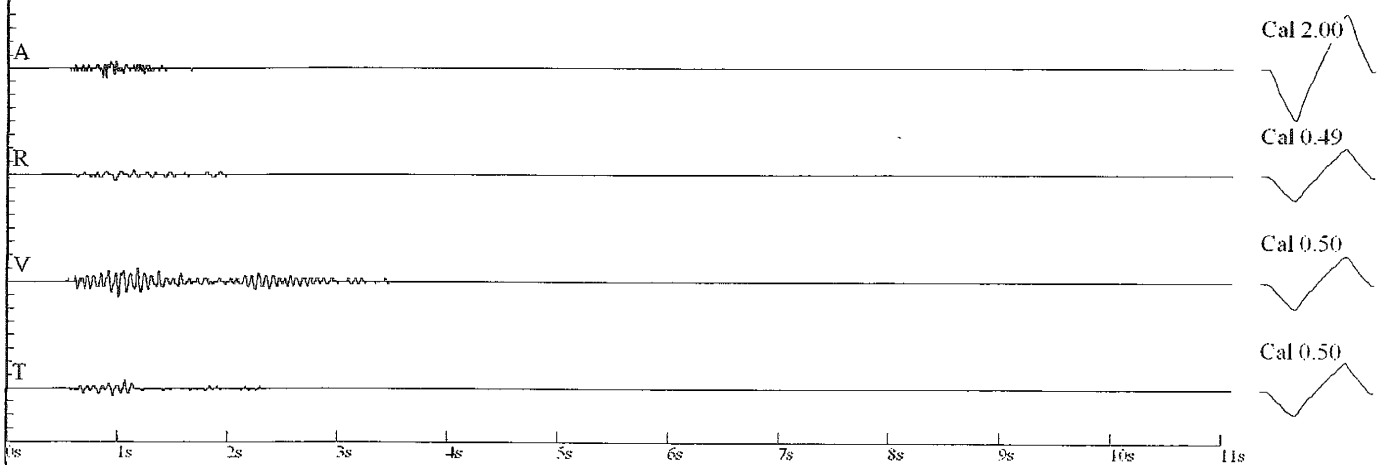
Acoustic Scale:

130dB 0.63Mb (0.158Mb/div)

Seismic Scale:

0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



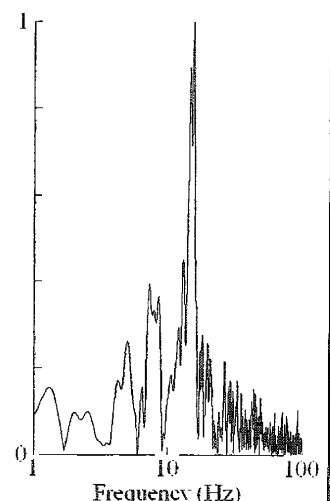
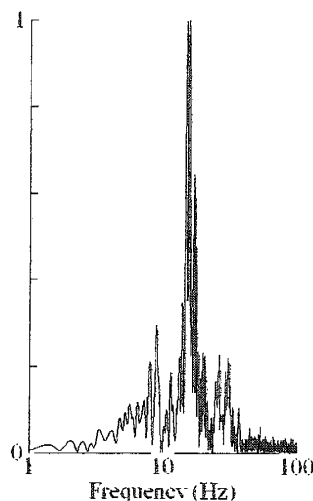
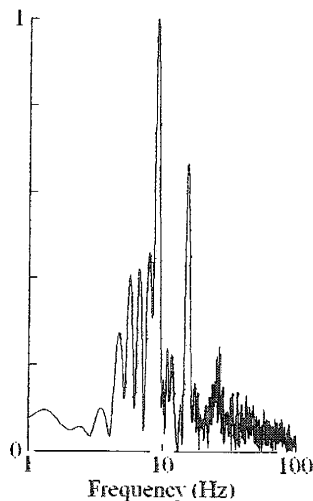
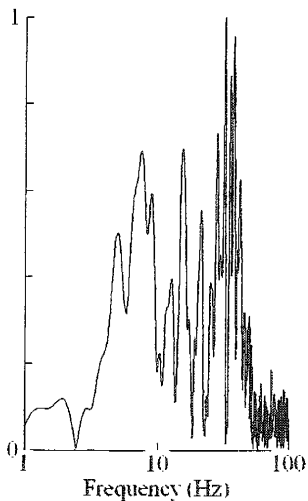
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
31.38 Hz

Radial  
9.00 Hz

Vertical  
15.50 Hz

Transverse  
15.56 Hz



**High Mesa  
Exterior Master**

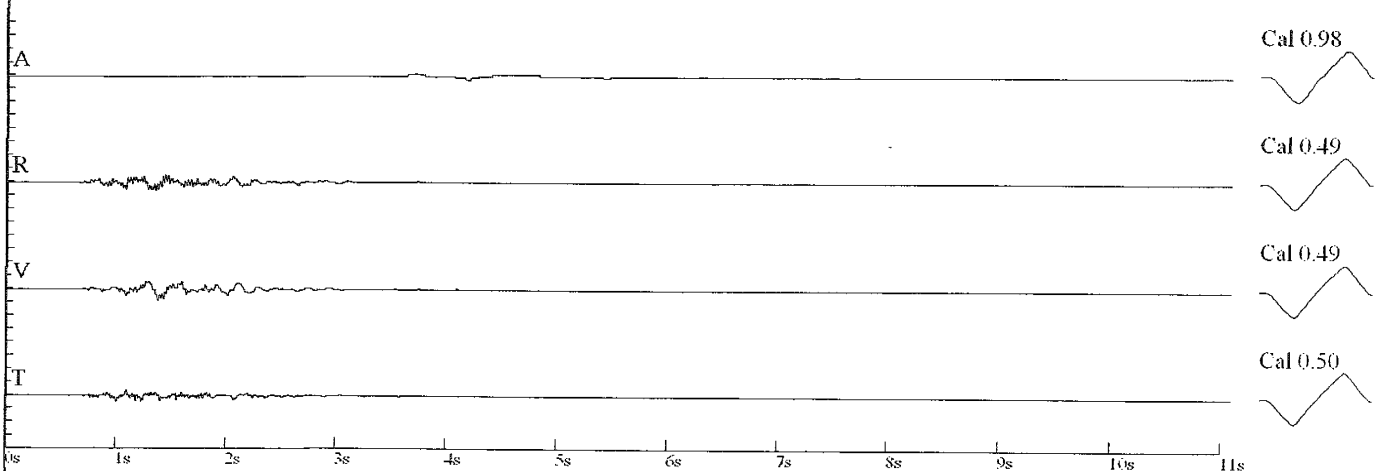
File Name: 01258061.DTB  
 Number: 061  
 Date: 3 18 2005  
 Time: 13:06  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 110 dB  $\bar{a}$ : 1.4 Hz  
 (0.06Mb 0.0009psi 0.0060kPa)  
 Radial: 0.035in/s 0.889mm/s  $\bar{a}$ : 4.4Hz  
 Vertical: 0.045in/s 1.143mm/s  $\bar{a}$ : 4.4Hz  
 Transverse: 0.025in/s 0.635mm/s  $\bar{a}$ : 6.9Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



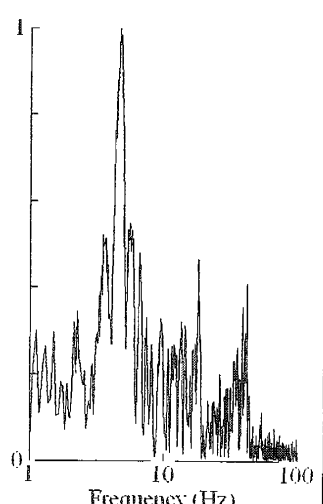
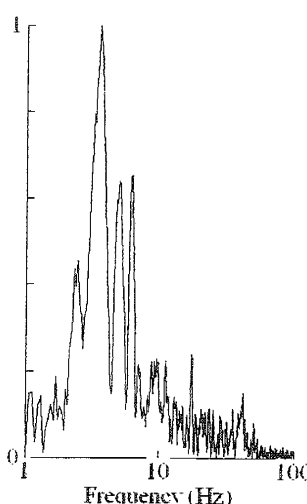
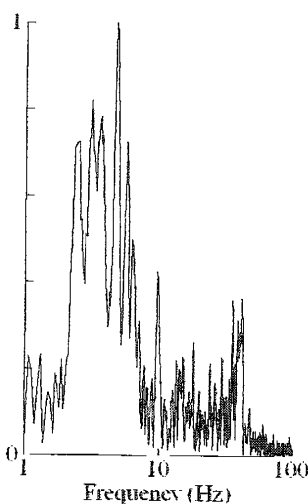
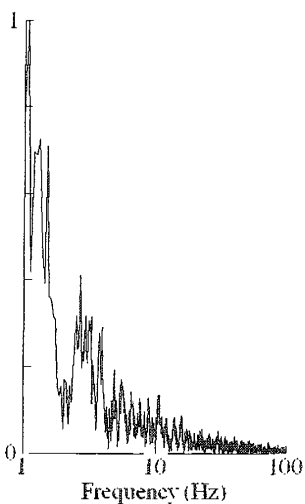
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.06 Hz

Radial  
4.75 Hz

Vertical  
3.56 Hz

Transverse  
4.63 Hz



**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

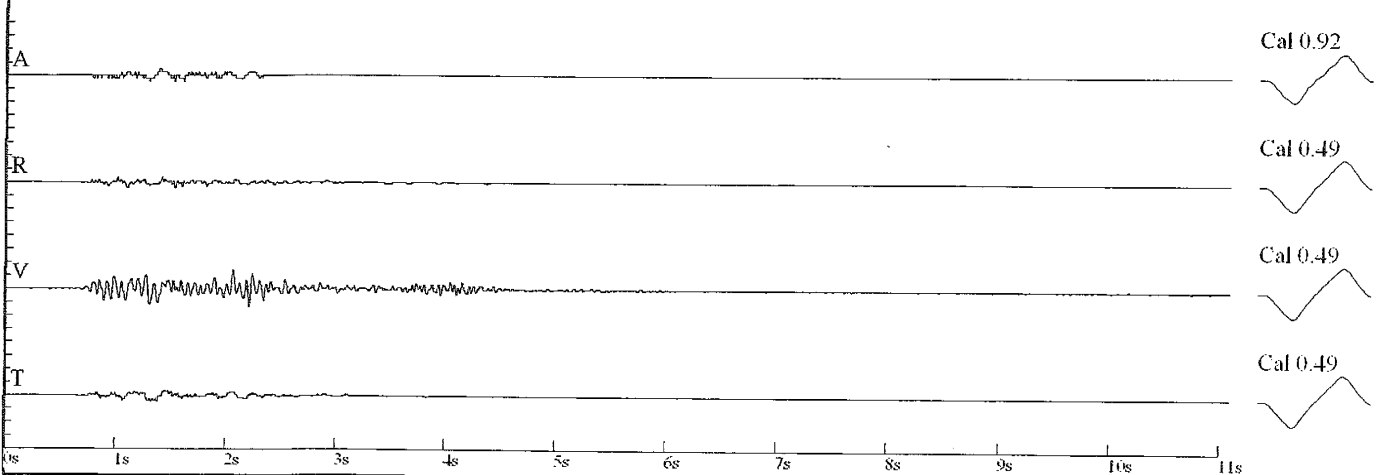
File Name: 00930021.DTB  
 Number: 021  
 Date: 3 18 2005  
 Time: 13:07  
 Serial Number: 930  
 Seismic Trigger: 0.0450 in s 1.1430 mm s  
 Acoustic Trigger: 126 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 112 dB @ 0.0 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.02in/s 0.508mm/s @ 21.3Hz  
 Vertical: **0.07in/s 1.778mm/s @ 14.2Hz**  
 Transverse: 0.025in/s 0.635mm/s @ 3.7Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



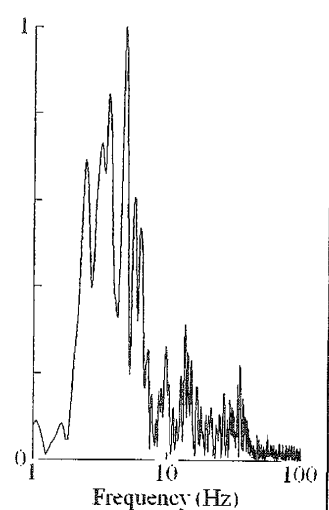
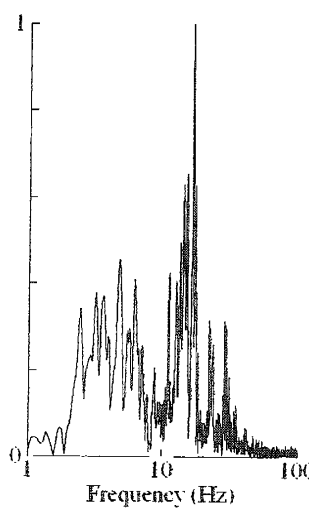
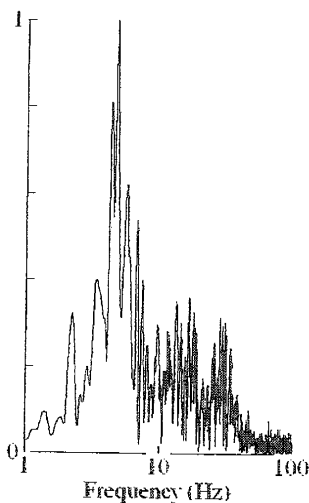
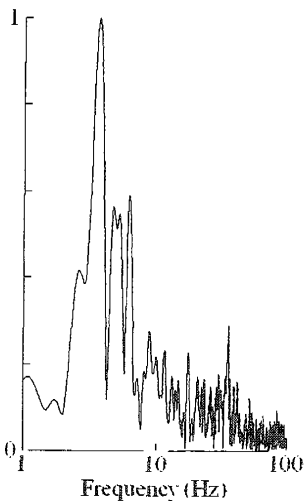
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
3.63 Hz

Radial  
4.75 Hz

Vertical  
16.81 Hz

Transverse  
4.81 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

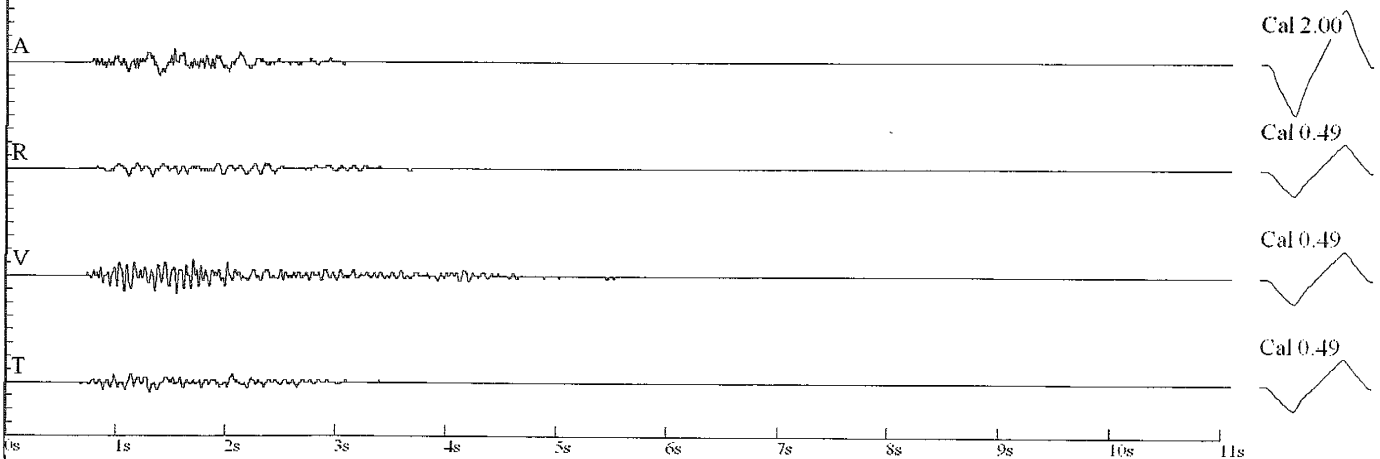
File Name: 02276302.DTB  
 Number: 302  
 Date: 3 18 2005  
 Time: 13:06  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 118 dB @ 25.6 Hz  
 (0.16Mb 0.0023psi 0.0160kPa)  
 Radial: 0.03in/s 0.762mm/s @ 12.8Hz  
 Vertical: 0.07in/s 1.778mm/s @ 21.3Hz  
 Transverse: 0.04in/s 1.016mm/s @ 9.4Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



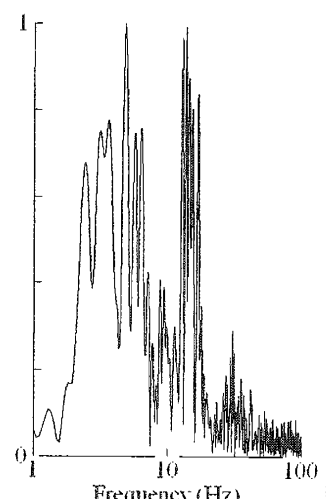
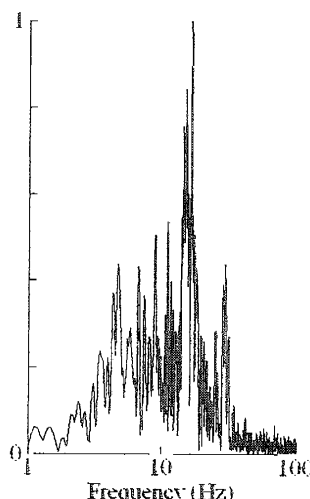
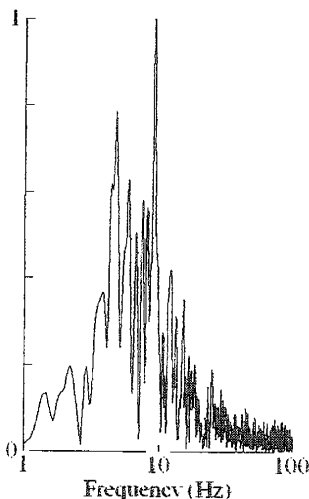
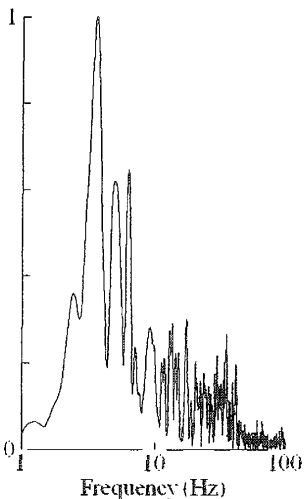
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
3.56 Hz

Radial  
9.13 Hz

Vertical  
16.69 Hz

Transverse  
4.75 Hz





**High Mesa  
Exterior Master**

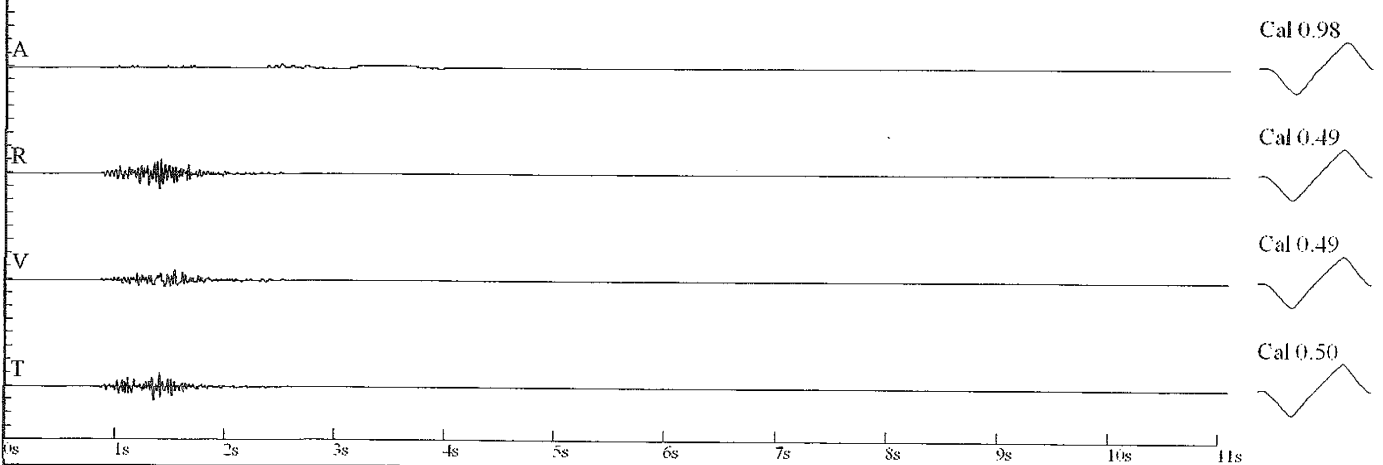
File Name: 01258063.DTB  
 Number: 063  
 Date: 3 21 2005  
 Time: 11:04  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 106 dB  $\bar{a}$ : 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
*Radial:* 0.06in/s 1.524mm/s  $\bar{a}$ : 32.0Hz  
*Vertical:* 0.035in/s 0.889mm/s  $\bar{a}$ : 28.4Hz  
*Transverse:* 0.055in/s 1.397mm/s  $\bar{a}$ : 23.2Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



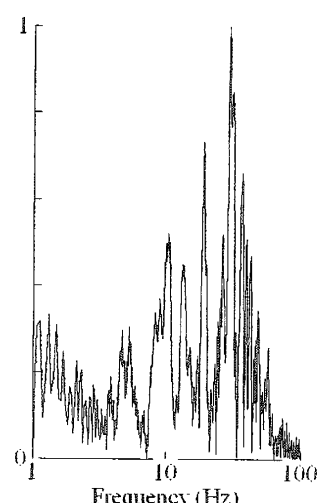
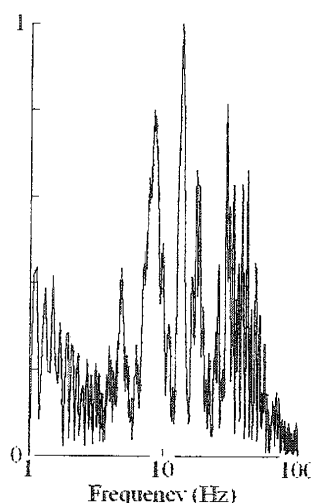
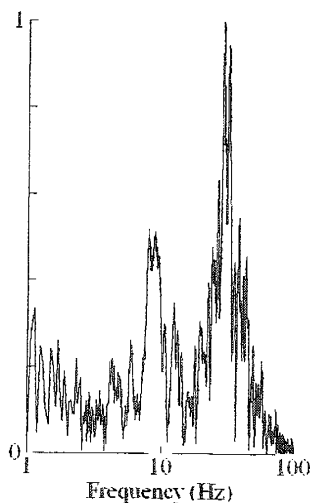
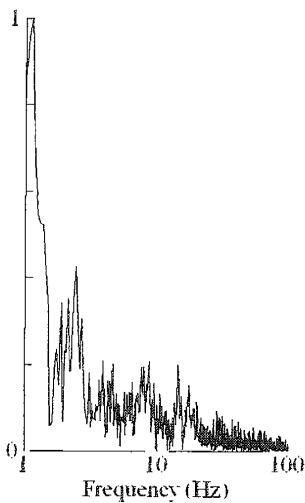
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
1.13 Hz

**Radial**  
28.94 Hz

**Vertical**  
13.69 Hz

**Transverse**  
29.19 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

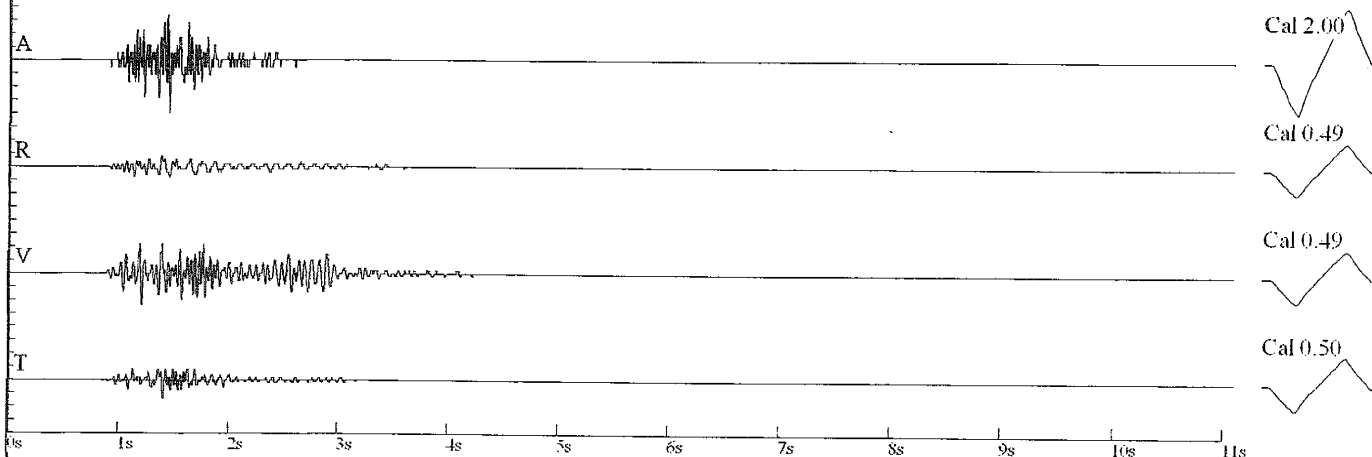
File Name: 02276304.DTB  
 Number: 304  
 Date: 3 21 2005  
 Time: 11:05  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 123 dB @ 25.6 Hz  
 (0.28Mb 0.0041psi 0.0280kPa)  
*Radial:* 0.04in/s 1.016mm/s @ 10.6Hz  
*Vertical:* **0.12in/s 3.048mm/s @ 21.3Hz**  
*Transverse:* 0.07in/s 1.778mm/s @ 25.6Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 123dB 0.28Mb (0.071Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



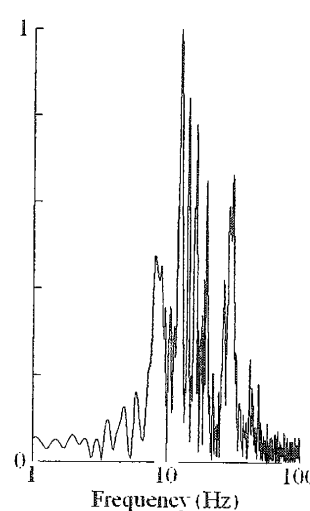
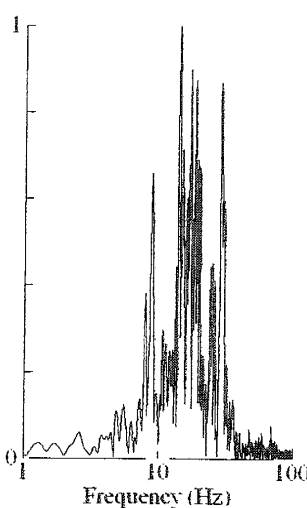
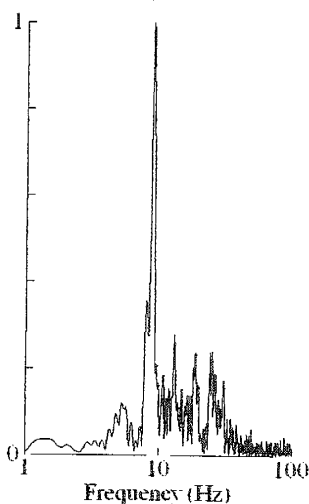
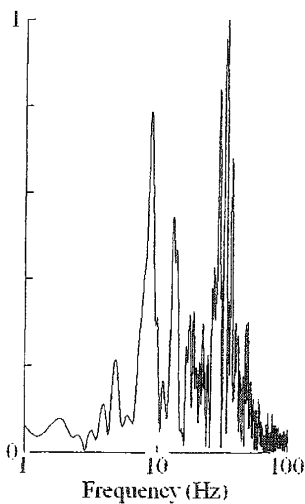
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
**32.69 Hz**

**Radial**  
**8.88 Hz**

**Vertical**  
**14.06 Hz**

**Transverse**  
**12.63 Hz**



**High Mesa  
Exterior Master**

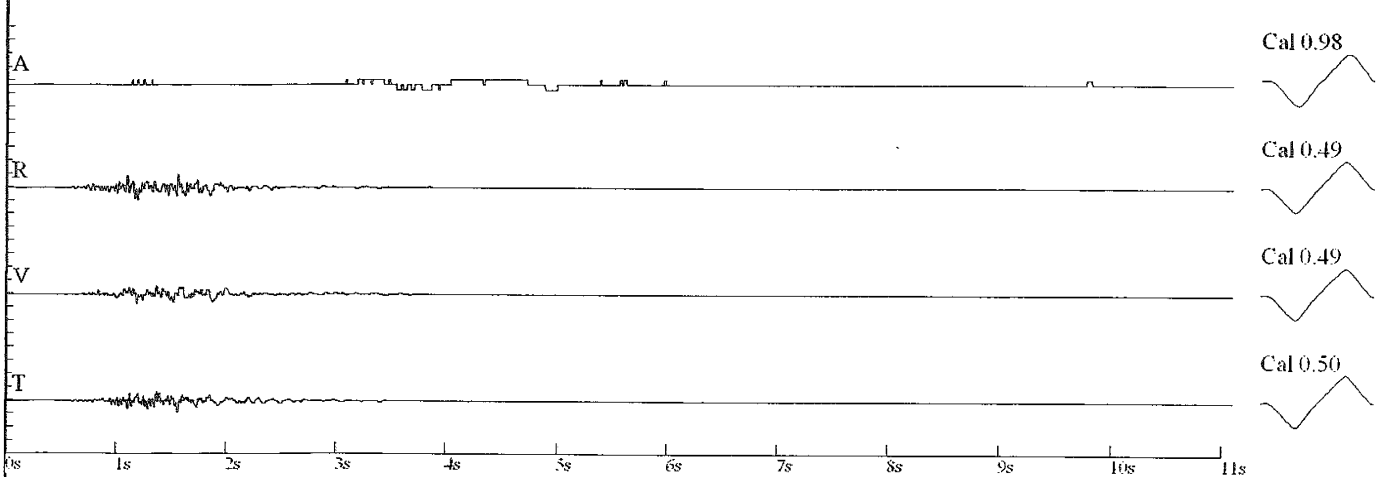
File Name: 01258064.DTB  
 Number: 064  
 Date: 3 22 2005  
 Time: 12:35  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.05in/s 1.27mm/s @ 7.3Hz  
 Vertical: 0.04in/s 1.016mm/s @ 5.4Hz  
 Transverse: 0.05in/s 1.27mm/s @ 10.6Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



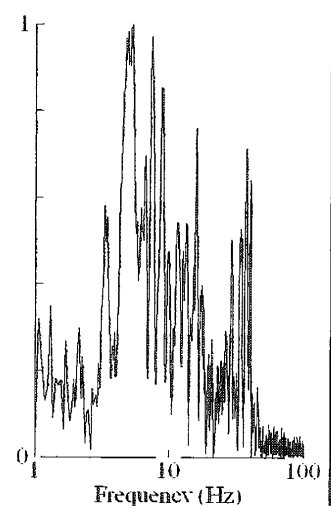
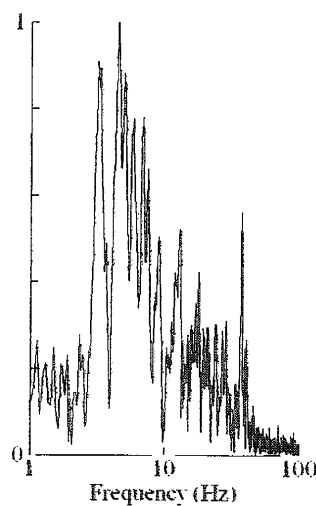
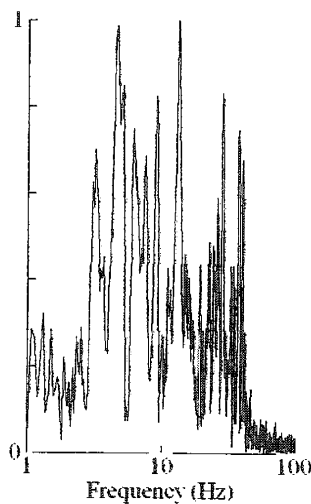
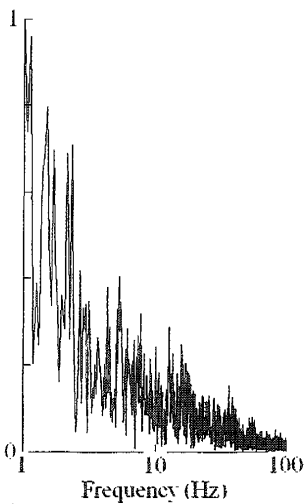
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.00 Hz

Radial  
13.13 Hz

Vertical  
4.50 Hz

Transverse  
5.31 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

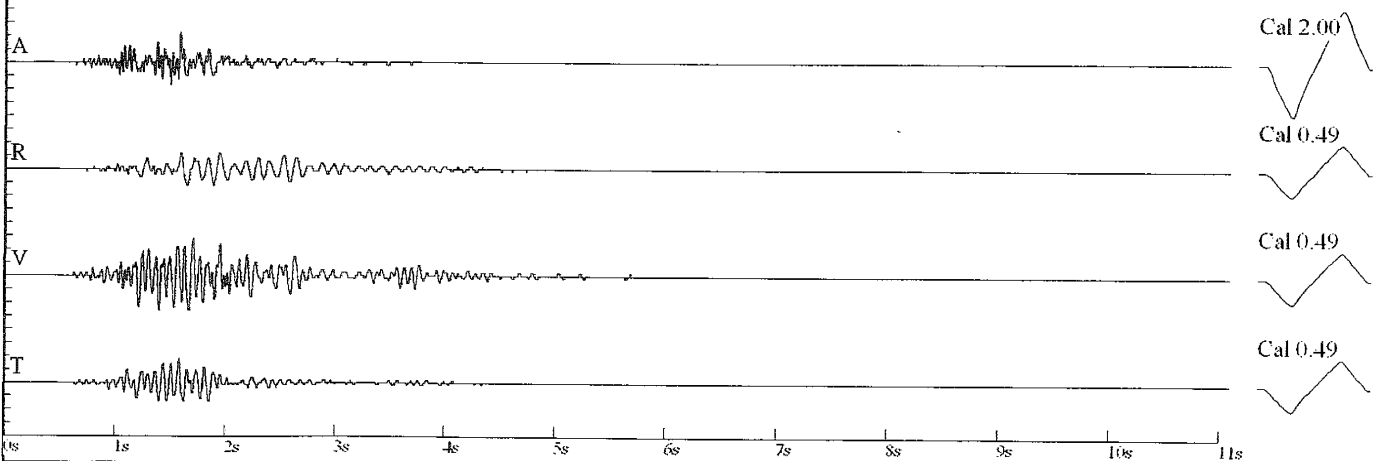
File Name: 02276305.DTB  
 Number: 305  
 Date: 3 22 2005  
 Time: 12:36  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 125 dB @ 11.1 Hz  
 (0.36Mb 0.0052psi 0.0360kPa)  
 Radial: 0.06in/s 1.524mm/s @ 11.6Hz  
 Vertical: 0.14in/s 3.556mm/s @ 14.2Hz  
 Transverse: 0.09in/s 2.286mm/s @ 15.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



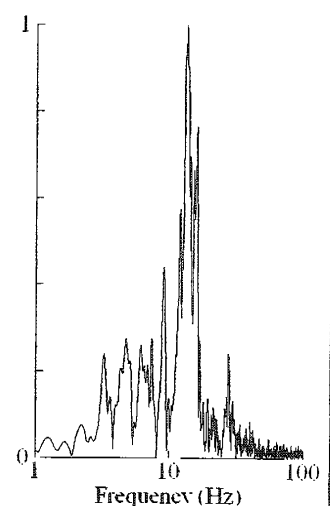
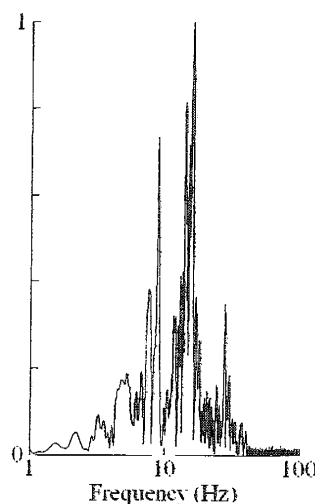
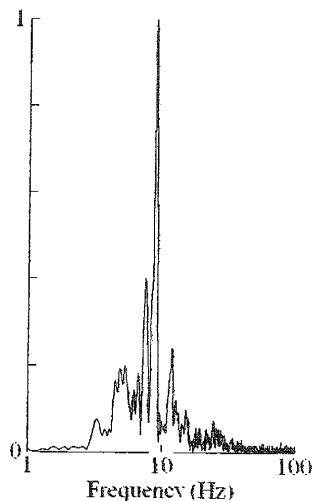
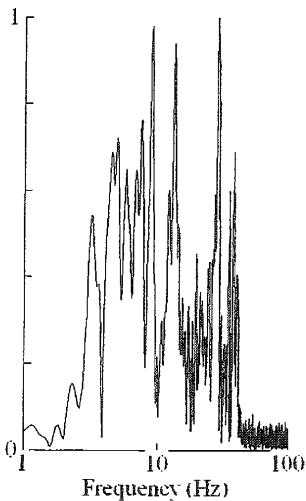
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
28.19 Hz

Radial  
8.88 Hz

Vertical  
16.06 Hz

Transverse  
13.38 Hz



**High Mesa  
Exterior Master**

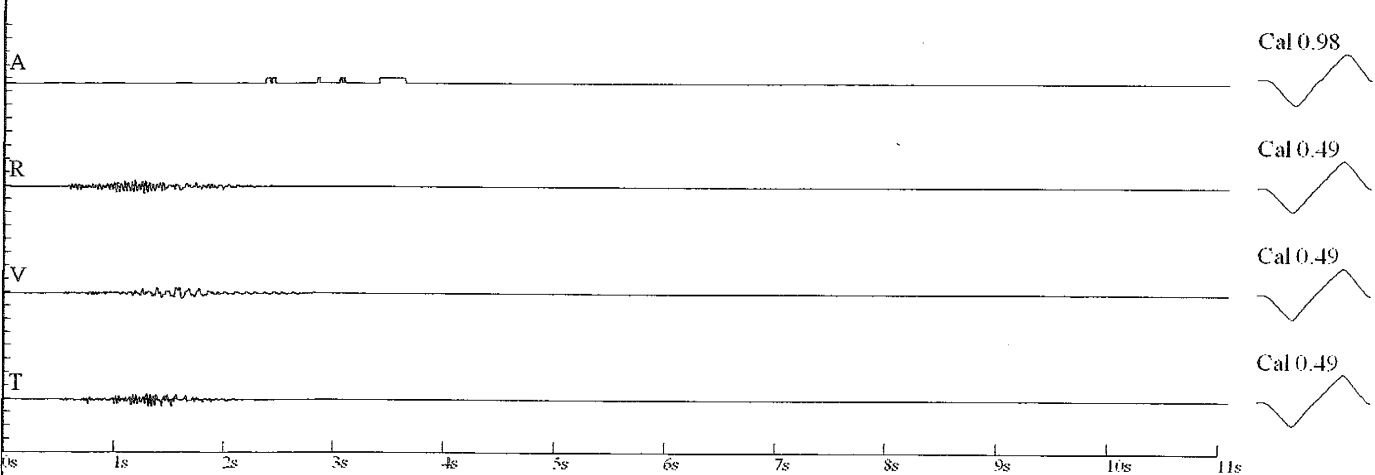
File Name: 01258082.DTB  
 Number: 082  
 Date: 3 25 2005  
 Time: 11:00  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 100 dB  $\bar{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.03in/s 0.762mm/s  $\bar{a}$ : 32.0Hz  
 Vertical: 0.025in/s 0.635mm/s  $\bar{a}$ : 11.1Hz  
 Transverse: 0.03in/s 0.762mm/s  $\bar{a}$ : 28.4Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



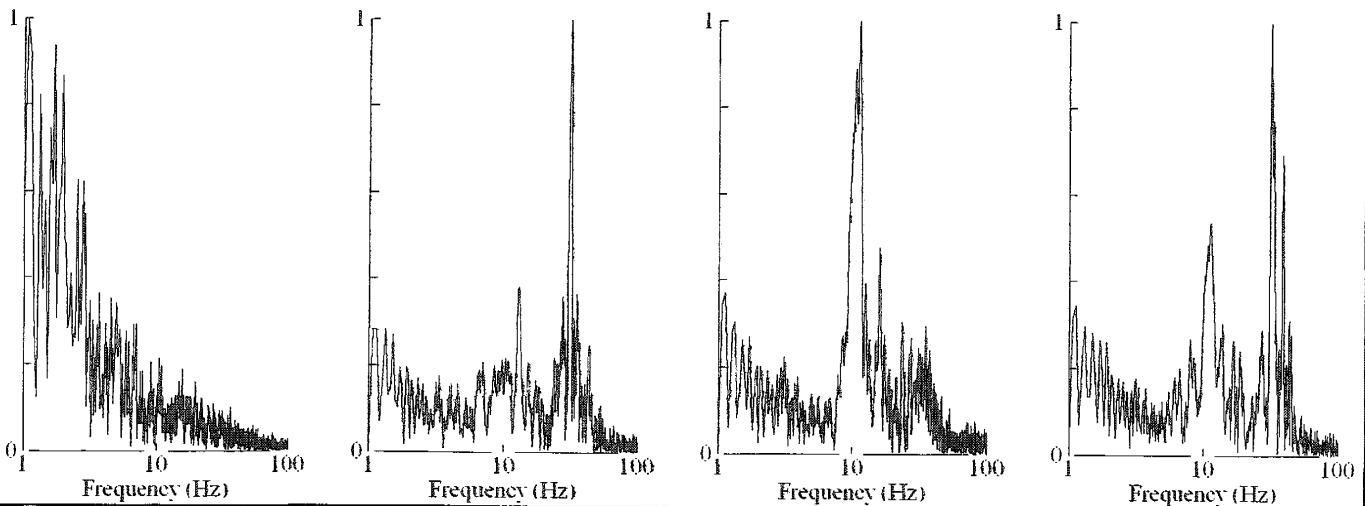
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.06 Hz

Radial  
31.75 Hz

Vertical  
11.44 Hz

Transverse  
31.69 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

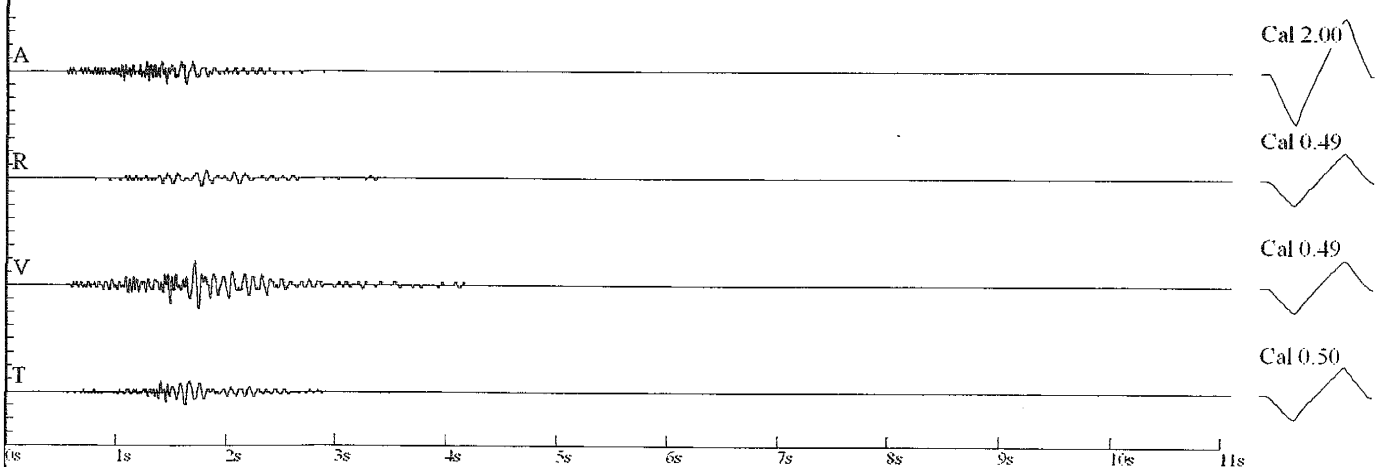
File Name: 02276323.DTB  
 Number: 323  
 Date: 3 25 2005  
 Time: 11:01  
 Serial Number: 2276  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 118 dB ( $\bar{a}$ : 28.4 Hz  
 (0.16Mb 0.0023psi 0.0160kPa)  
*Radial:* 0.03in/s 0.762mm/s ( $\bar{a}$ : 17.0Hz  
*Vertical:* **0.09in/s 2.286mm/s** ( $\bar{a}$ : **15.0Hz**  
*Transverse:* 0.05in/s 1.27mm/s ( $\bar{a}$ : 16.0Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



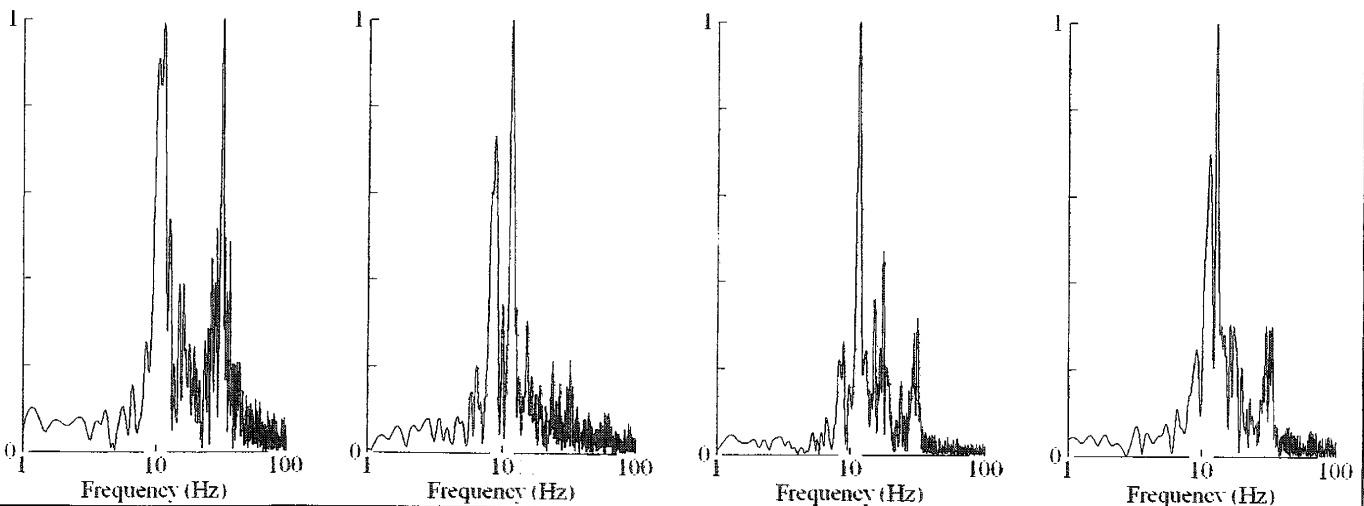
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
**31.75 Hz**

**Radial**  
**11.50 Hz**

**Vertical**  
**11.56 Hz**

**Transverse**  
**12.88 Hz**



**High Mesa  
Exterior Master**

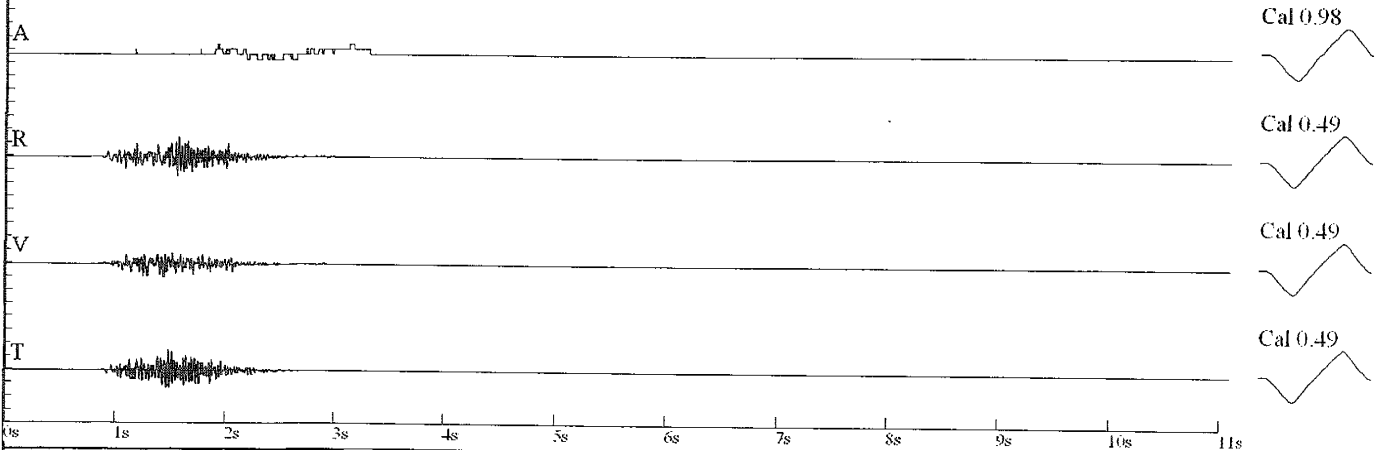
File Name: 01258001.DTB  
 Number: 001  
 Date: 4 8 2005  
 Time: 11:18  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 106 dB ( $\dot{a}$ : 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
*Radial:* 0.075in/s 1.905mm/s ( $\dot{a}$ : 32.0Hz  
*Vertical:* 0.055in/s 1.397mm/s ( $\dot{a}$ : 25.6Hz  
*Transverse:* 0.07in/s 1.778mm/s ( $\dot{a}$ : 42.6Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 120dB 0.20Mb (0.050Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



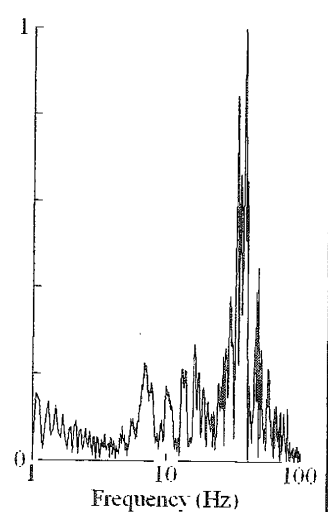
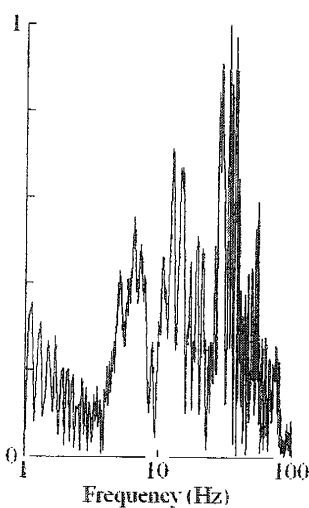
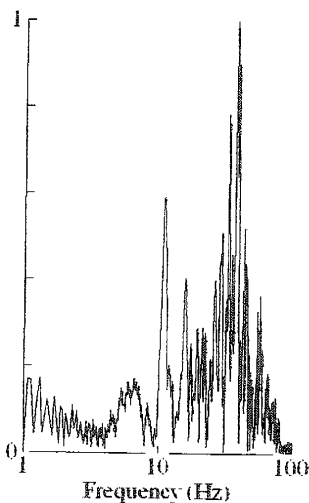
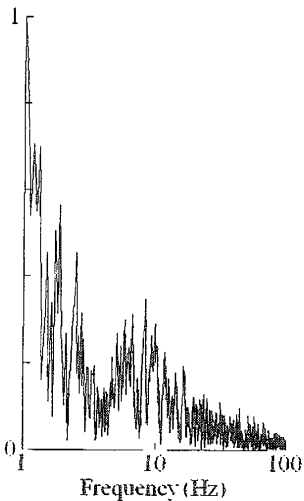
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
1.00 Hz

**Radial**  
37.88 Hz

**Vertical**  
33.50 Hz

**Transverse**  
37.63 Hz



**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

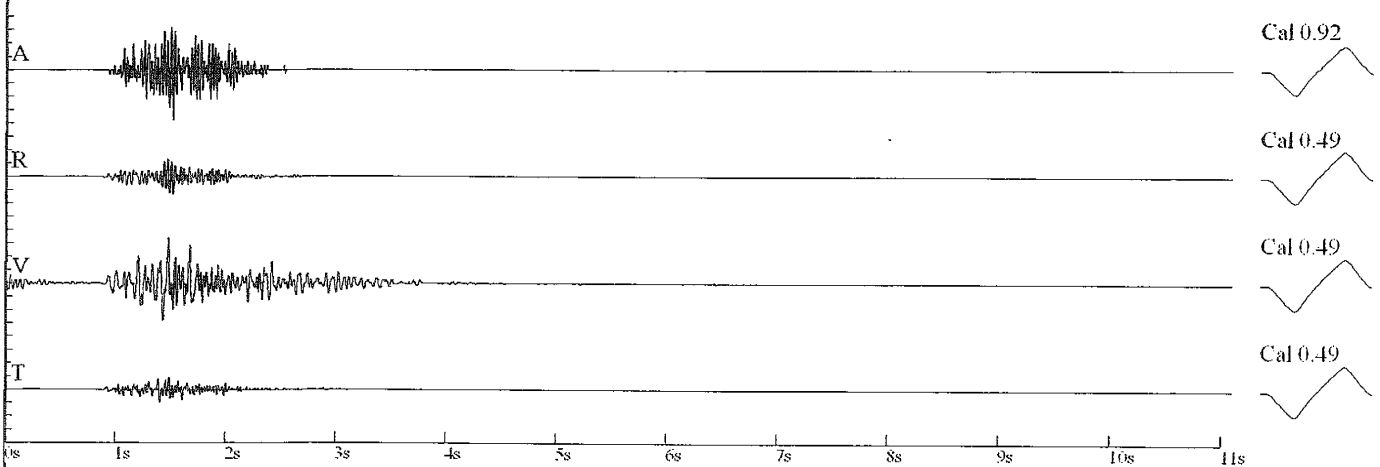
File Name: 00930004.DTB  
 Number: 004  
 Date: 4 8 2005  
 Time: 11:18  
 Serial Number: 930  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 124 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 122 dB  $\hat{a}$ : 32.0 Hz  
 (0.24Mb 0.0035psi 0.0240kPa)  
 Radial: 0.065in/s 1.651mm/s  $\hat{a}$ : 32.0Hz  
 Vertical: 0.17in/s 4.318mm/s  $\hat{a}$ : 21.3Hz  
 Transverse: 0.05in/s 1.27mm/s  $\hat{a}$ : 21.3Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 122dB 0.25Mb (0.063Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



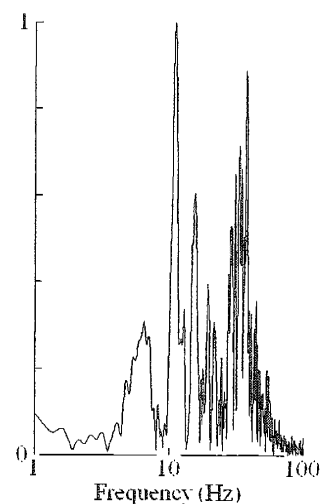
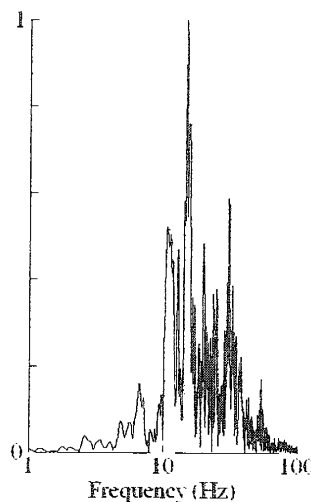
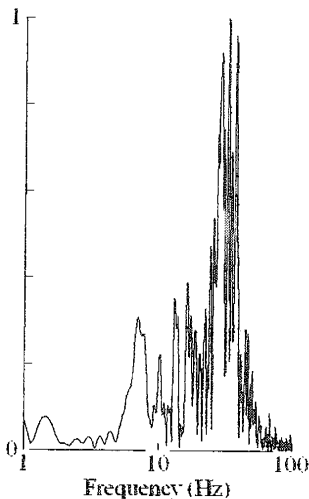
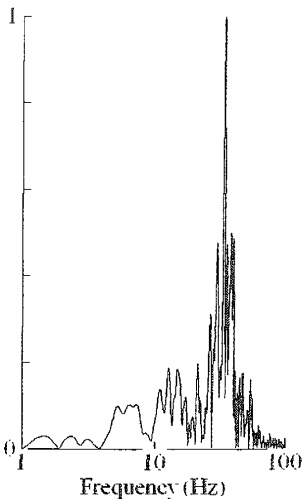
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
33.44 Hz

Radial  
33.06 Hz

Vertical  
14.94 Hz

Transverse  
11.00 Hz





**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**Transvers component feel from corner**  
**as a result of high winds**

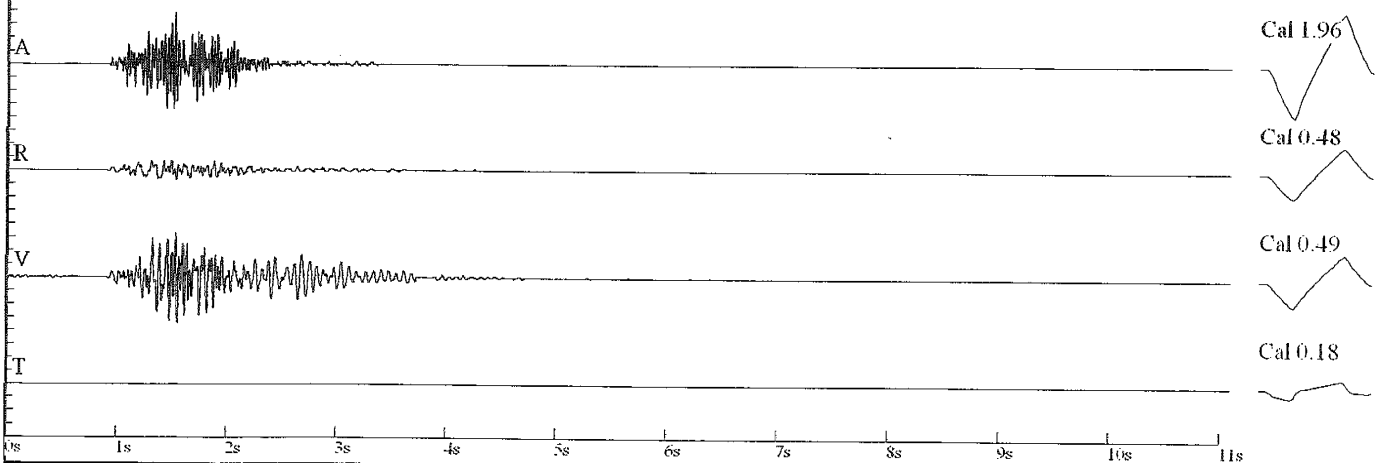
File Name: 02276003.DTB  
 Number: 003  
 Date: 4 8 2005  
 Time: 11:18  
 Serial Number: 2276  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 117 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

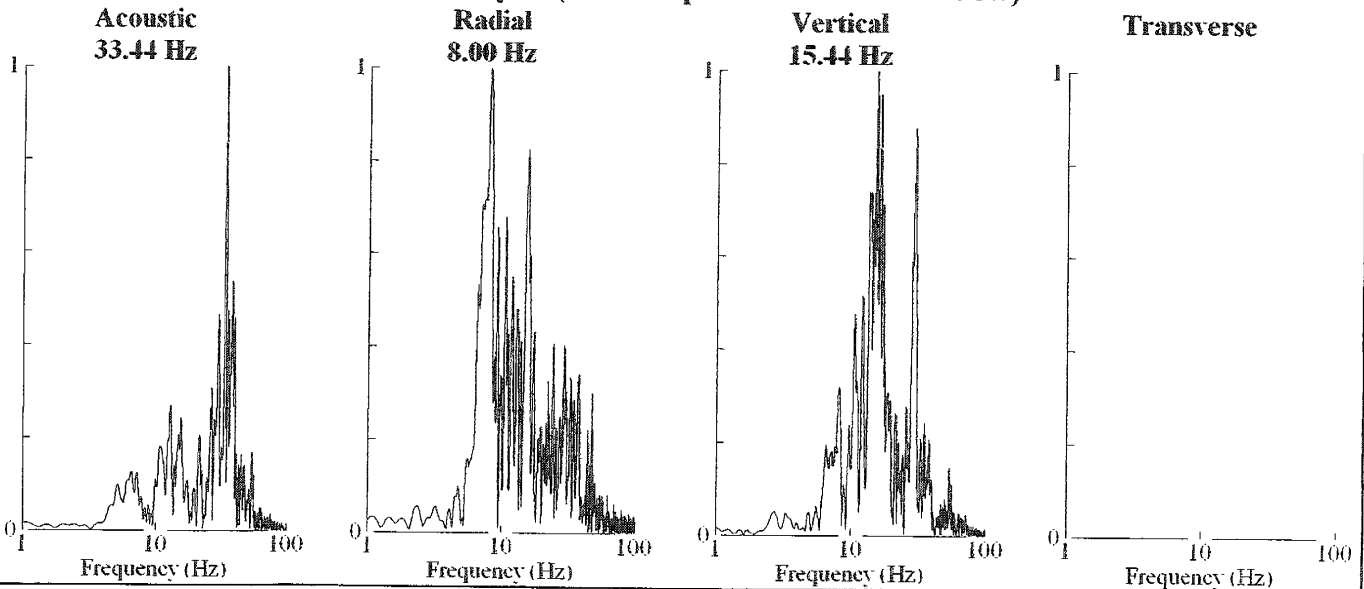
Acoustic: 128 dB  $\hat{a}$ : 32.0 Hz  
 (0.48Mb 0.0070psi 0.0480kPa)  
 Radial: 0.035in/s 0.889mm/s  $\hat{a}$ : 8.2Hz  
 Vertical: 0.17in/s 4.318mm/s  $\hat{a}$ : 23.2Hz  
 Transverse: 0.00in/s 0.00mm/s  $\hat{a}$ : 0.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 128dB 0.50Mb (0.126Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**



**High Mesa  
Exterior Master**

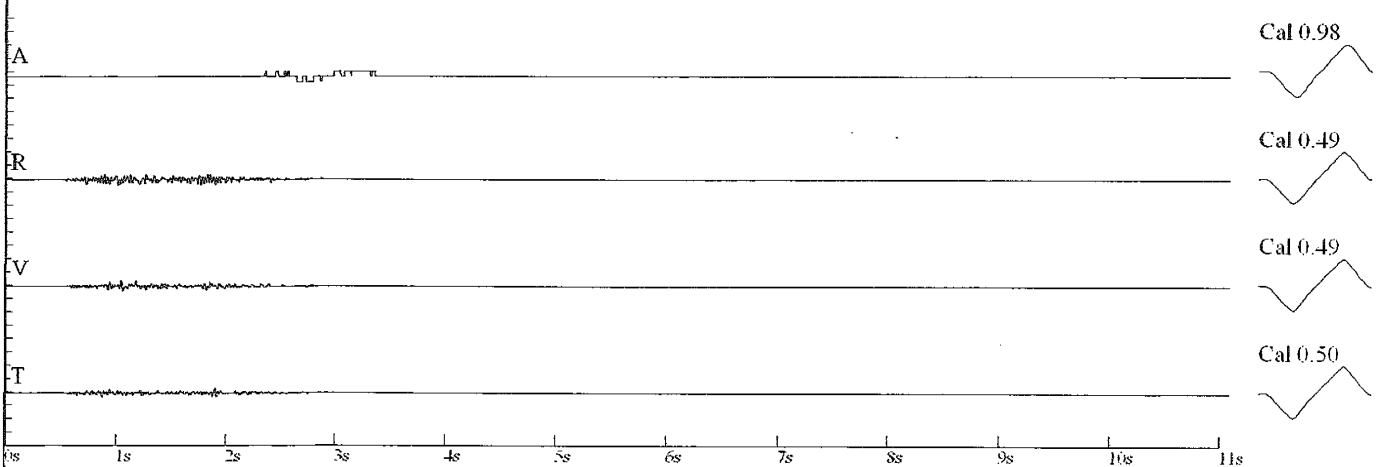
File Name: 01258022.DTB  
 Number: 022  
 Date: 4 12 2005  
 Time: 14:21  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.025in/s 0.635mm/s @ 12.8Hz  
 Vertical: 0.025in/s 0.635mm/s @ 8.5Hz  
 Transverse: 0.02in/s 0.508mm/s @ 32.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



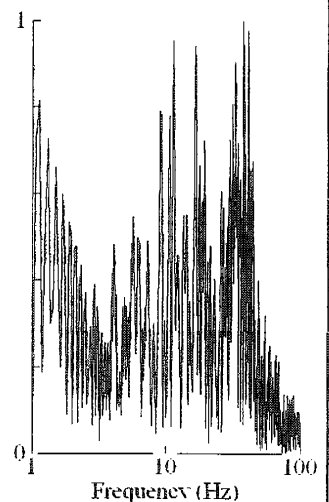
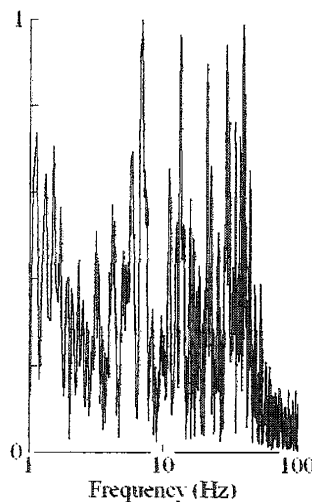
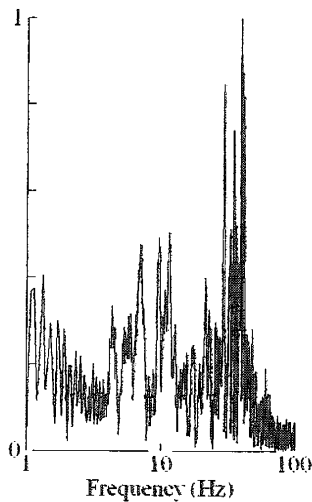
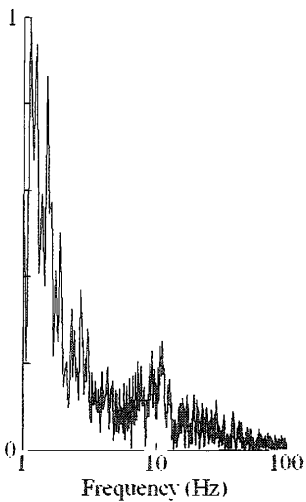
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.13 Hz

Radial  
39.13 Hz

Vertical  
6.88 Hz

Transverse  
37.25 Hz



# High Mesa

## Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

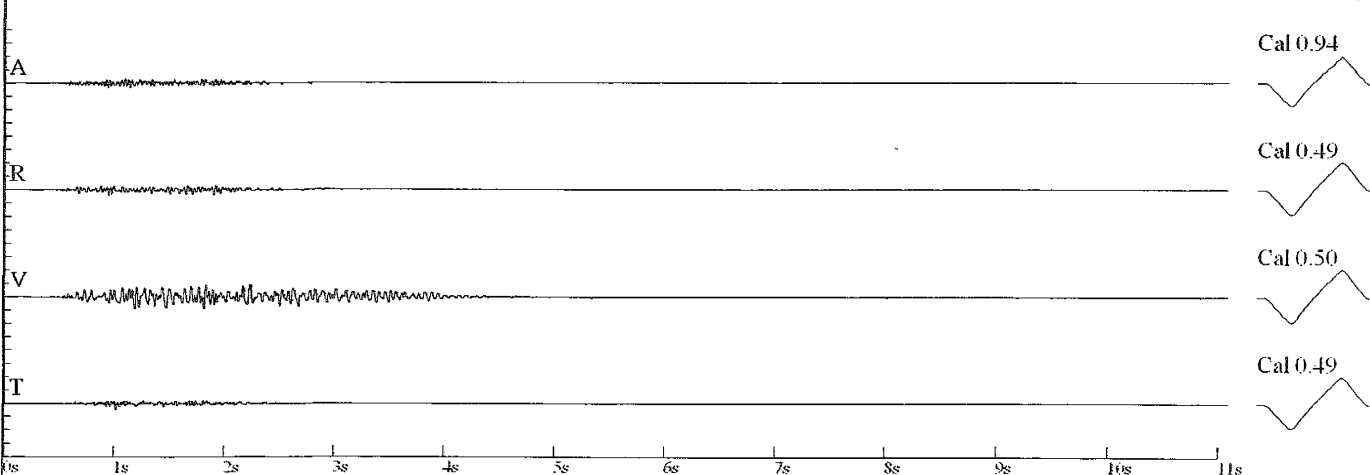
File Name: 00930024.DTB  
Number: 024  
Date: 4 12 2005  
Time: 14:21  
Serial Number: 930  
Seismic Trigger: 0.0300 in s 0.7620 mm s  
Acoustic Trigger: 124 dB  
Sample Rate: 512  
Record Duration: 10.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.0

### Amplitudes and Frequencies

Acoustic: 110 dB @ 36.5 Hz  
(0.06Mb 0.0009psi 0.0060kPa)  
Radial: 0.02in/s 0.508mm/s @ 36.5Hz  
Vertical: 0.045in/s 1.143mm/s @ 23.2Hz  
Transverse: 0.025in/s 0.635mm/s @ 28.4Hz

### Graph Information

Duration: 0.000s To: 11.000s  
Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



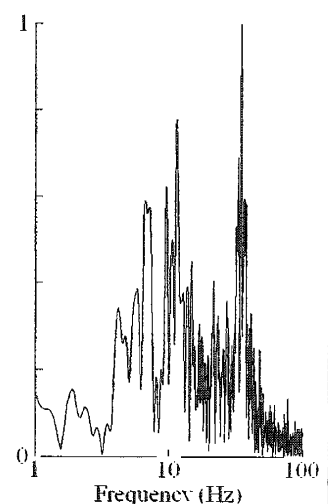
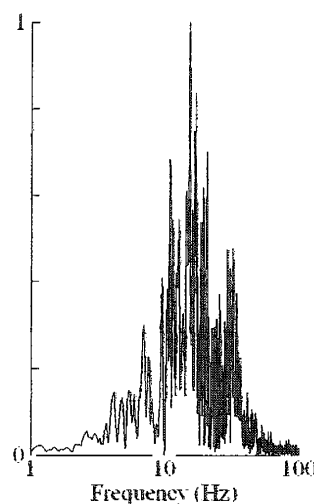
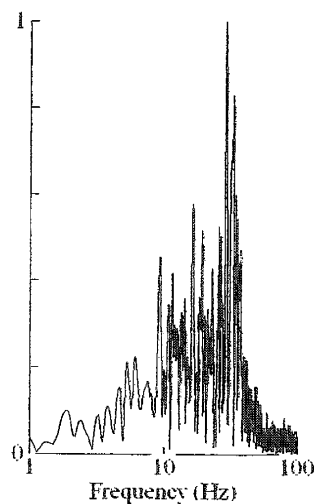
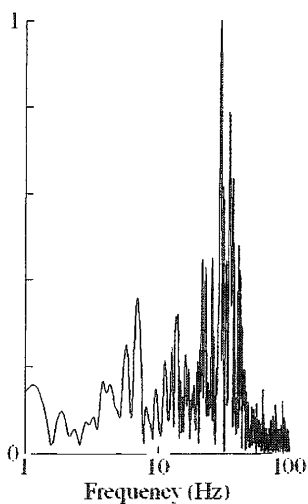
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
29.38 Hz

Radial  
29.06 Hz

Vertical  
15.38 Hz

Transverse  
34.44 Hz



# High Mesa

## Upper corner

V = NE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

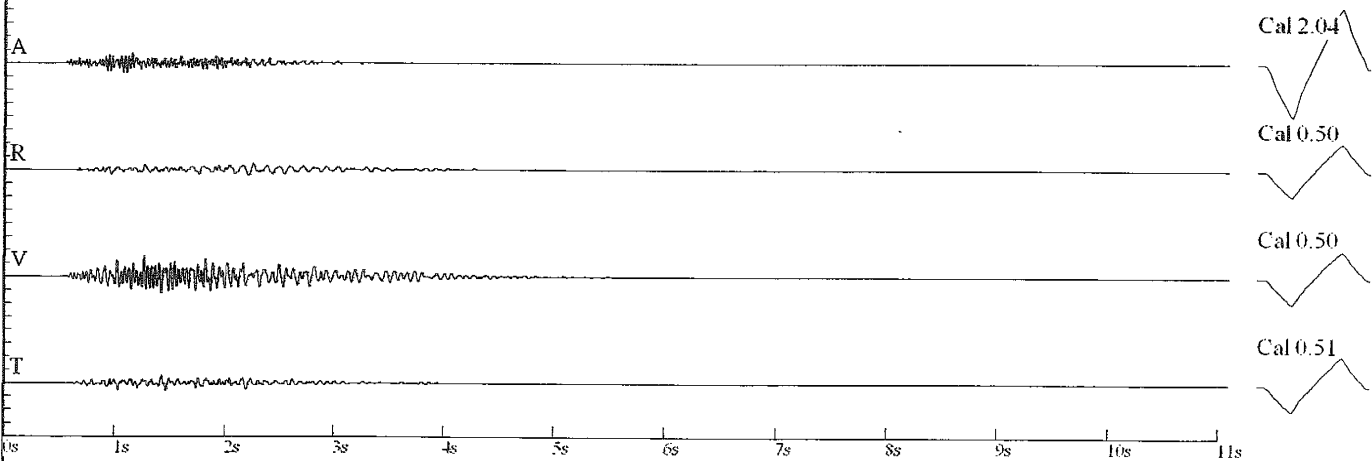
File Name: 02276023.DTB  
Number: 023  
Date: 4 12 2005  
Time: 14:21  
Serial Number: 2276  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 117 dB  
Sample Rate: 512  
Record Duration: 10.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

### Amplitudes and Frequencies

Acoustic: 116 dB @ 32.0 Hz  
(0.12Mb 0.0017psi 0.0120kPa)  
Radial: 0.025in/s 0.635mm/s @ 14.2Hz  
Vertical: 0.08in/s 2.032mm/s @ 23.2Hz  
Transverse: 0.03in/s 0.762mm/s @ 21.3Hz

### Graph Information

Duration: 0.000s To: 11.000s  
Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



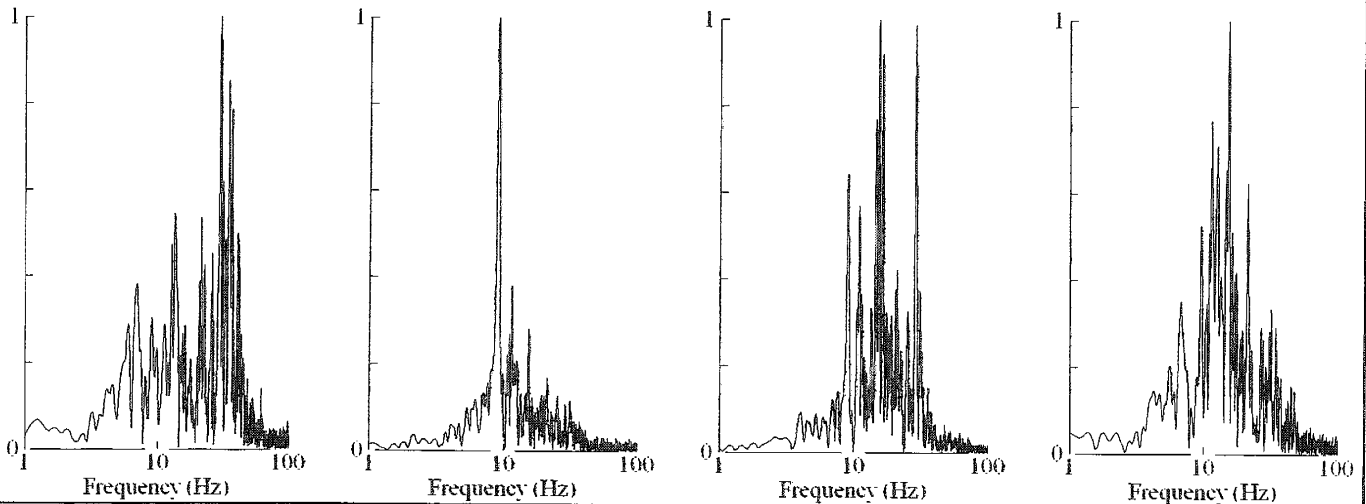
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
29.44 Hz

Radial  
9.06 Hz

Vertical  
15.38 Hz

Transverse  
15.38 Hz



**High Mesa  
Exterior Master**

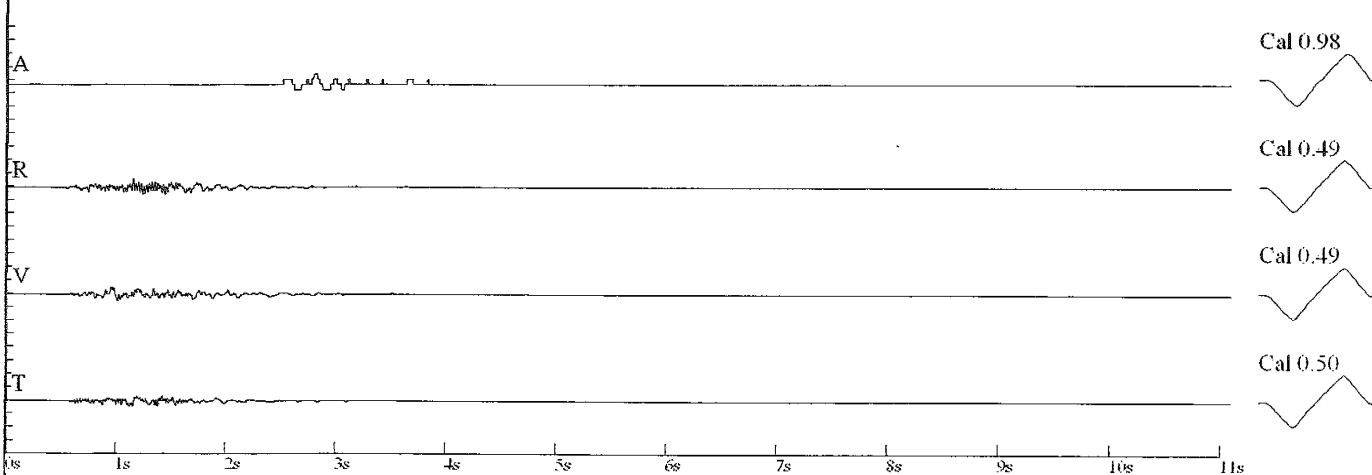
File Name: 01258023.DTB  
 Number: 023  
 Date: 4 13 2005  
 Time: 15:39  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.03in/s 0.762mm/s @ 36.5Hz  
 Vertical: 0.03in/s 0.762mm/s @ 6.5Hz  
 Transverse: 0.025in/s 0.635mm/s @ 7.3Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



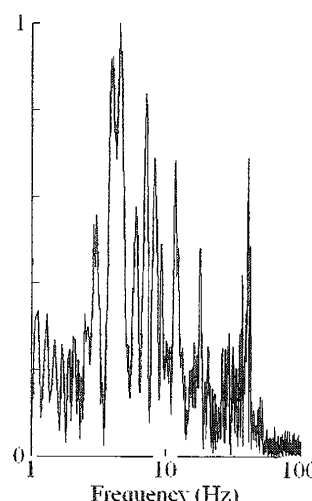
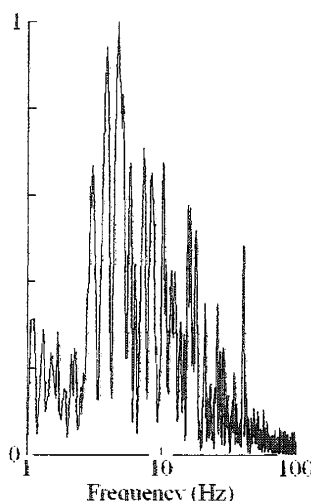
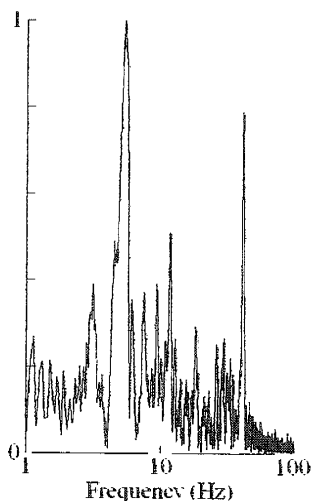
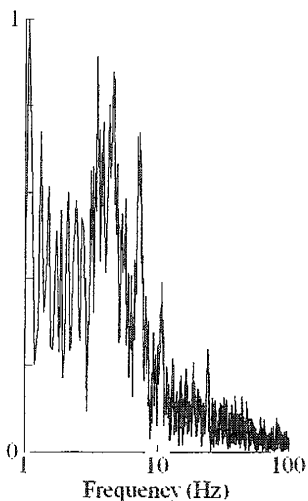
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.06 Hz

Radial  
5.38 Hz

Vertical  
4.75 Hz

Transverse  
4.56 Hz



**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

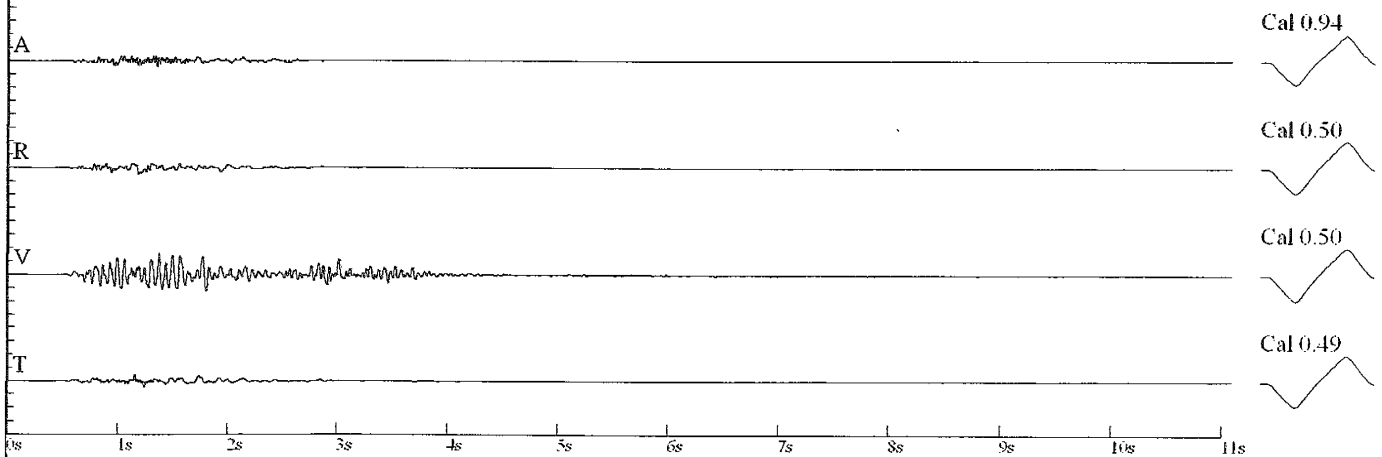
File Name: 00930025.DTB  
 Number: 025  
 Date: 4 13 2005  
 Time: 15:40  
 Serial Number: 930  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 124 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 112 dB @ 42.6 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.025in/s 0.635mm/s @ 5.9Hz  
 Vertical: 0.08in/s 2.032mm/s @ 19.6Hz  
 Transverse: 0.025in/s 0.635mm/s @ 25.6Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



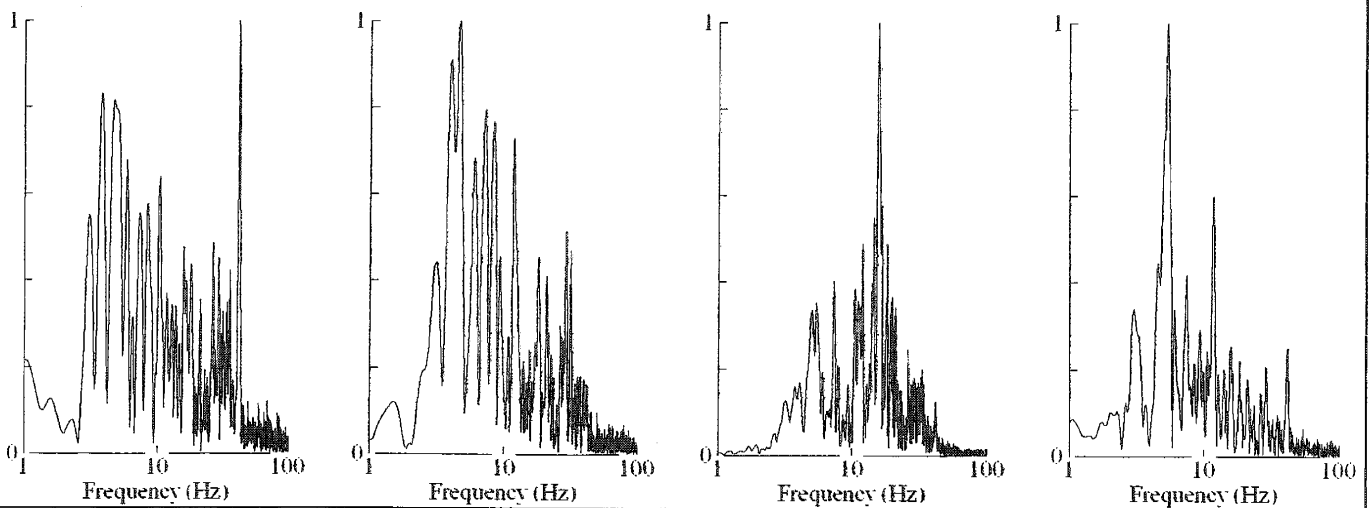
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
41.13 Hz

Radial  
4.63 Hz

Vertical  
15.75 Hz

Transverse  
5.38 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

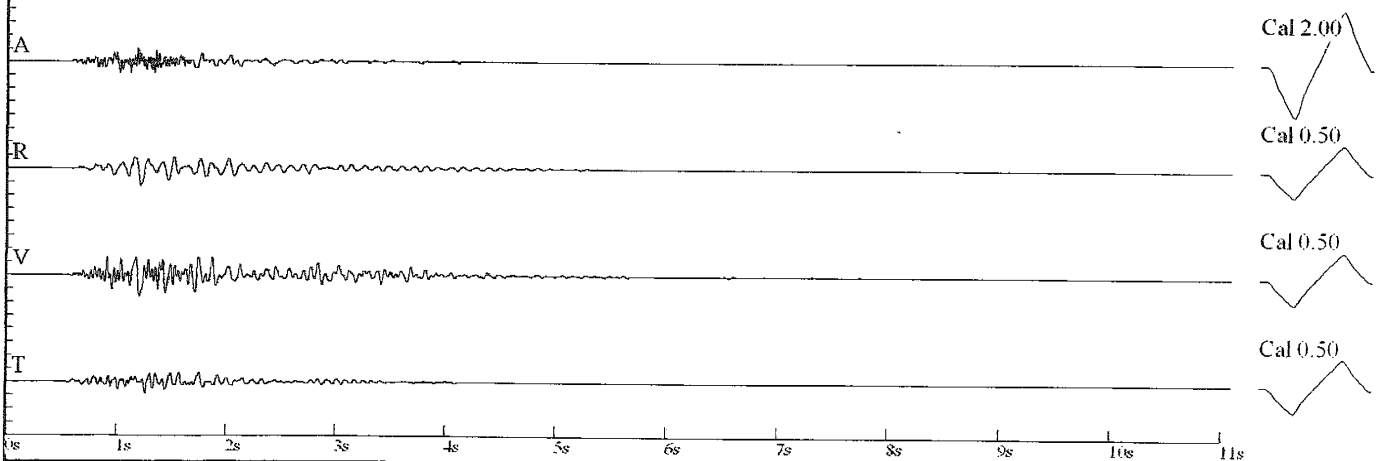
File Name: 02276024.DTB  
 Number: 024  
 Date: 4 13 2005  
 Time: 15:39  
 Serial Number: 2276  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 117 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 118 dB @ 28.4 Hz  
 (0.16Mb 0.0023psi 0.0160kPa)  
 Radial: 0.065in/s 1.651mm/s @ 8.8Hz  
 Vertical: 0.08in/s 2.032mm/s @ 9.4Hz  
 Transverse: 0.045in/s 1.143mm/s @ 17.0Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



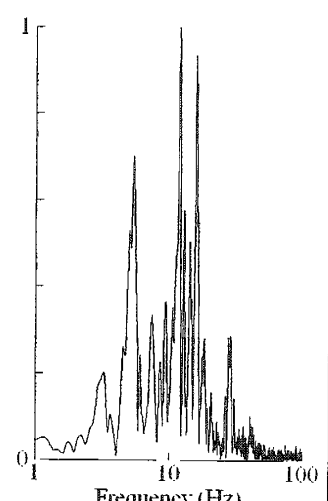
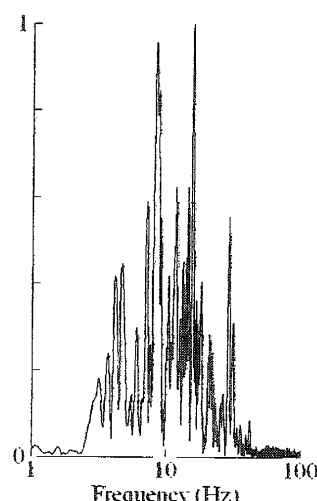
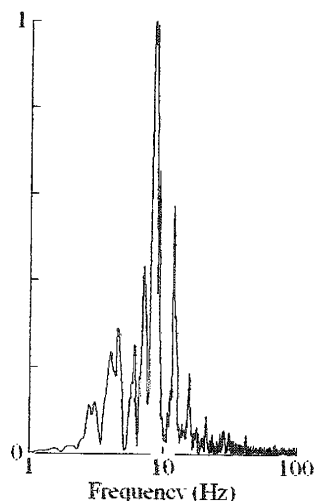
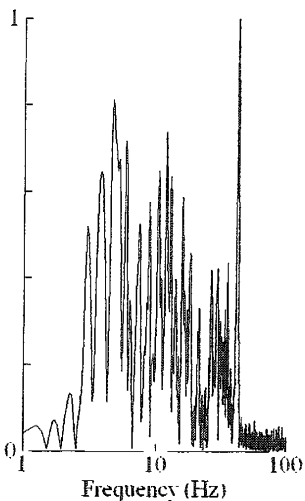
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
41.31 Hz

Radial  
8.50 Hz

Vertical  
15.69 Hz

Transverse  
11.88 Hz



**High Mesa  
Exterior Master**

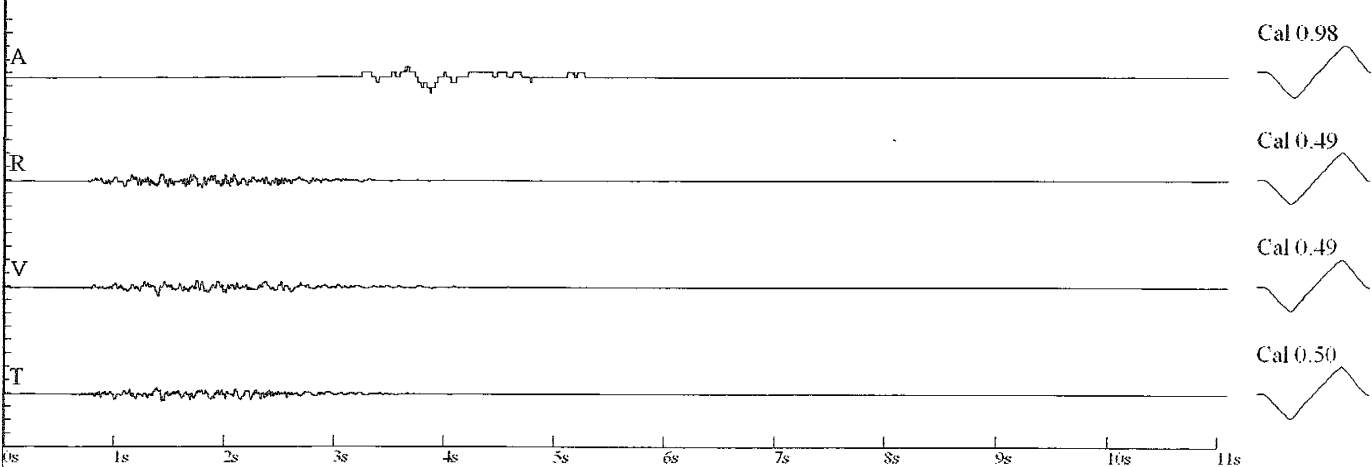
File Name: 01258024.DTB  
 Number: 024  
 Date: 4/14/2005  
 Time: 15:56  
 Serial Number: 1258  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

*Acoustic:* 112 dB @ 2.1 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
*Radial:* 0.03in/s 0.762mm/s @ 25.6Hz  
*Vertical:* 0.04in/s 1.016mm/s @ 10.6Hz  
*Transverse:* 0.035in/s 0.889mm/s @ 11.6Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 120dB 0.20Mb (0.050Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



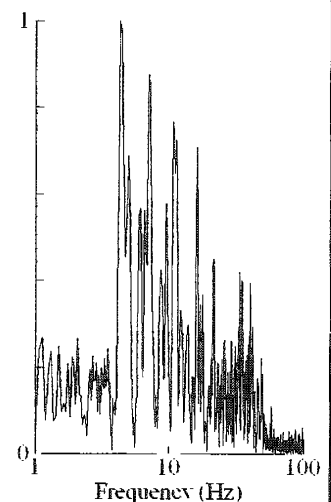
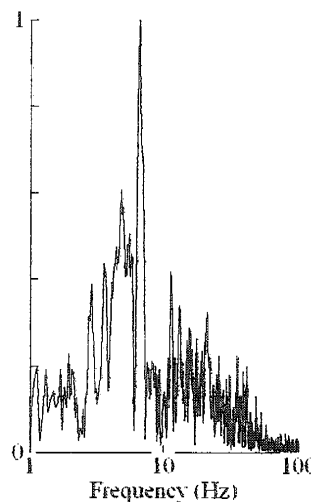
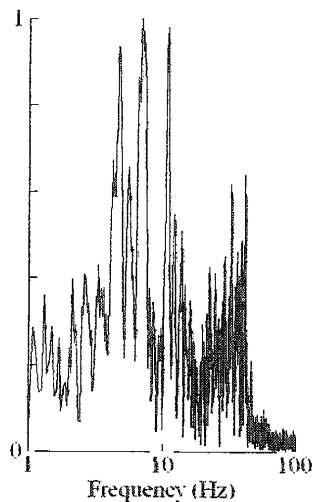
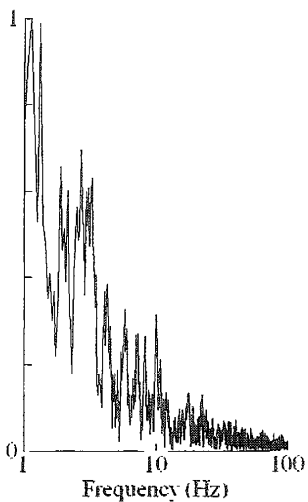
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
1.13 Hz

**Radial**  
7.06 Hz

**Vertical**  
6.56 Hz

**Transverse**  
4.31 Hz





**High Mesa**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

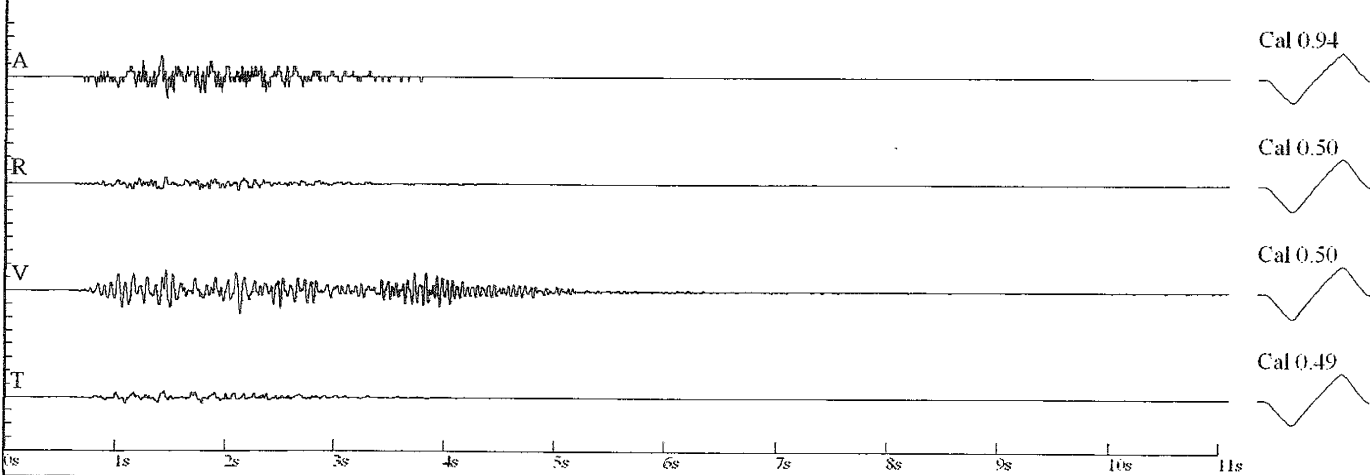
File Name: 00930026.DTB  
 Number: 026  
 Date: 4 14 2005  
 Time: 15:56  
 Serial Number: 930  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 124 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 112 dB  $\bar{a}$ : 14.2 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
 Radial: 0.025in/s 0.635mm/s  $\bar{a}$ : 16.0Hz  
 Vertical: **0.085in/s 2.159mm/s  $\bar{a}$ : 15.0Hz**  
 Transverse: 0.025in/s 0.635mm/s  $\bar{a}$ : 10.2Hz

**Graph Information**

Duration: 0.000s To: 11.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



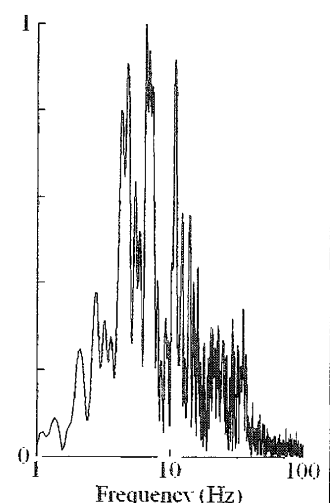
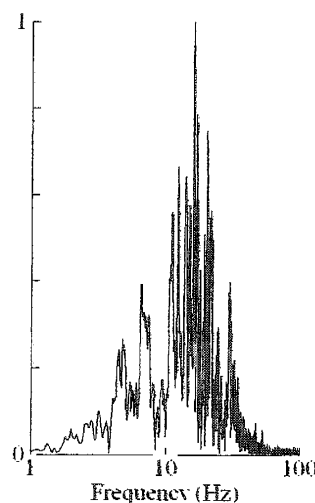
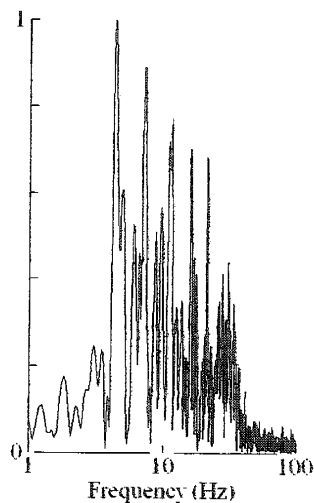
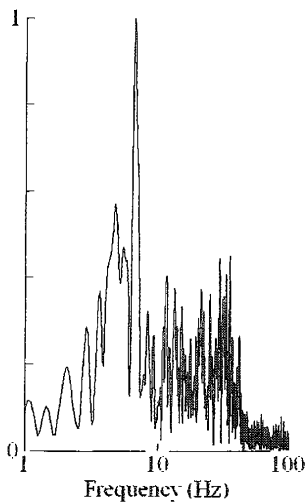
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
6.56 Hz

Radial  
4.38 Hz

Vertical  
16.06 Hz

Transverse  
6.56 Hz



**High Mesa**  
**Upper corner**  
**V = NE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

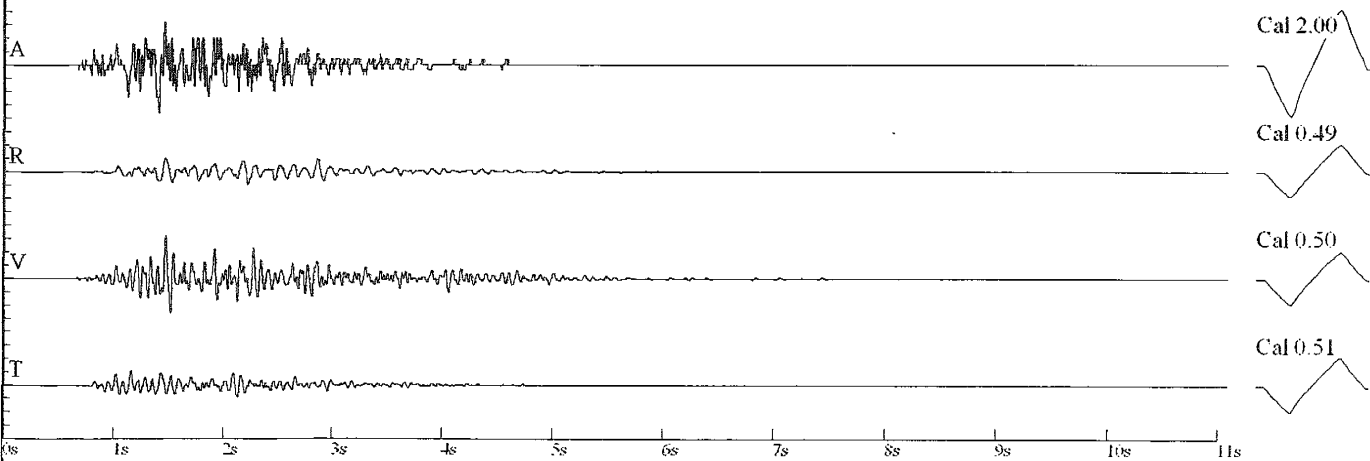
File Name: 02276025.DTB  
 Number: 025  
 Date: 4 14 2005  
 Time: 15:56  
 Serial Number: 2276  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 117 dB  
 Sample Rate: 512  
 Record Duration: 10.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

*Acoustic:* 119 dB @ 12.1 Hz  
 (0.18Mb 0.0026psi 0.0180kPa)  
*Radial:* 0.05in/s 1.27mm/s @ 8.8Hz  
*Vertical:* 0.16in/s 4.064mm/s @ 15.0Hz  
*Transverse:* 0.055in/s 1.397mm/s @ 13.4Hz

**Graph Information**

*Duration:* 0.000s To: 11.000s  
*Acoustic Scale:*  
 120dB 0.20Mb (0.050Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



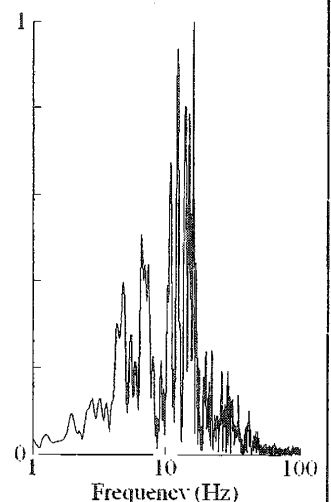
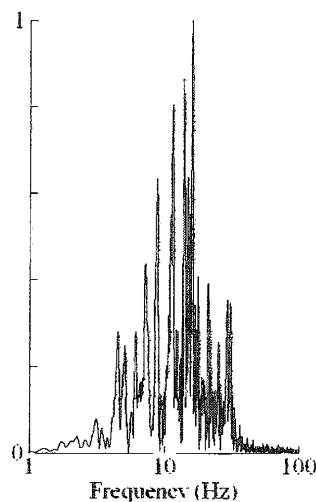
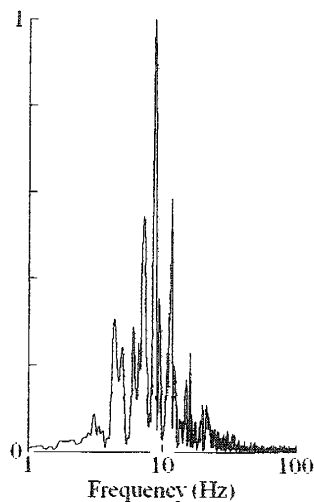
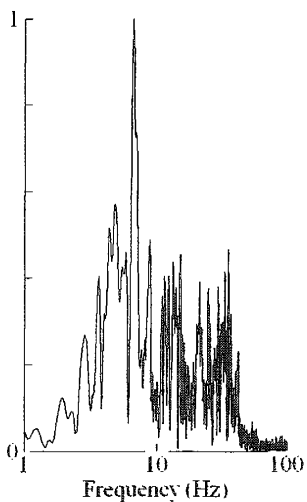
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
6.50 Hz

**Radial**  
8.81 Hz

**Vertical**  
16.06 Hz

**Transverse**  
16.06 Hz



Appendix B

Blasting seismograph records for  
structure at Bighorn

**Bighorn  
Exterior Master**

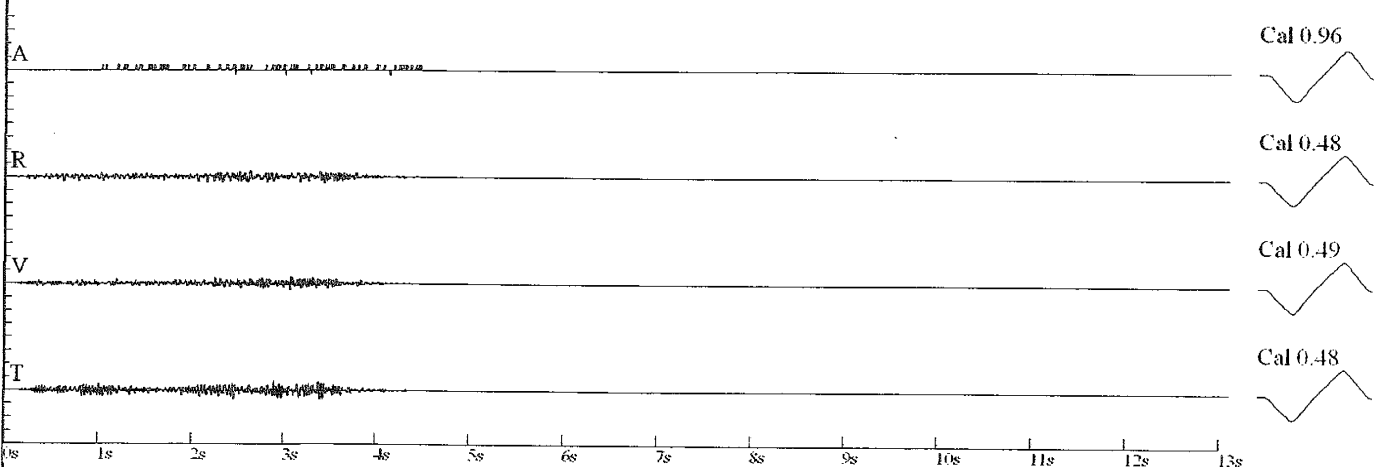
File Name: 03047015.DTB  
 Number: 015  
 Date: 3 15 2005  
 Time: 09:59  
 Serial Number: 3047  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 124 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 100 dB ( $\hat{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.025in/s 0.635mm/s ( $\hat{a}$ : 23.2Hz  
 Vertical: 0.025in/s 0.635mm/s ( $\hat{a}$ : 32.0Hz  
 Transverse: 0.035in/s 0.889mm/s ( $\hat{a}$ : 32.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



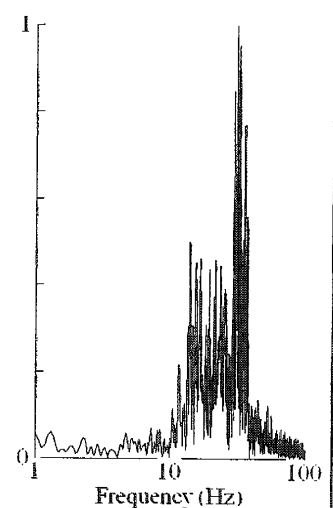
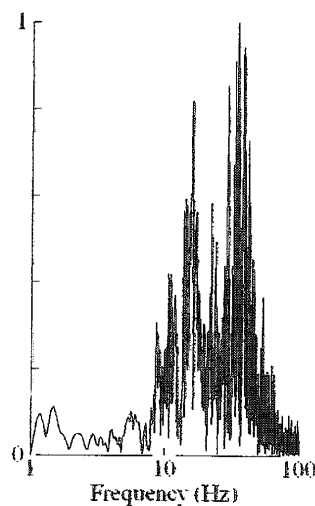
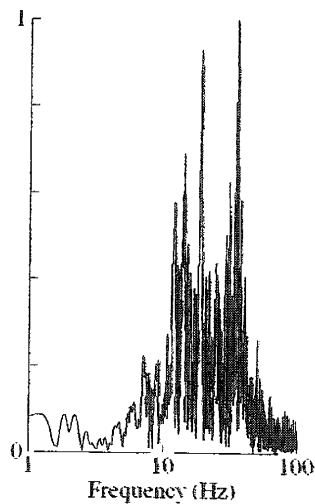
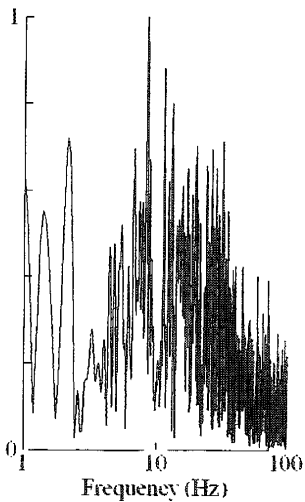
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
8.31 Hz

Radial  
35.31 Hz

Vertical  
34.25 Hz

Transverse  
30.94 Hz



**Bighorn**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

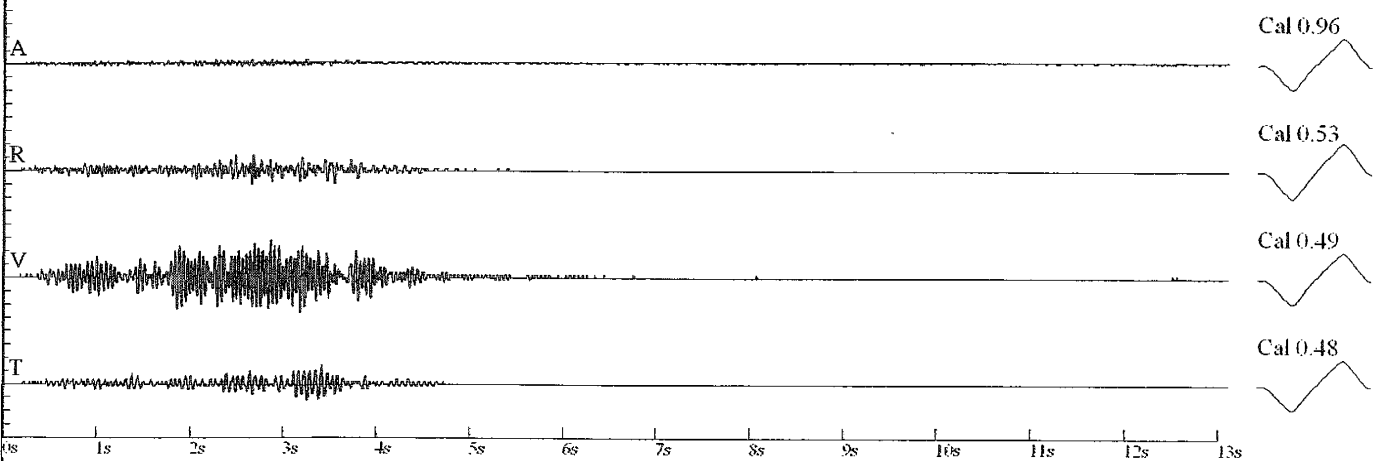
File Name: 01010027.DTB  
 Number: 027  
 Date: 3 15 2005  
 Time: 09:59  
 Serial Number: 1010  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 136 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 110 dB @ 25.6 Hz  
 (0.06Mb 0.0009psi 0.0060kPa)  
 Radial: 0.06in/s 1.524mm/s @ 23.2Hz  
 Vertical: 0.14in/s 3.556mm/s @ 23.2Hz  
 Transverse: 0.07in/s 1.778mm/s @ 19.6Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



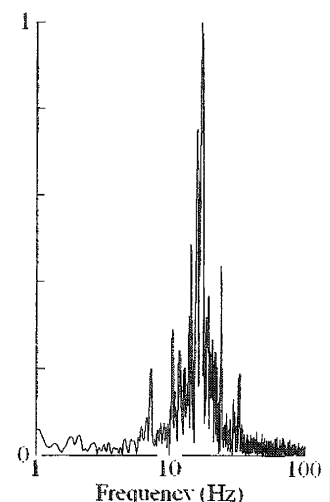
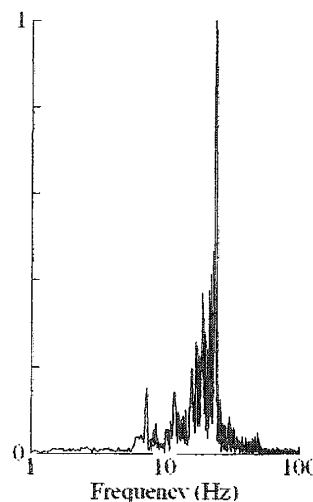
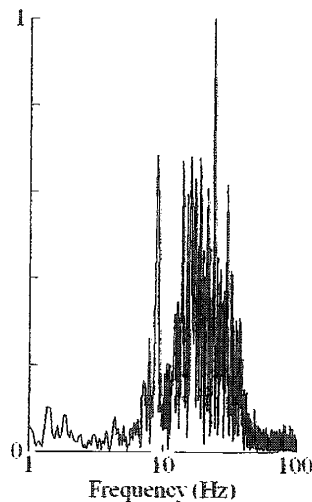
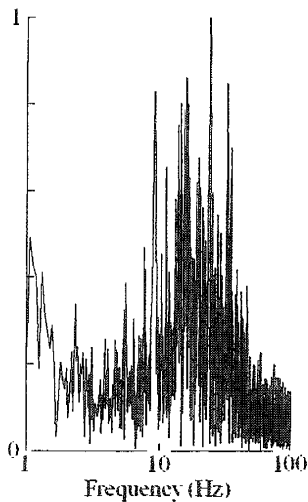
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
23.63 Hz

Radial  
23.88 Hz

Vertical  
23.69 Hz

Transverse  
17.06 Hz



**Bighorn**

**Upper corner**

**V = SW midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

**R,V,T \* 0.60 factor**

File Name: 02279251.DTB

Number: 251

Date: 3 15 2005

Time: 09:58

Serial Number: 2279

Seismic Trigger: 0.0600 in s 1.5240 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 12.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 110 dB @ 25.6 Hz  
(0.06Mb 0.0009psi 0.0060kPa)

Radial: 0.15in/s 3.81mm/s @ 11.1Hz

Vertical: 0.38in/s 9.652mm/s @ 18.2Hz

Transverse: 0.11in/s 2.794mm/s @ 15.0Hz

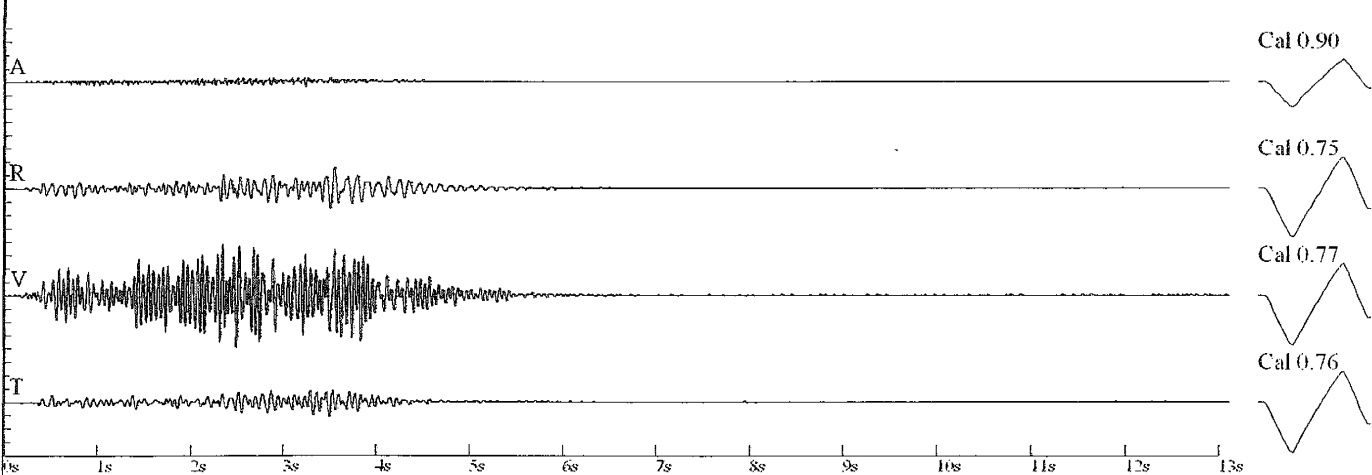
**Graph Information**

Duration: 0.000s To: 13.000s

Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)

Seismic Scale:  
0.38in/s (0.095in/s/div) 9.65mm/s (2.413mm/s/div)

Time Line Intervals at: 1.00 s



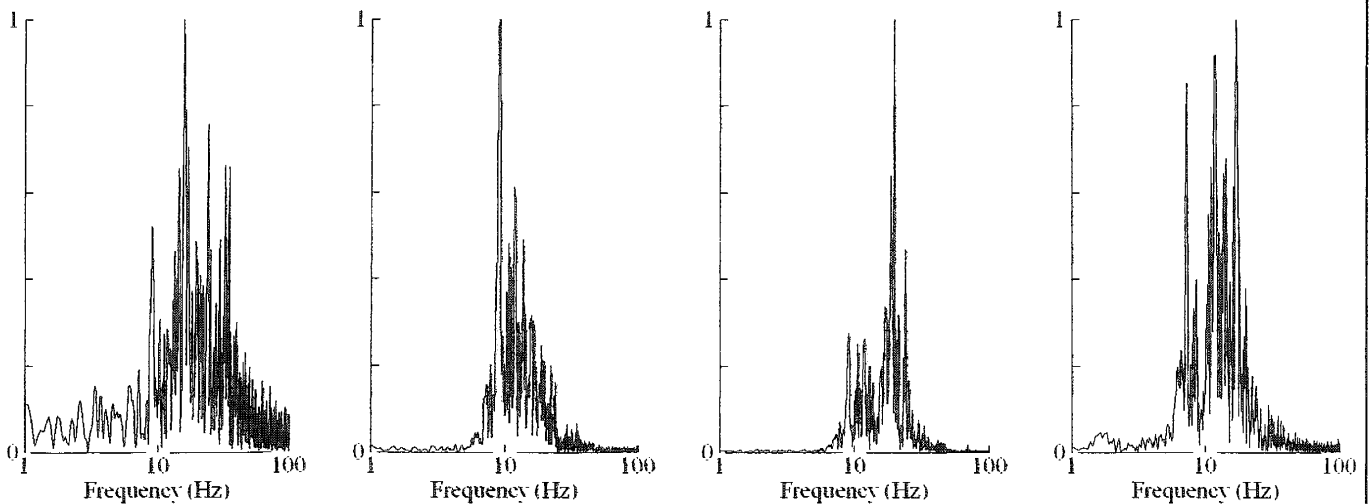
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
15.63 Hz

Radial  
9.13 Hz

Vertical  
19.81 Hz

Transverse  
16.88 Hz



**Bighorn  
Exterior Master**

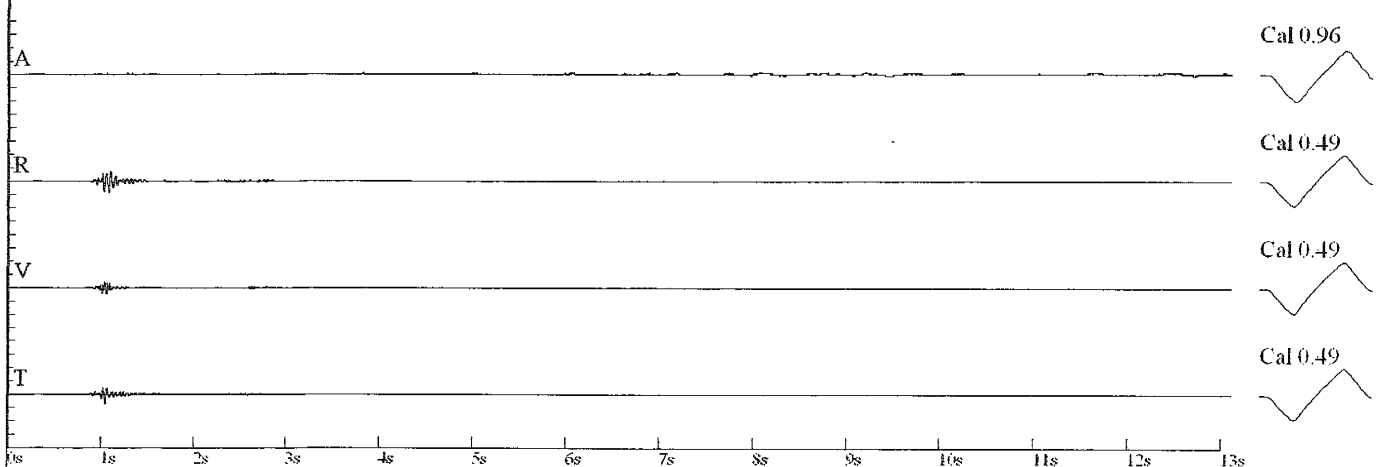
File Name: 03047003.DTB  
 Number: 003  
 Date: 3 21 2005  
 Time: 12:11  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.045in/s 1.143mm/s @ 21.3Hz  
 Vertical: 0.025in/s 0.635mm/s @ 36.5Hz  
 Transverse: 0.04in/s 1.016mm/s @ 28.4Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



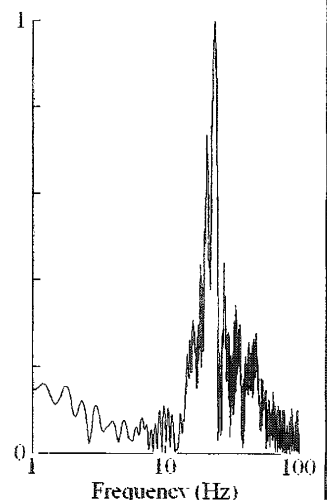
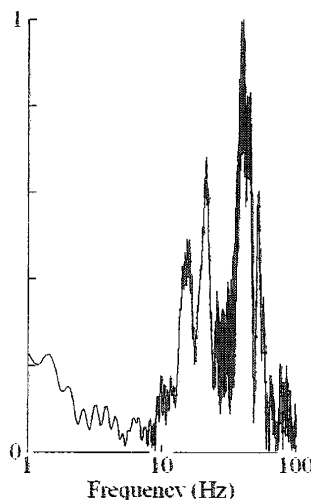
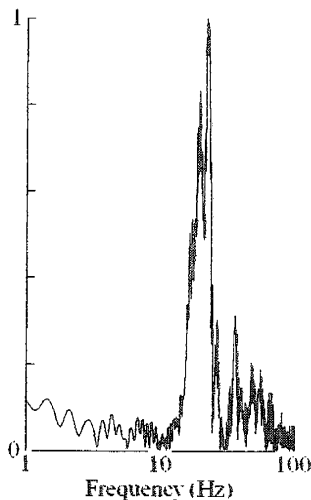
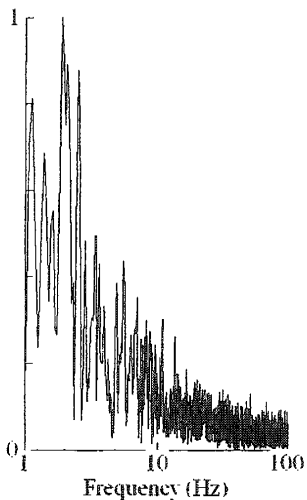
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.88 Hz

Radial  
22.06 Hz

Vertical  
40.63 Hz

Transverse  
23.13 Hz



**Bighorn**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

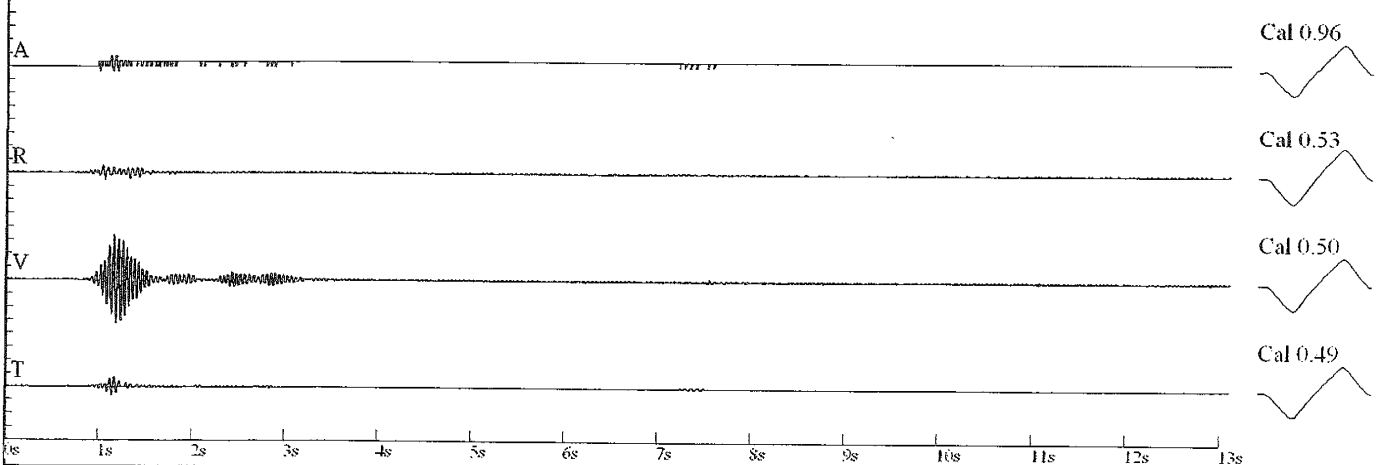
File Name: 01010002.DTB  
 Number: 002  
 Date: 3 21 2005  
 Time: 12:07  
 Serial Number: 1010  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 119 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.03in/s 0.762mm/s @ 21.3Hz  
 Vertical: 0.17in/s 4.318mm/s @ 21.3Hz  
 Transverse: 0.035in/s 0.889mm/s @ 21.3Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



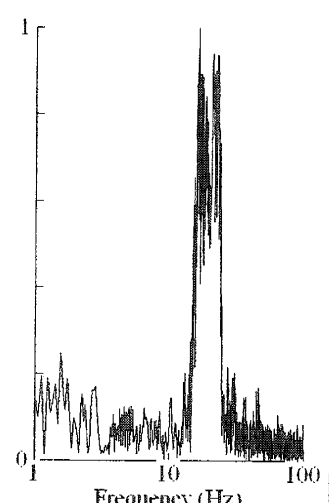
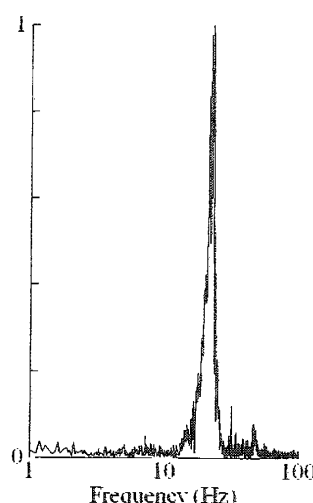
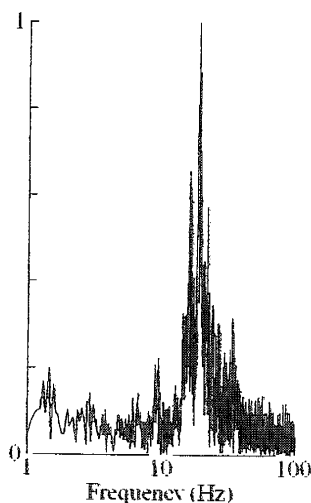
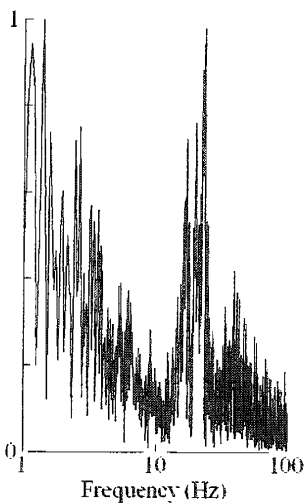
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.38 Hz

Radial  
18.94 Hz

Vertical  
22.75 Hz

Transverse  
16.44 Hz





**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

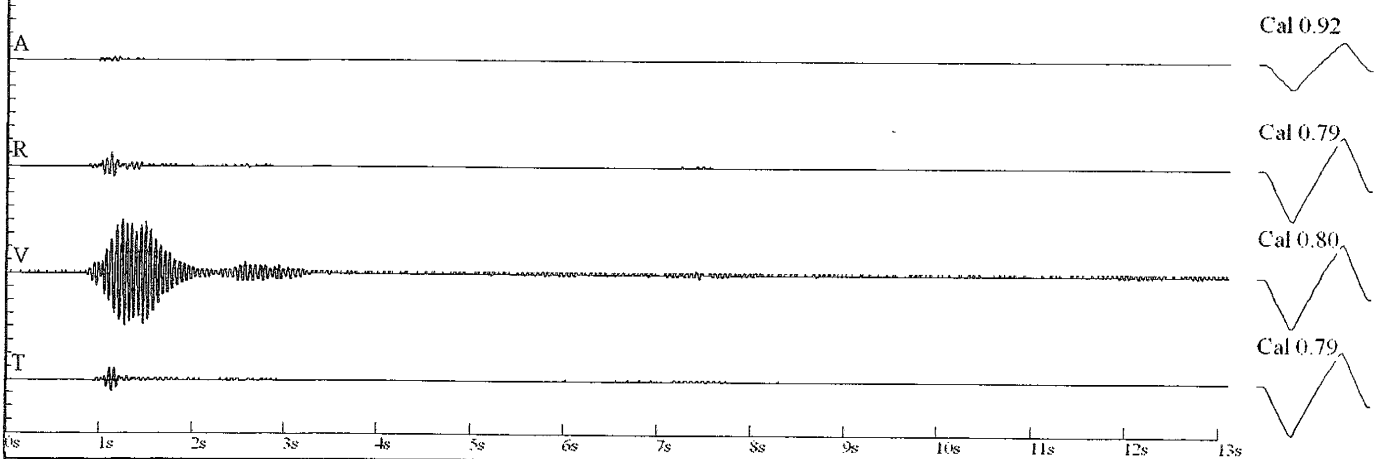
File Name: 02279001.DTB  
 Number: 001  
 Date: 3 21 2005  
 Time: 12:08  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 106 dB @ 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.07in/s 1.778mm/s @ 21.3Hz  
 Vertical: 0.27in/s 6.858mm/s @ 19.6Hz  
 Transverse: 0.06in/s 1.524mm/s @ 21.3Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.27in/s (0.068in/s/div) 6.86mm/s (1.715mm/s/div)  
 Time Line Intervals at: 1.00 s



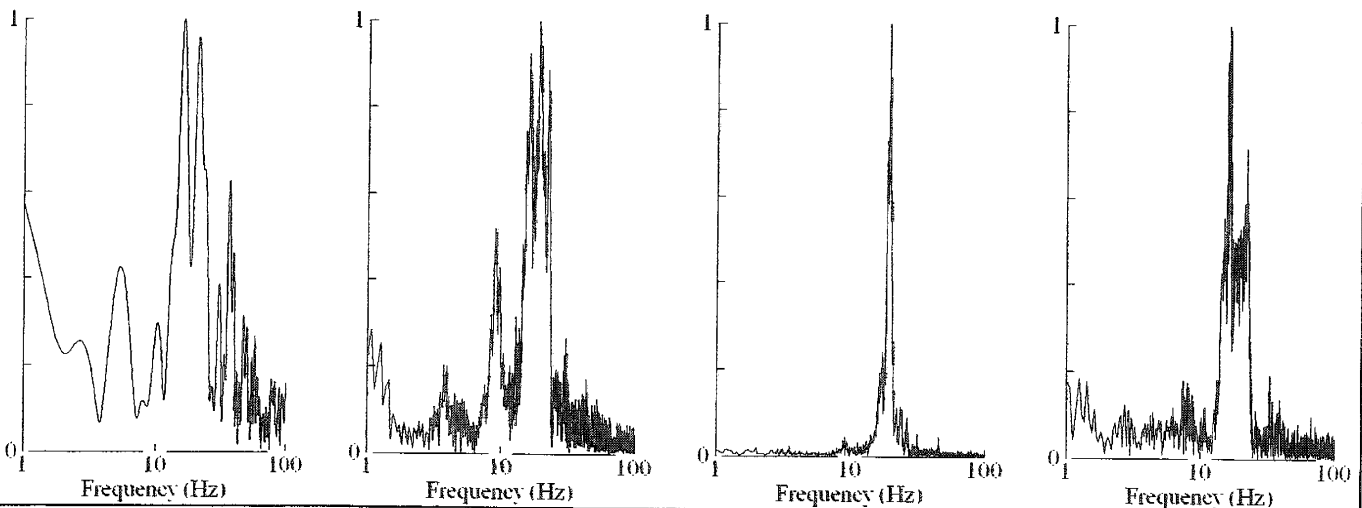
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
16.00 Hz

Radial  
18.75 Hz

Vertical  
19.56 Hz

Transverse  
16.44 Hz



**Bighorn  
Exterior Master**

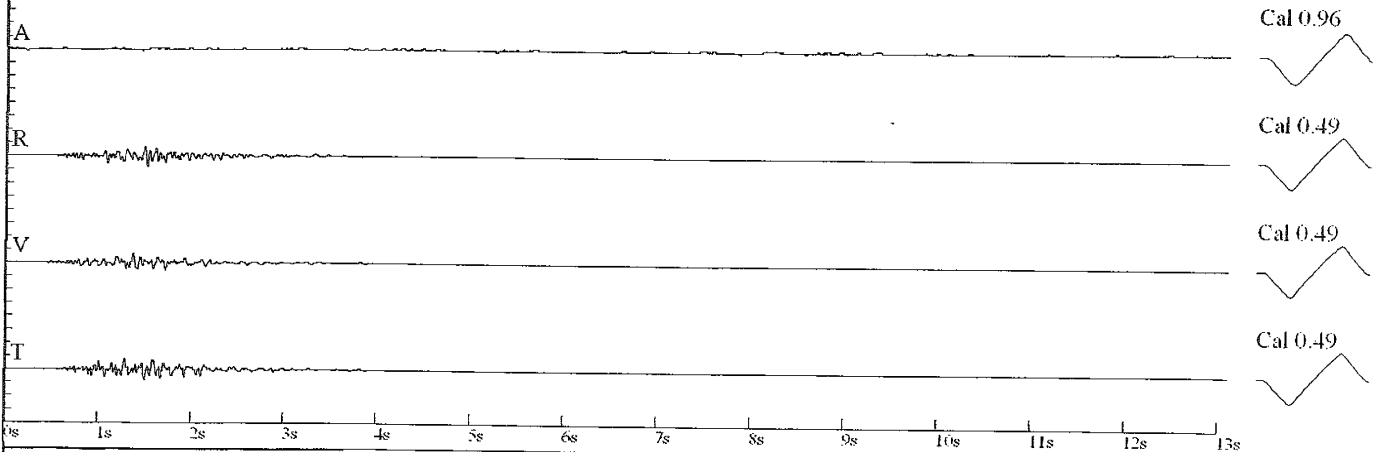
File Name: 03047004.DTB  
 Number: 004  
 Date: 3 22 2005  
 Time: 12:38  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 100 dB ( $\bar{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.04in/s 1.016mm/s ( $\bar{a}$ : 23.2Hz  
 Vertical: 0.035in/s 0.889mm/s ( $\bar{a}$ : 15.0Hz  
 Transverse: 0.04in/s 1.016mm/s ( $\bar{a}$ : 8.8Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



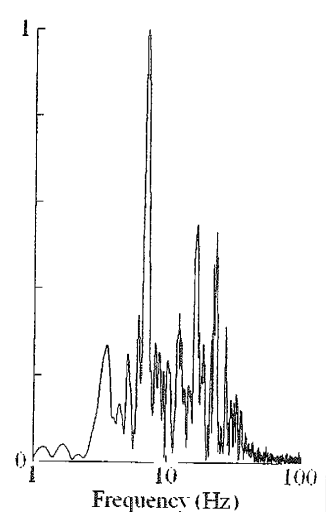
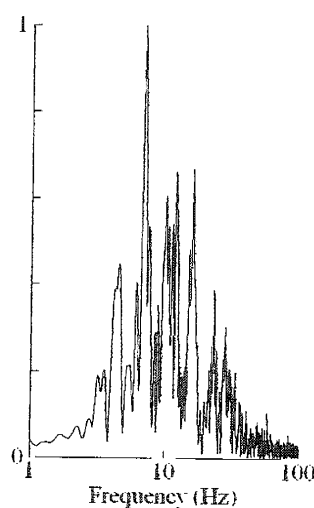
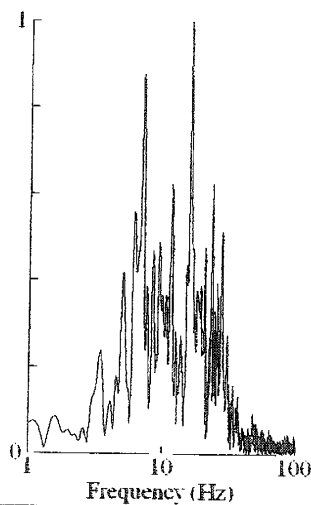
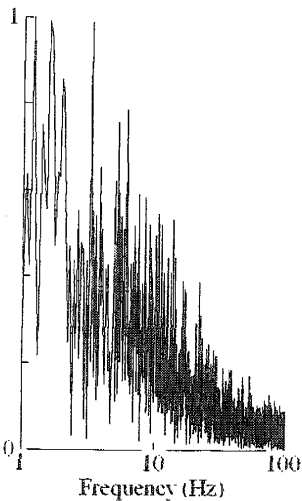
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.19 Hz

Radial  
16.00 Hz

Vertical  
7.00 Hz

Transverse  
7.06 Hz

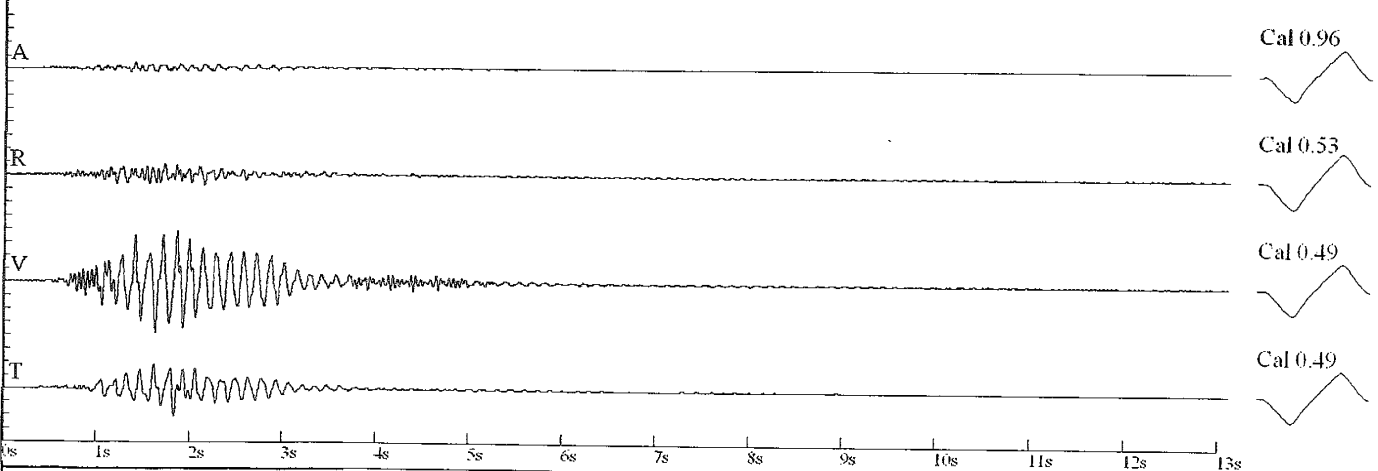


**Bighorn**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.25 ips**

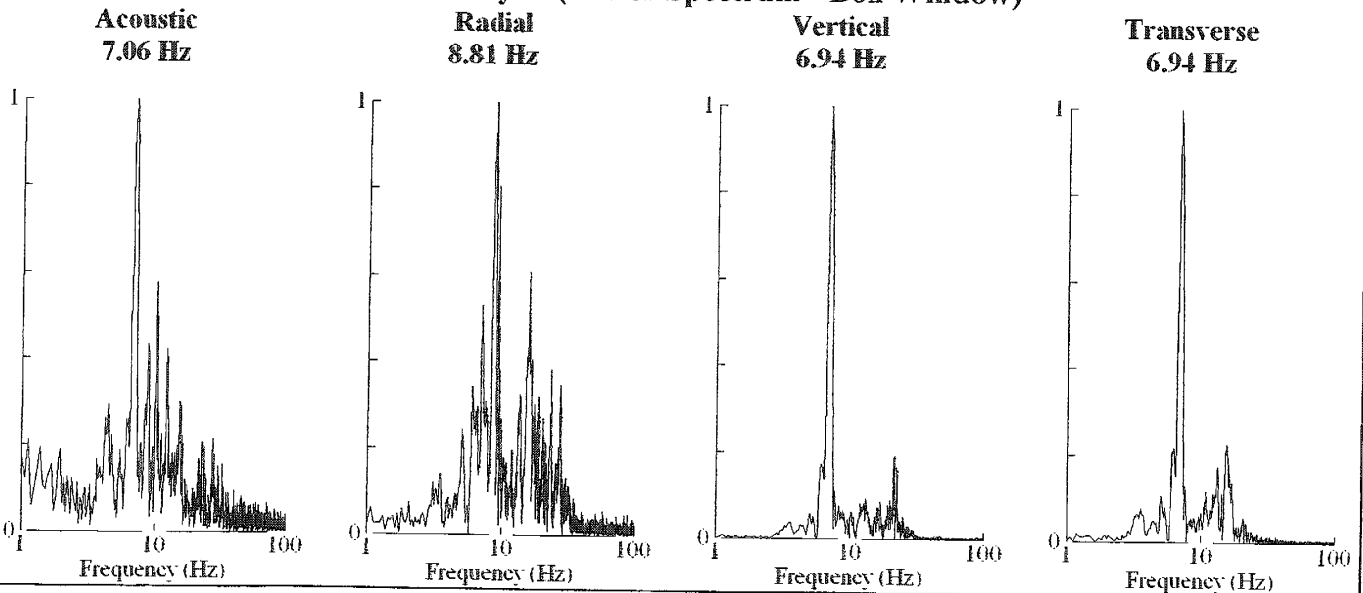
File Name: 01010003.DTB  
 Number: 003  
 Date: 3 22 2005  
 Time: 12:34  
 Serial Number: 1010  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 119 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**  
*Acoustic:* 112 dB @ 14.2 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
*Radial:* 0.045in/s 1.143mm/s @ 10.6Hz  
*Vertical:* 0.205in/s 5.207mm/s @ 8.8Hz  
*Transverse:* 0.11in/s 2.794mm/s @ 11.1Hz

**Graph Information**  
*Duration:* 0.000s To: 13.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.21in/s (0.053in/s/div) 5.33mm/s (1.334mm/s/div)  
*Time Line Intervals at:* 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**



**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

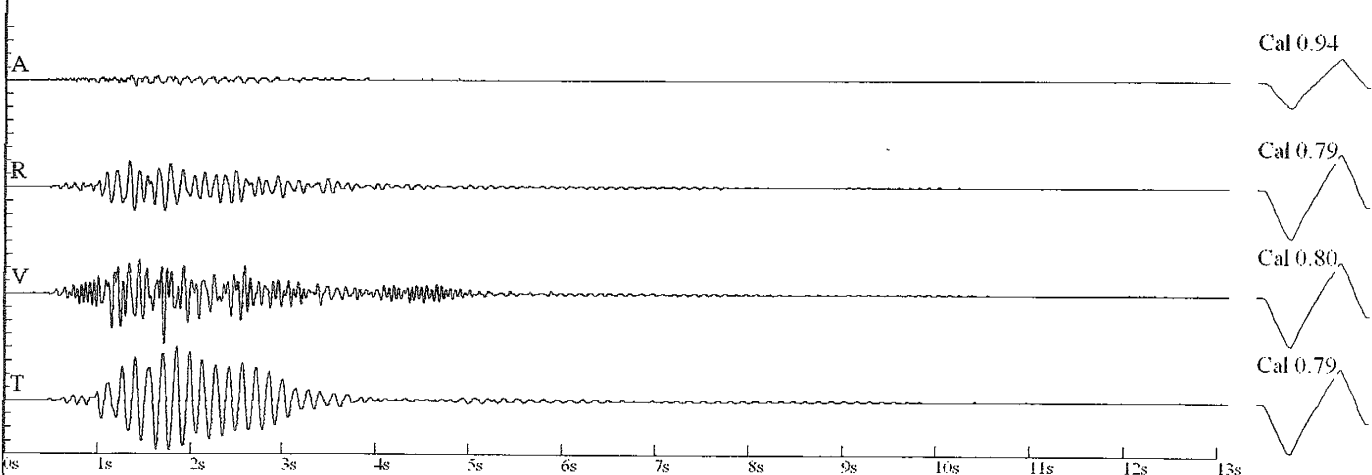
File Name: 02279002.DTB  
 Number: 002  
 Date: 3 22 2005  
 Time: 12:35  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

*Acoustic:* 112 dB ( $\bar{a}$ : 17.0 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
*Radial:* 0.19in/s 4.826mm/s ( $\bar{a}$ : 9.1Hz  
*Vertical:* 0.38in/s 9.652mm/s ( $\bar{a}$ : 15.0Hz  
*Transverse:* 0.40in/s 10.16mm/s ( $\bar{a}$ : 7.3Hz

**Graph Information**

*Duration:* 0.000s To: 13.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.40in/s (0.100in/s/div) 10.16mm/s (2.540mm/s/div)  
*Time Line Intervals at:* 1.00 s



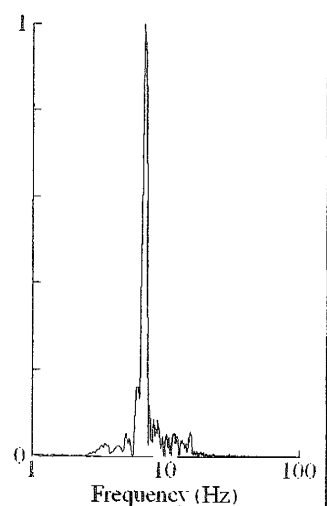
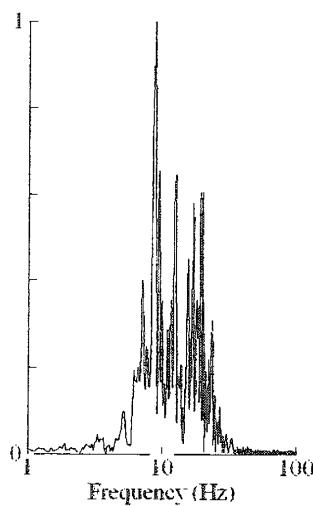
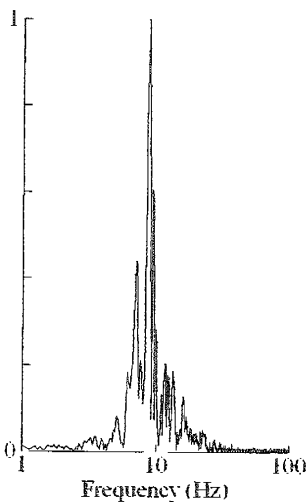
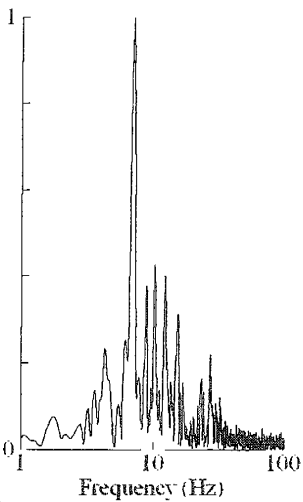
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
**7.00 Hz**

**Radial**  
**8.75 Hz**

**Vertical**  
**8.75 Hz**

**Transverse**  
**6.94 Hz**



**Bighorn  
Exterior Master**

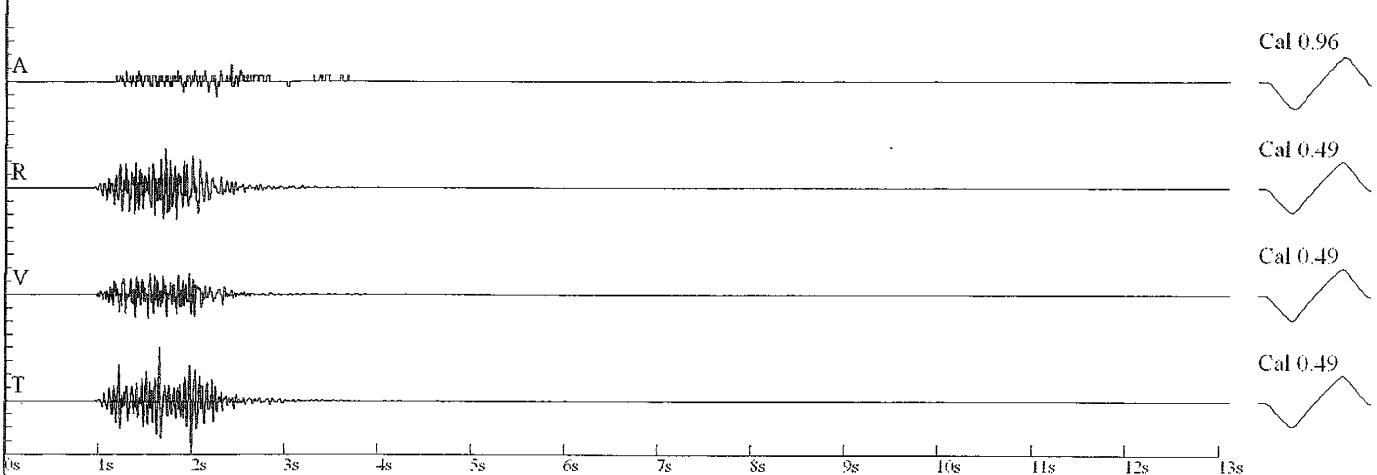
File Name: 03047010.DTB  
 Number: 010  
 Date: 3 23 2005  
 Time: 14:51  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 110 dB  $\bar{a}$ : 64.0 Hz  
 (0.06Mb 0.0009psi 0.0060kPa)  
 Radial: 0.33in/s 8.382mm/s  $\bar{a}$ : 23.2Hz  
 Vertical: 0.205in/s 5.207mm/s  $\bar{a}$ : 32.0Hz  
 Transverse: 0.45in/s 11.43mm/s  $\bar{a}$ : 21.3Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 120dB 0.20Mb (0.050Mb/div)  
 Seismic Scale:  
 0.45in/s (0.113in/s/div) 11.43mm/s (2.858mm/s/div)  
 Time Line Intervals at: 1.00 s



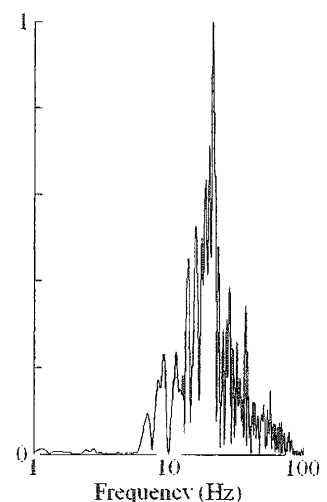
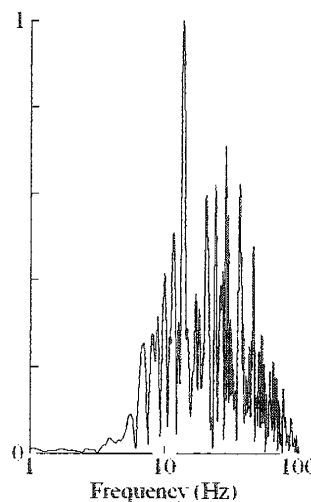
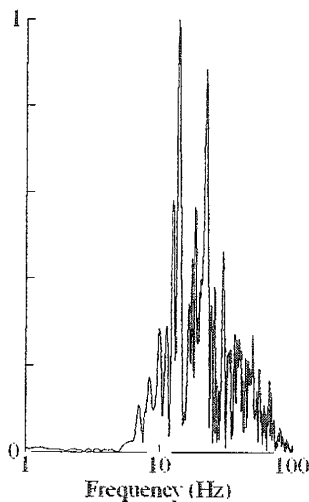
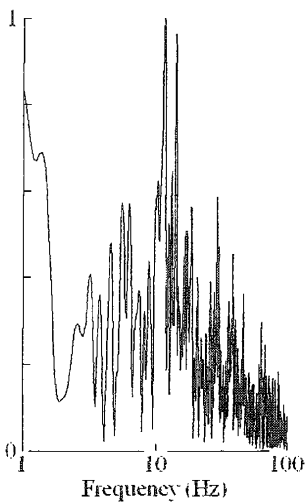
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
11.44 Hz

Radial  
13.94 Hz

Vertical  
13.81 Hz

Transverse  
21.13 Hz



# Bighorn

## Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.25 ips

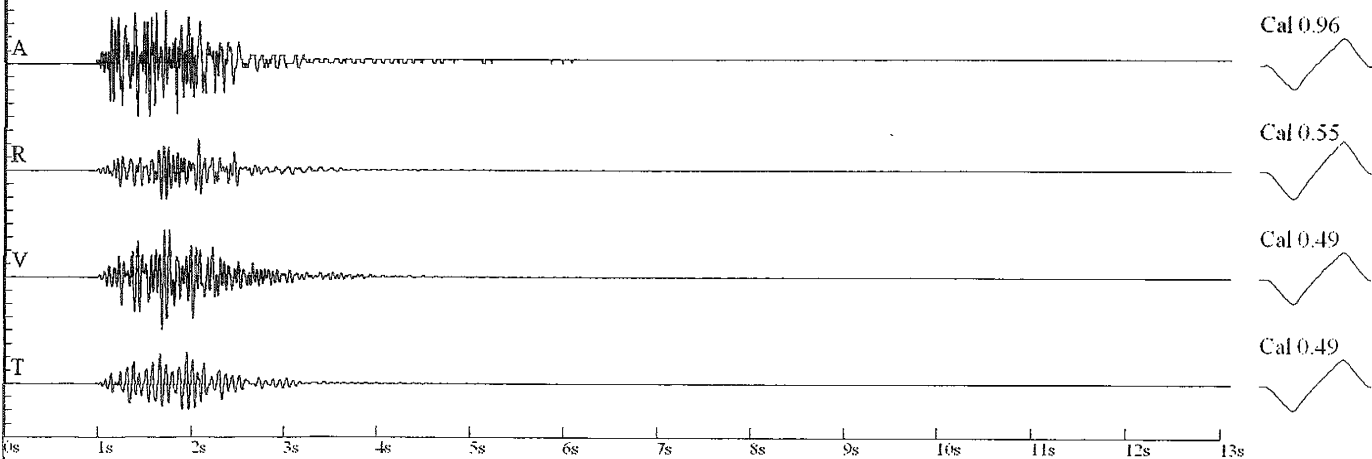
File Name: 01010009.DTB  
Number: 009  
Date: 3 23 2005  
Time: 14:47  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.2

### Amplitudes and Frequencies

Acoustic: 122 dB @ 28.4 Hz  
(0.26Mb 0.0038psi 0.0260kPa)  
Radial: 0.315in/s 8.001mm/s @ 17.0Hz  
Vertical: 0.535in/s 13.589mm/s @ 19.6Hz  
Transverse: 0.315in/s 8.001mm/s @ 15.0Hz

### Graph Information

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
122dB 0.25Mb (0.063Mb/div)  
Seismic Scale:  
0.54in/s (0.135in/s/div) 13.72mm/s (3.429mm/s/div)  
Time Line Intervals at: 1.00 s



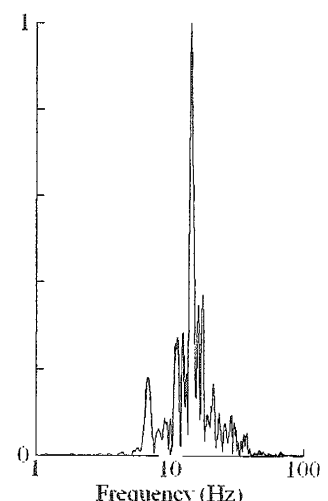
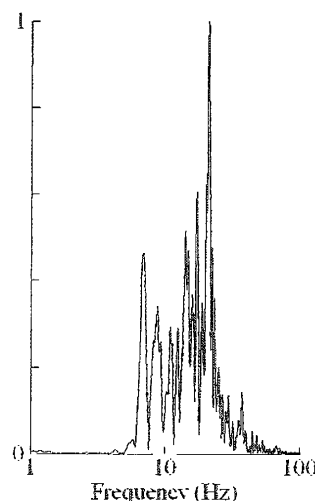
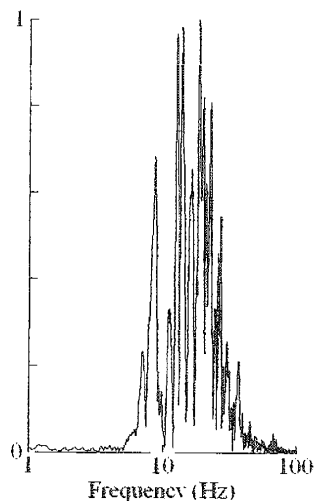
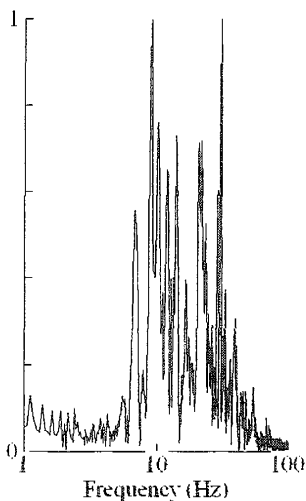
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
29.81 Hz

Radial  
18.63 Hz

Vertical  
21.19 Hz

Transverse  
14.13 Hz



**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R, V, T \* 0.60 factor**

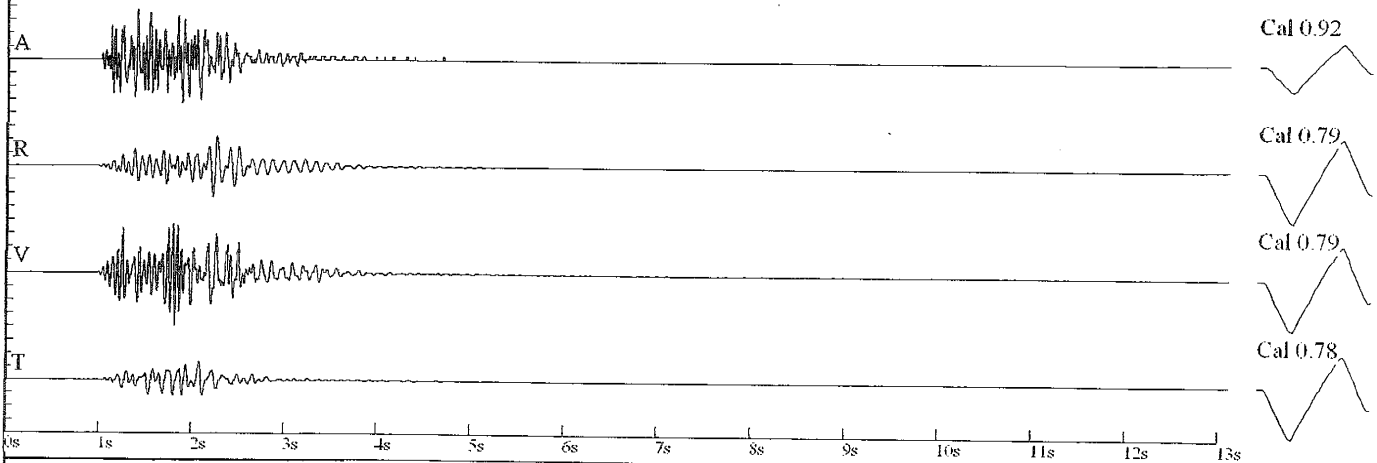
File Name: 02279008.DTB  
 Number: 008  
 Date: 3 23 2005  
 Time: 14:48  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 124 dB @ 18.2 Hz  
 (0.30Mb 0.0044psi 0.0300kPa)  
 Radial: 0.90in/s 22.86mm/s @ 11.1Hz  
 Vertical: 1.52in/s 38.608mm/s @ 21.3Hz  
 Transverse: 0.52in/s 13.208mm/s @ 10.2Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 124dB 0.32Mb (0.079Mb/div)  
 Seismic Scale:  
 1.52in/s (0.380in/s/div) 38.61mm/s (9.652mm/s/div)  
 Time Line Intervals at: 1.00 s



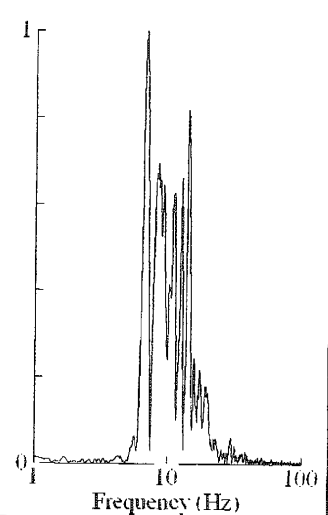
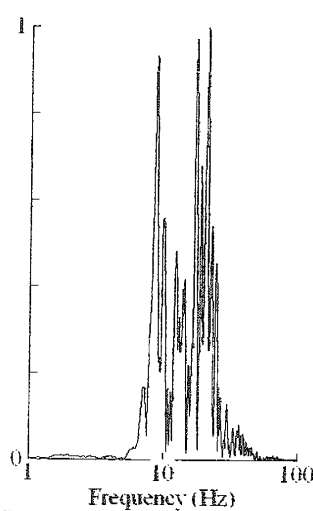
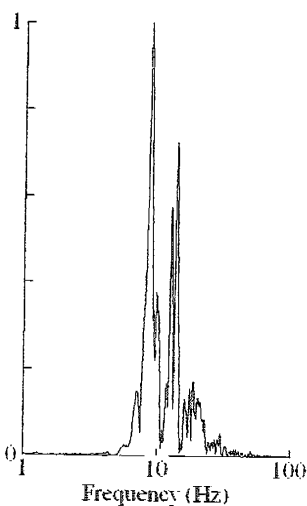
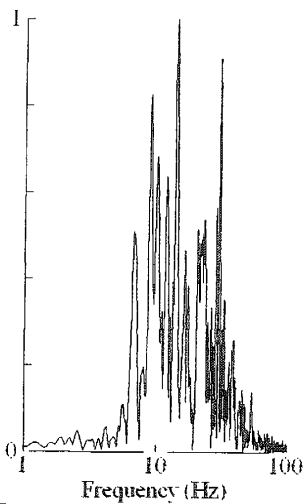
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
13.88 Hz

Radial  
8.75 Hz

Vertical  
20.81 Hz

Transverse  
6.81 Hz



**Bighorn  
Exterior Master**

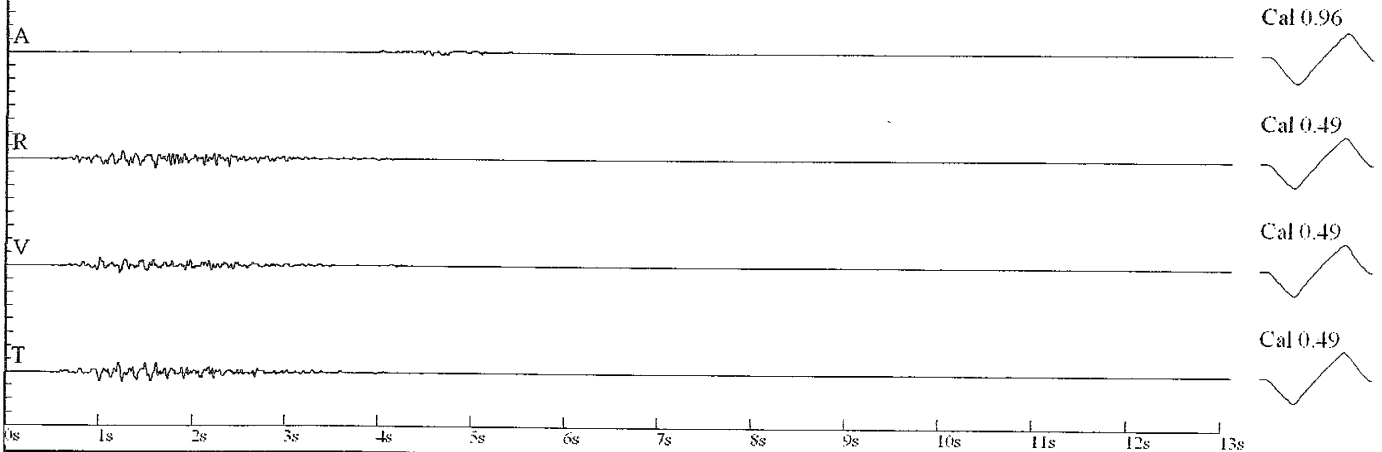
File Name: 03047068.DTB  
 Number: 068  
 Date: 4 14 2005  
 Time: 14:58  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

*Acoustic:* 106 dB  $\bar{a}$ : 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
*Radial:* 0.035in/s 0.889mm/s  $\bar{a}$ : 10.2Hz  
*Vertical:* 0.03in/s 0.762mm/s  $\bar{a}$ : 10.6Hz  
*Transverse:* 0.04in/s 1.016mm/s  $\bar{a}$ : 7.1Hz

**Graph Information**

*Duration:* 0.000s To: 13.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



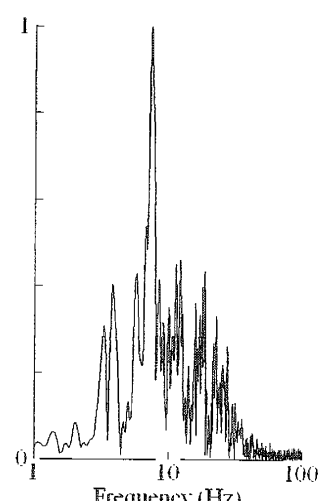
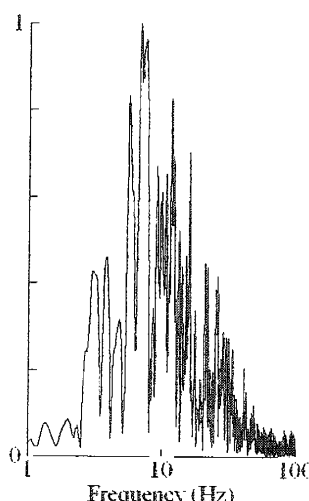
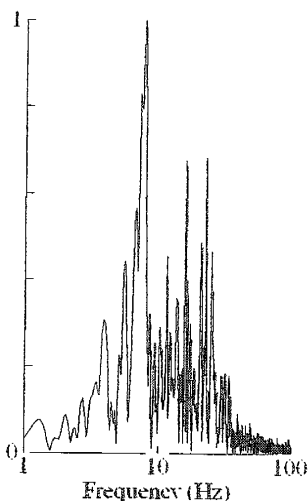
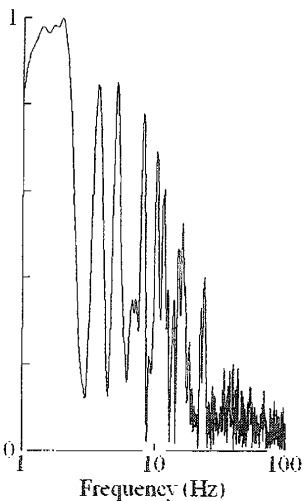
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
1.94 Hz

**Radial**  
7.75 Hz

**Vertical**  
6.81 Hz

**Transverse**  
7.38 Hz





# Bighorn

## Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.25 ips

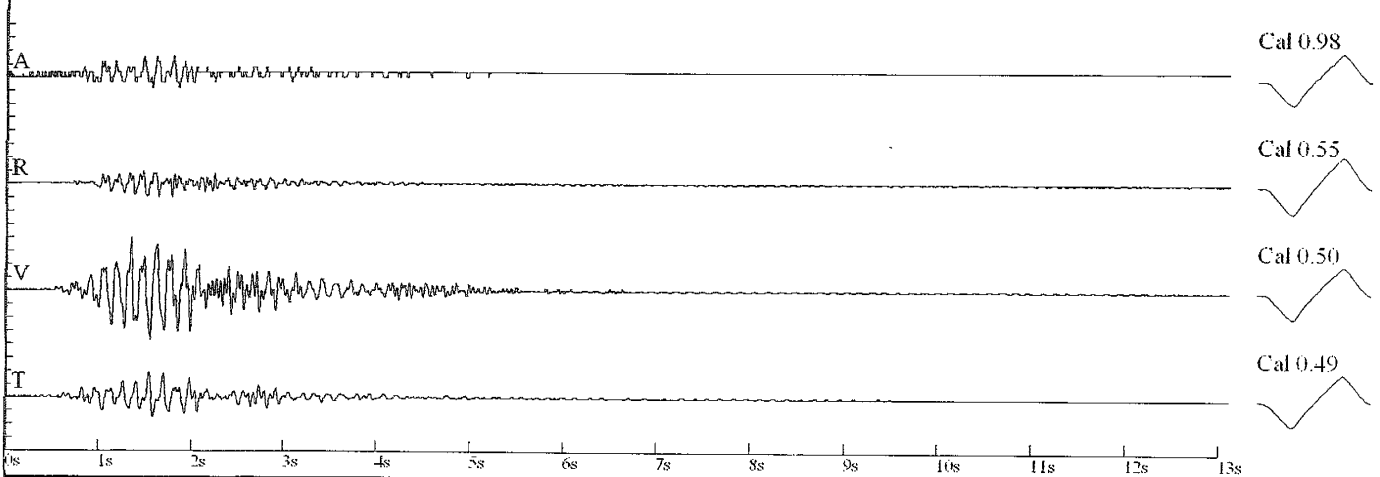
File Name: 01010062.DTB  
Number: 062  
Date: 4 14 2005  
Time: 15:54  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

### Amplitudes and Frequencies

Acoustic: 112 dB  $\bar{a}$ : 9.4 Hz  
(0.08Mb 0.0012psi 0.0080kPa)  
Radial: 0.05in/s 1.27mm/s  $\bar{a}$ : 7.7Hz  
Vertical: 0.20in/s 5.08mm/s  $\bar{a}$ : 7.3Hz  
Transverse: 0.095in/s 2.413mm/s  $\bar{a}$ : 9.8Hz

### Graph Information

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
120dB 0.20Mb (0.050Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



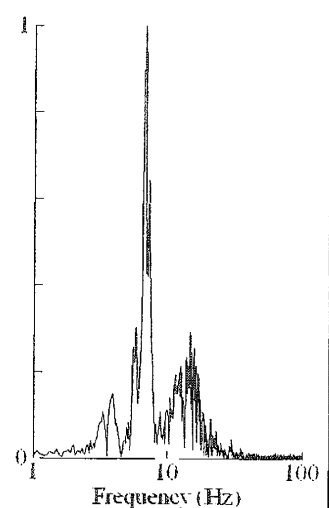
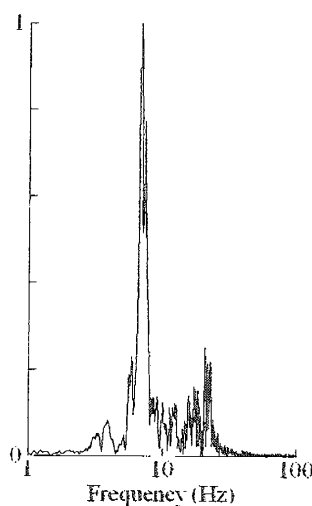
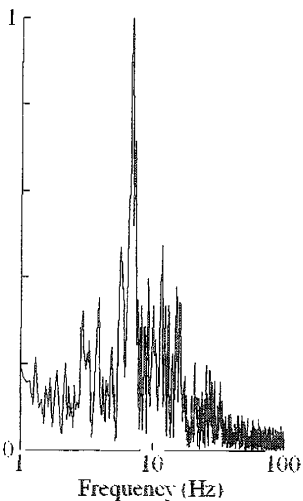
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
6.81 Hz

Radial  
7.88 Hz

Vertical  
6.81 Hz

Transverse  
6.81 Hz



**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

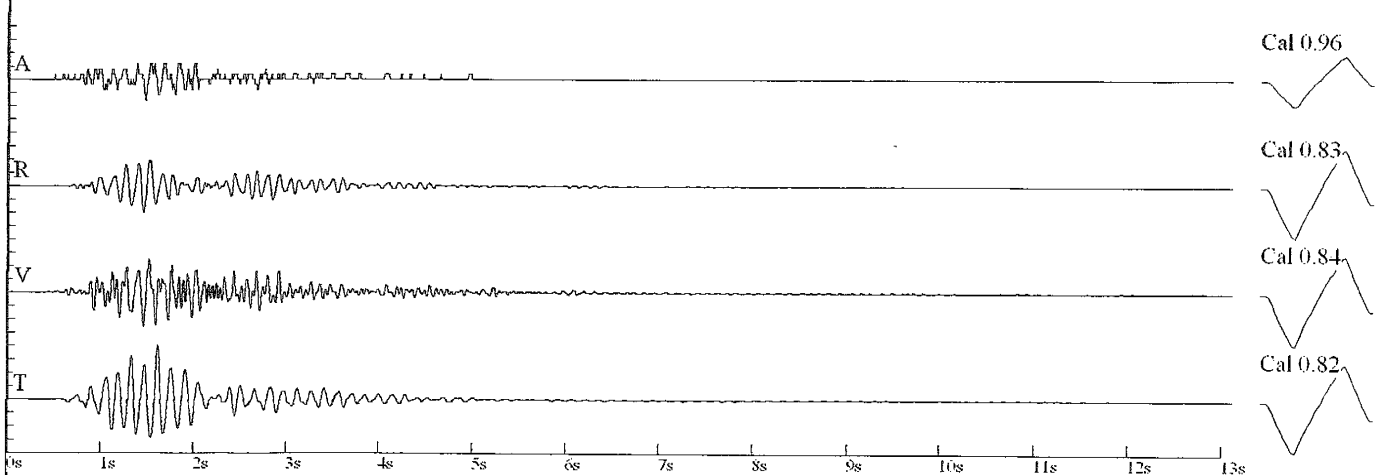
File Name: 02279064.DTB  
 Number: 064  
 Date: 4 14 2005  
 Time: 15:54  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 112 dB @ 14.2 Hz  
 (0.08Mb 0.0012psi 0.0080kPa)  
*Radial:* 0.26in/s 6.604mm/s @ 8.8Hz  
*Vertical:* 0.32in/s 8.128mm/s @ 9.1Hz  
*Transverse:* 0.50in/s 12.70mm/s @ 7.7Hz

**Graph Information**

*Duration:* 0.000s To: 13.000s  
*Acoustic Scale:*  
 120dB 0.20Mb (0.050Mb/div)  
*Seismic Scale:*  
 0.50in/s (0.125in/s/div) 12.70mm/s (3.175mm/s/div)  
*Time Line Intervals at:* 1.00 s



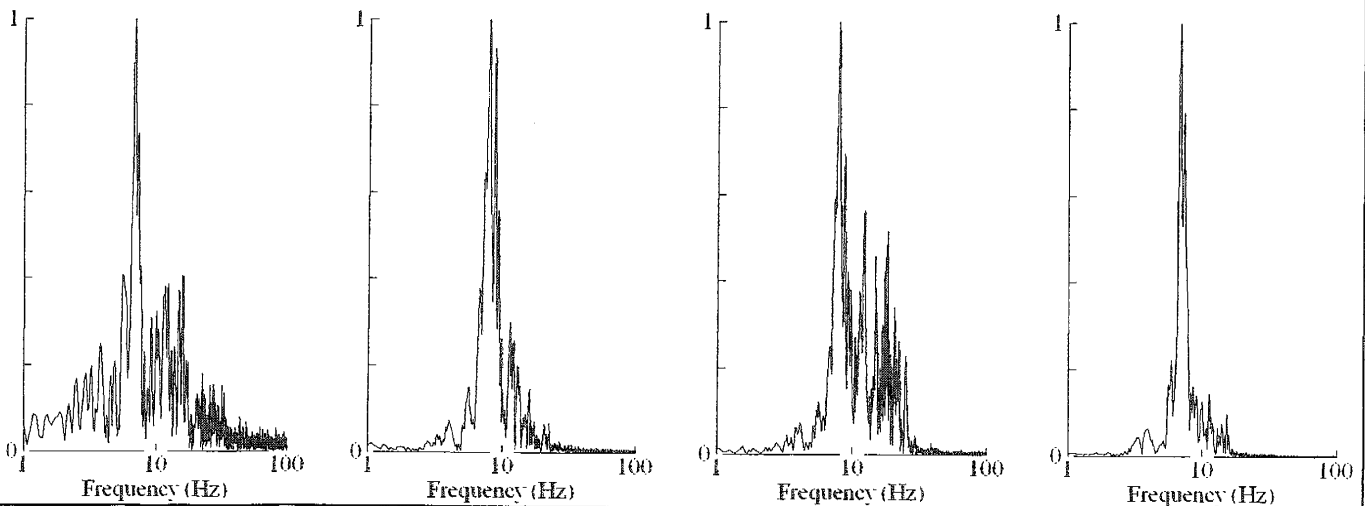
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
6.81 Hz

**Radial**  
7.81 Hz

**Vertical**  
7.88 Hz

**Transverse**  
6.81 Hz



## Appendix C

Seismograph records during construction excavation activities and wind for  
structures at Bighorn and High Mesa

**Bighorn Equipment and wind  
Exterior Master**

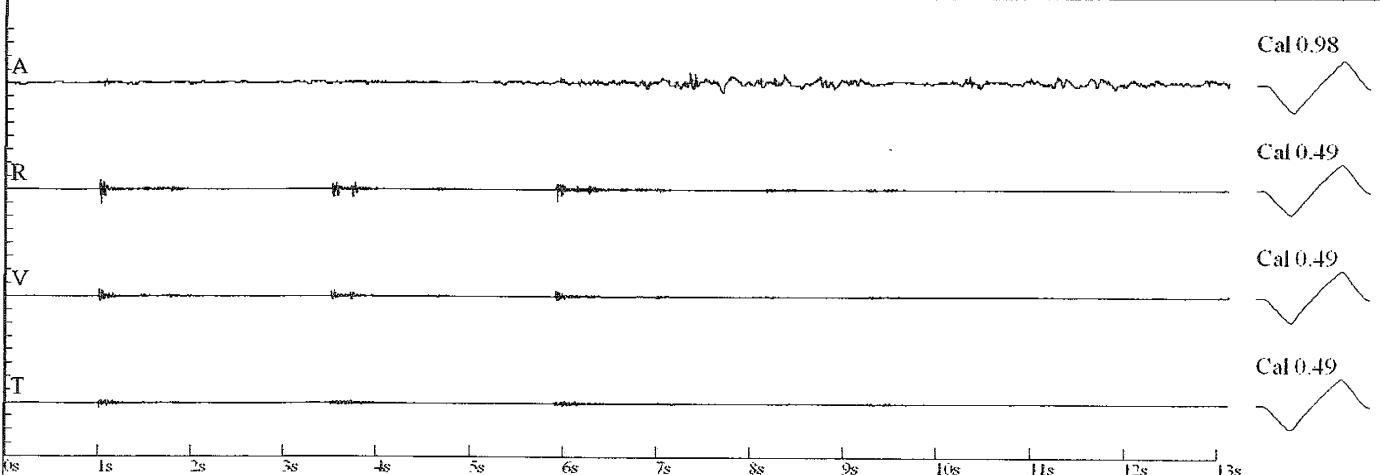
File Name: 03047135.DTB  
 Number: 135  
 Date: 3 18 2005  
 Time: 12:54  
 Serial Number: 3047  
 Seismic Trigger: 0.0250 in s 0.6350 mm s  
 Acoustic Trigger: 124 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 116 dB ( $\bar{a}$ : 42.6 Hz  
 (0.12Mb 0.0017psi 0.0120kPa)  
 Radial: 0.055in/s 1.397mm/s ( $\bar{a}$ : 64.0Hz  
 Vertical: 0.025in/s 0.635mm/s ( $\bar{a}$ : 64.0Hz  
 Transverse: 0.02in/s 0.508mm/s ( $\bar{a}$ : 85.3Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 129dB 0.56Mb (0.141Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



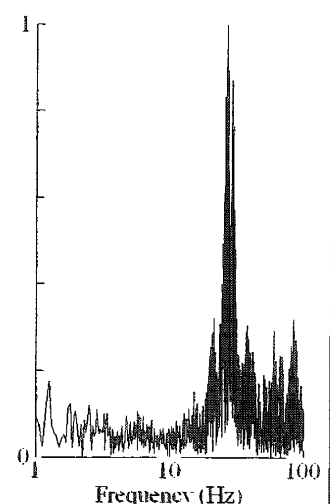
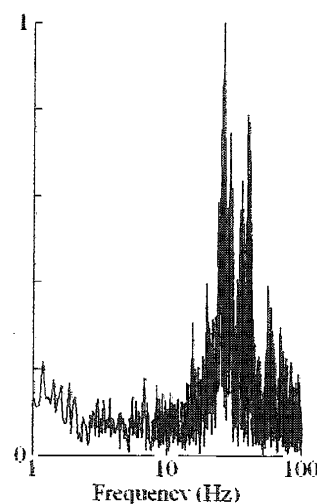
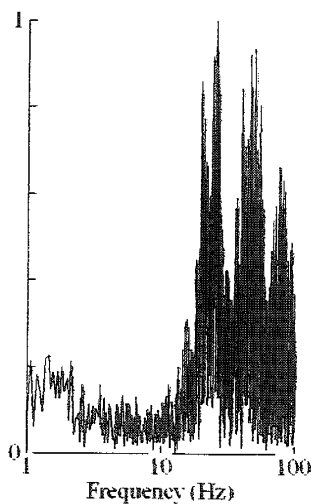
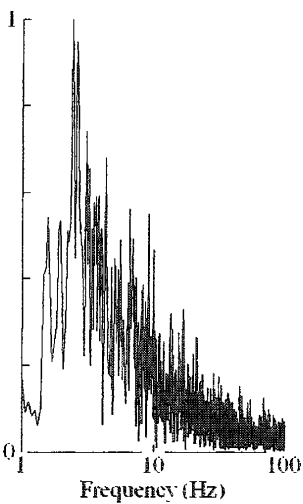
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
2.38 Hz

Radial  
25.69 Hz

Vertical  
26.56 Hz

Transverse  
26.56 Hz



### Bighorn Equipment

Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

File Name: 01010145.DTB

Number: 145

Date: 3 18 2005

Time: 12:53

Serial Number: 1010

Seismic Trigger: 0.0600 in s 1.5240 mm s

Acoustic Trigger: 136 dB

Sample Rate: 512

Record Duration: 12.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.1

#### Amplitudes and Frequencies

Acoustic: 106 dB @ 0.0 Hz

(0.04Mb 0.0006psi 0.0040kPa)

Radial: 0.02in/s 0.508mm/s @ 0.0Hz

Vertical: 0.03in/s 0.762mm/s @ 51.2Hz

Transverse: 0.01in/s 0.254mm/s @ 0.0Hz

#### Graph Information

Duration: 0.000s To: 13.000s

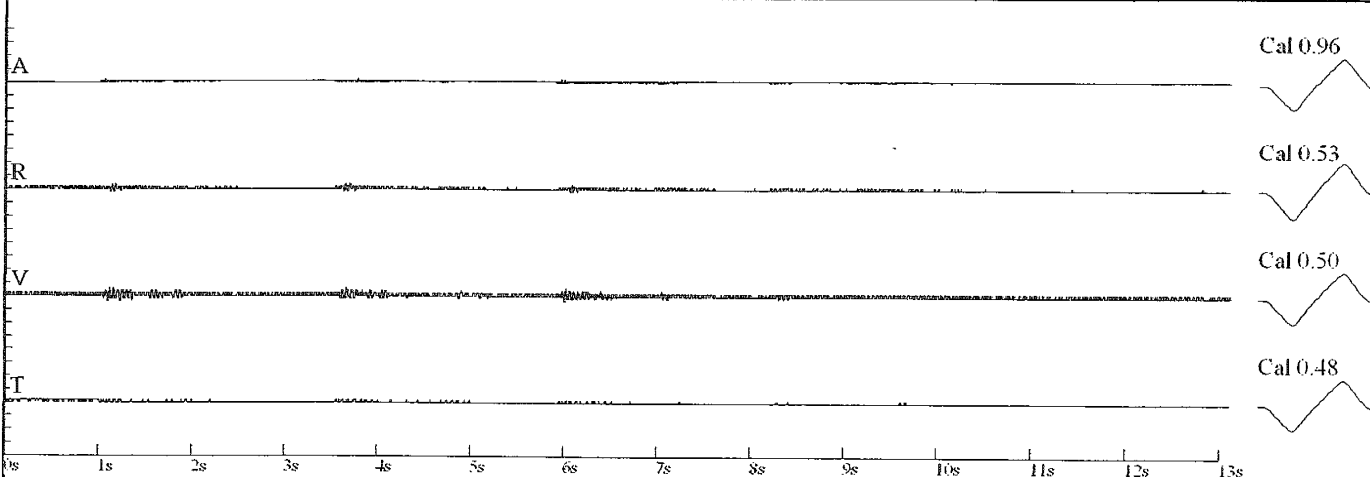
Acoustic Scale:

130dB 0.63Mb (0.158Mb/div)

Seismic Scale:

0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



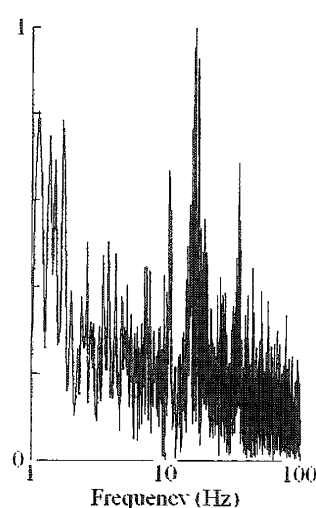
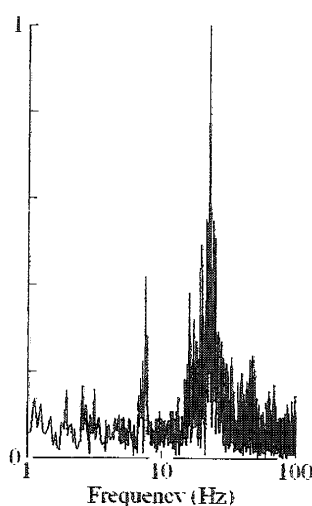
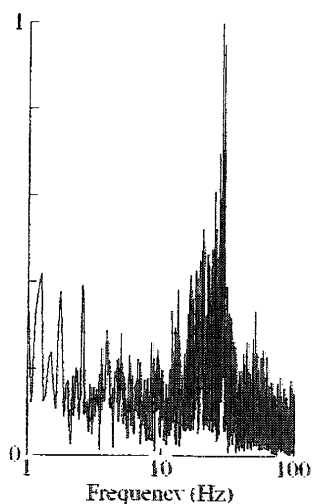
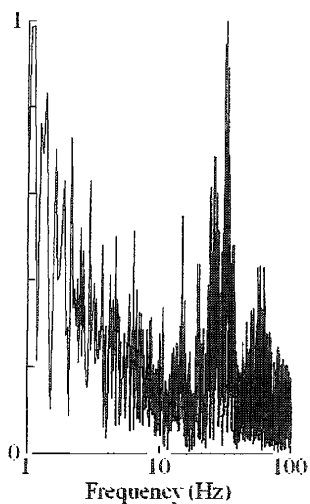
#### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
31.06 Hz

Radial  
28.56 Hz

Vertical  
22.63 Hz

Transverse  
16.44 Hz



**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

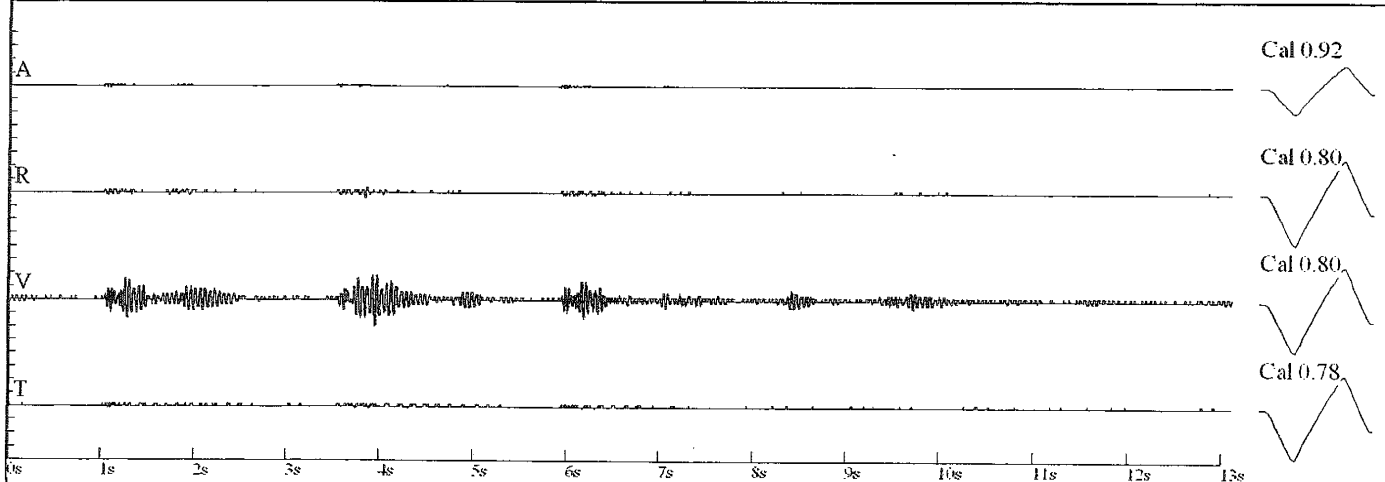
File Name: 02279029.DTB  
 Number: 029  
 Date: 3 18 2005  
 Time: 12:53  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 100 dB ( $\bar{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.02in/s 0.508mm/s ( $\bar{a}$ : 0.0Hz  
 Vertical: 0.10in/s 2.54mm/s ( $\bar{a}$ : 23.2Hz  
 Transverse: 0.01in/s 0.254mm/s ( $\bar{a}$ : 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 129dB 0.56Mb (0.141Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



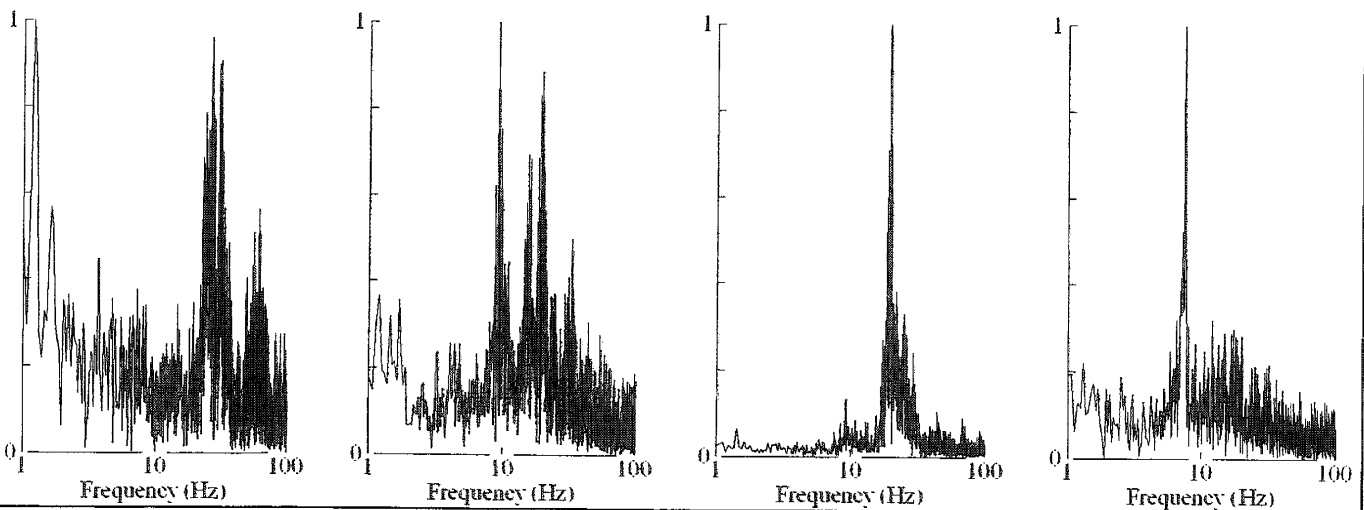
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.19 Hz

Radial  
9.25 Hz

Vertical  
19.75 Hz

Transverse  
7.56 Hz



**Bighorn**  
**Exterior Master**  
**Wind - 40.3 mps gusts**

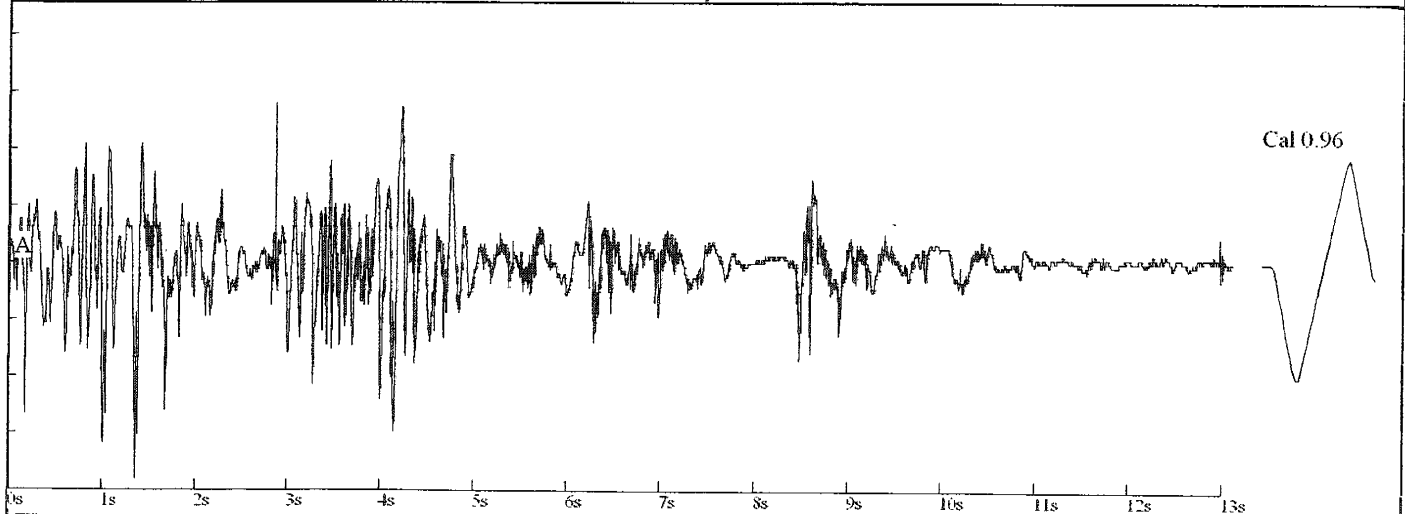
File Name: 03047005.DTB  
Number: 005  
Date: 3 22 2005  
Time: 23:54  
Serial Number: 3047  
Seismic Trigger: 0.0300 in s 0.7620 mm s  
Acoustic Trigger: 133 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 136 dB  $\hat{a}$ : 6.7 Hz  
(1.20Mb 0.0174psi 0.1200kPa)

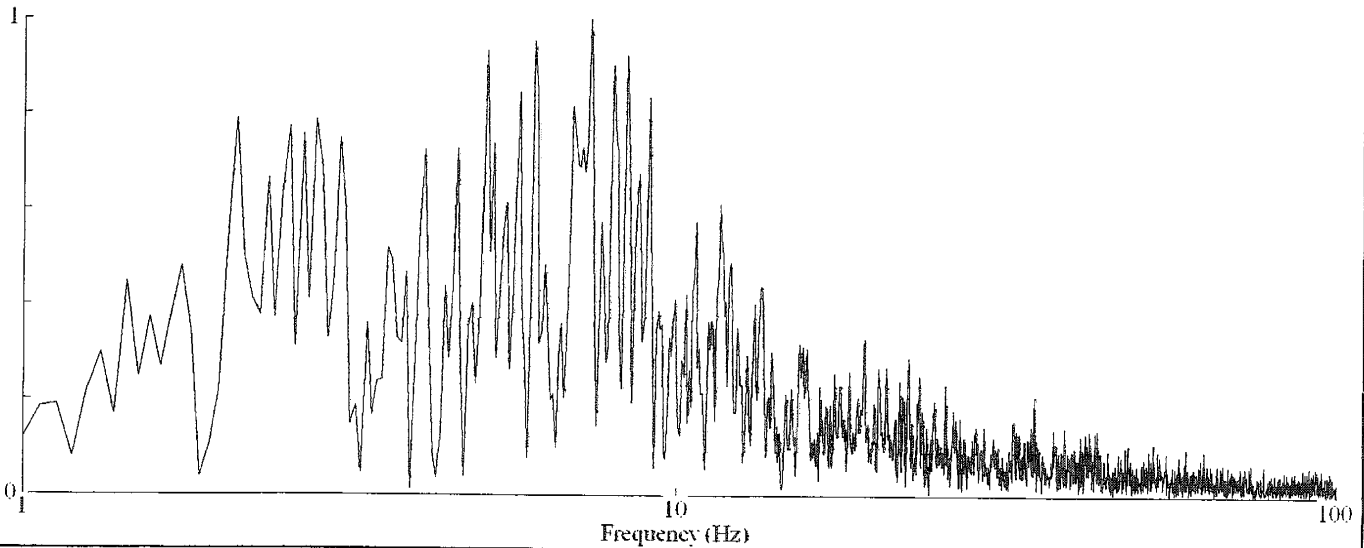
**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
136dB 1.26Mb (0.315Mb/div)  
Time Line Intervals at: 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
7.38 Hz



**Bighorn**

**Lower corner**

**V = SE midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

**Wind**

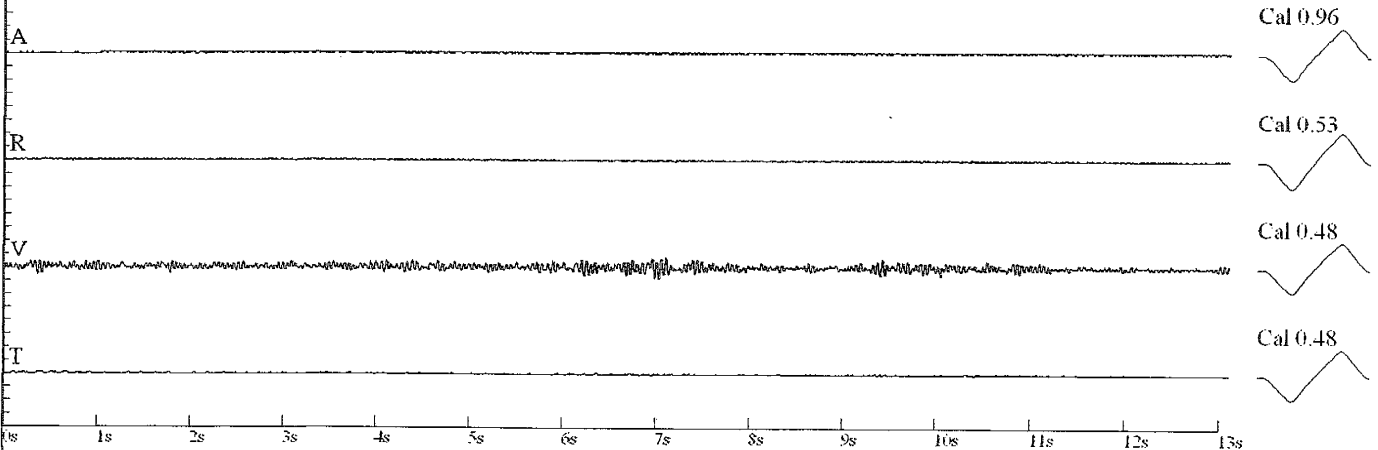
File Name: 01010004.DTB  
Number: 004  
Date: 3 22 2005  
Time: 23:50  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 100 dB ( $\bar{a}$ : 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)  
Radial: 0.005in/s 0.127mm/s ( $\bar{a}$ : 0.0Hz  
Vertical: **0.04in/s 1.016mm/s ( $\bar{a}$ : 21.3Hz**  
Transverse: 0.005in/s 0.127mm/s ( $\bar{a}$ : 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



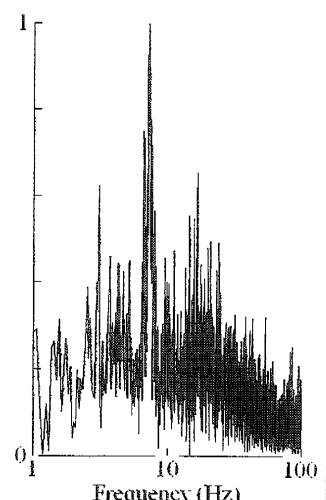
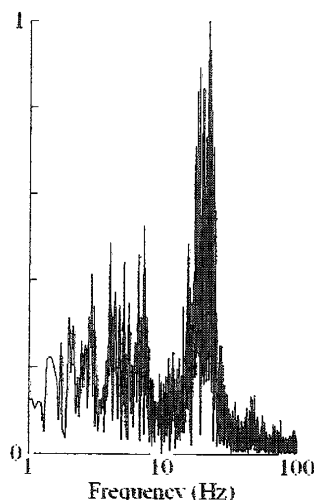
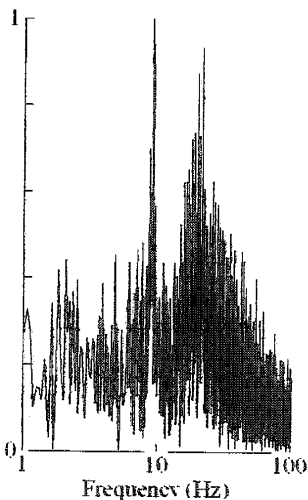
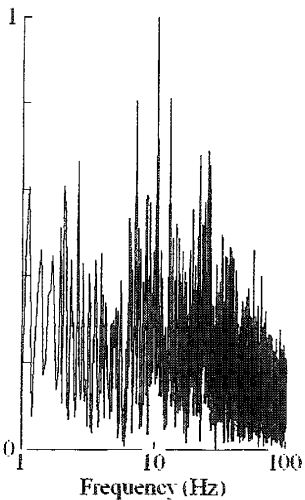
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
10.31 Hz

Radial  
9.19 Hz

Vertical  
21.81 Hz

Transverse  
7.19 Hz





# Bighorn

## Upper corner

V = SW midwall; A = vertical

A channel: 1 Mb = 0.5 ips

R, V, T \* 0.60 factor

Wind

File Name: 02279003.DTB

Number: 003

Date: 3 22 2005

Time: 23:51

Serial Number: 2279

Seismic Trigger: 0.0600 in s 1.5240 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 12.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.2

### Amplitudes and Frequencies

Acoustic: 100 dB @ 0.0 Hz

(0.02Mb 0.0003psi 0.0020kPa)

Radial: 0.02in/s 0.508mm/s @ 0.0Hz

Vertical: 0.09in/s 2.286mm/s @ 17.0Hz

Transverse: 0.02in/s 0.508mm/s @ 0.0Hz

### Graph Information

Duration: 0.000s To: 13.000s

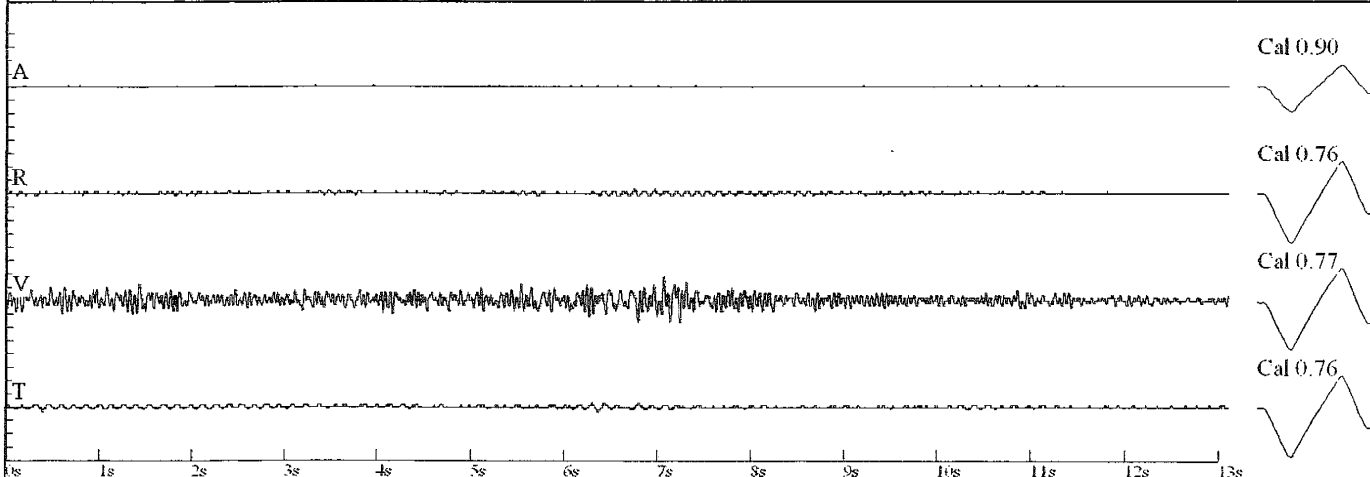
Acoustic Scale:

130dB 0.63Mb (0.158Mb/div)

Seismic Scale:

0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



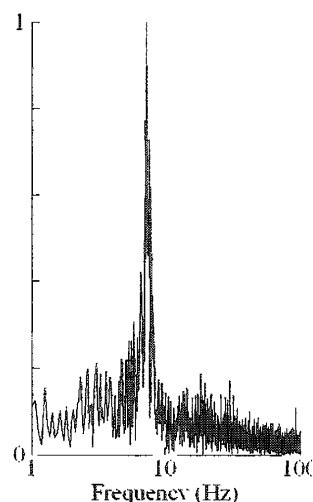
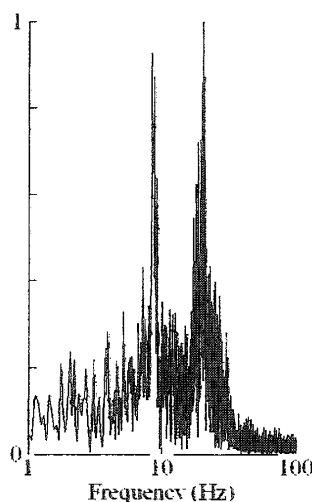
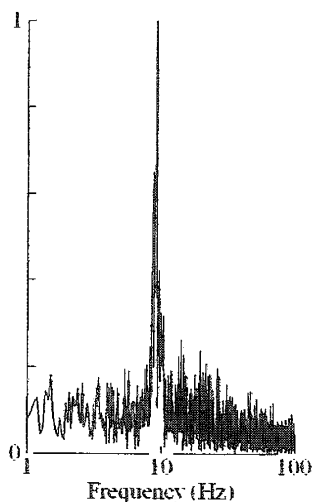
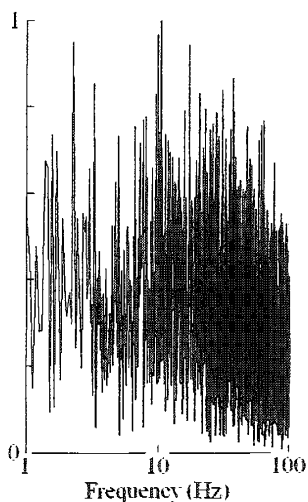
### Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
10.50 Hz

Radial  
9.25 Hz

Vertical  
20.44 Hz

Transverse  
7.19 Hz



**Bighorn**  
**Exterior Master**  
**Wind - 40.3 mps gusts**

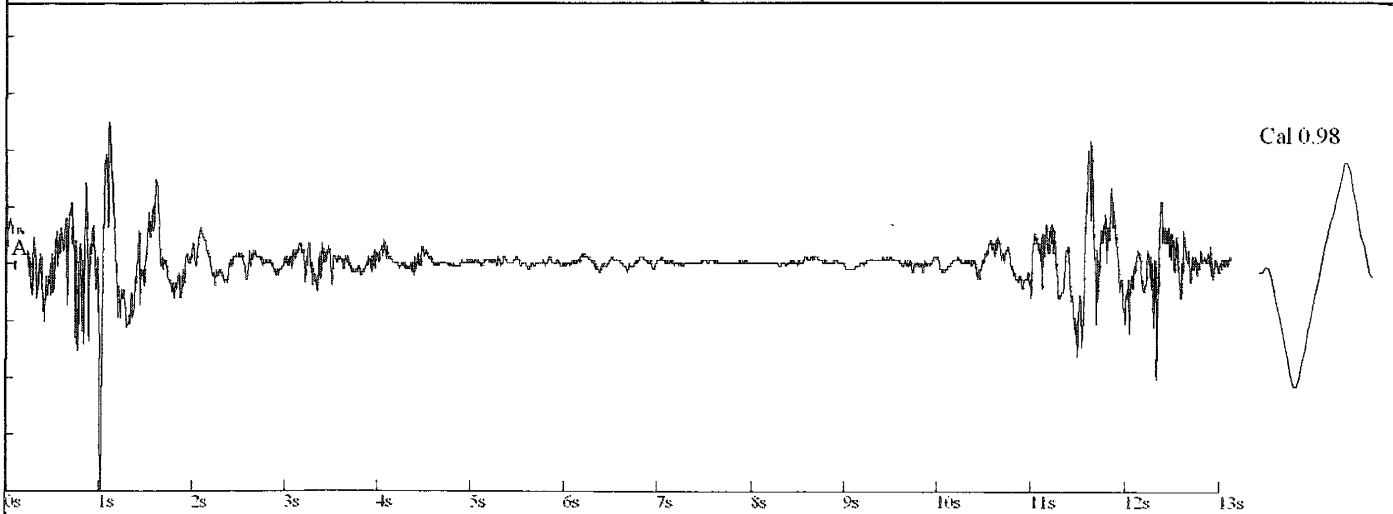
File Name: 03047007.DTB  
Number: 007  
Date: 3 23 2005  
Time: 02:16  
Serial Number: 3047  
Seismic Trigger: 0.0300 in s 0.7620 mm s  
Acoustic Trigger: 133 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 137 dB @ 9.1 Hz  
(1.46Mb 0.0212psi 0.1460kPa)

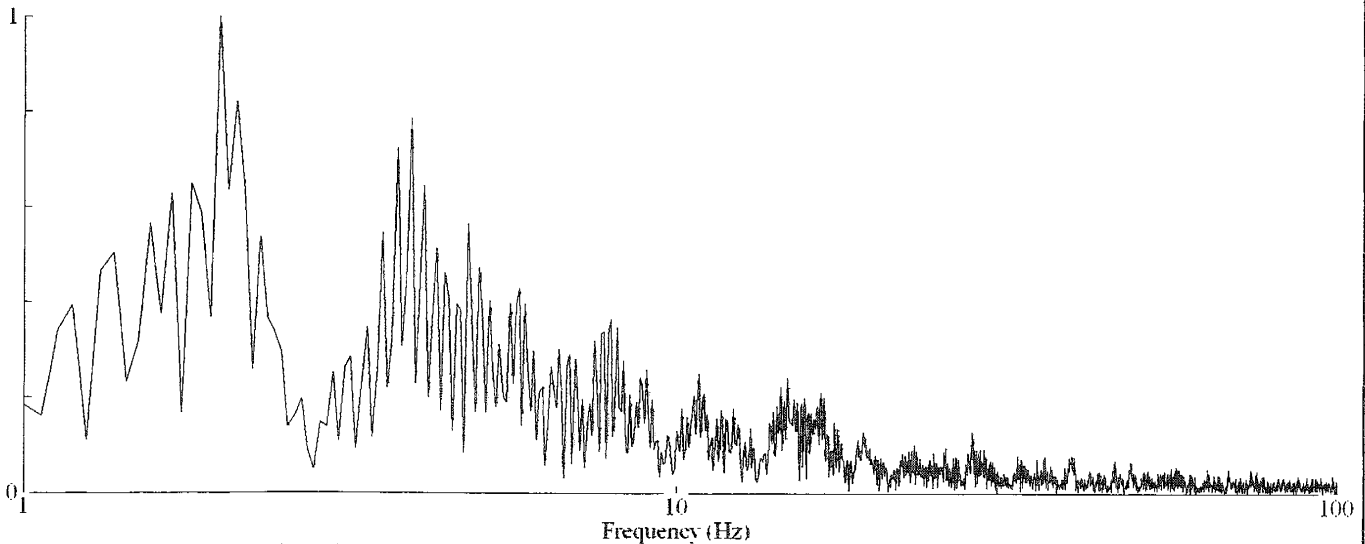
**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
137dB 1.42Mb (0.354Mb/div)  
Time Line Intervals at: 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
2.00 Hz



**Bighorn**

**Lower corner**

**V = SE midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

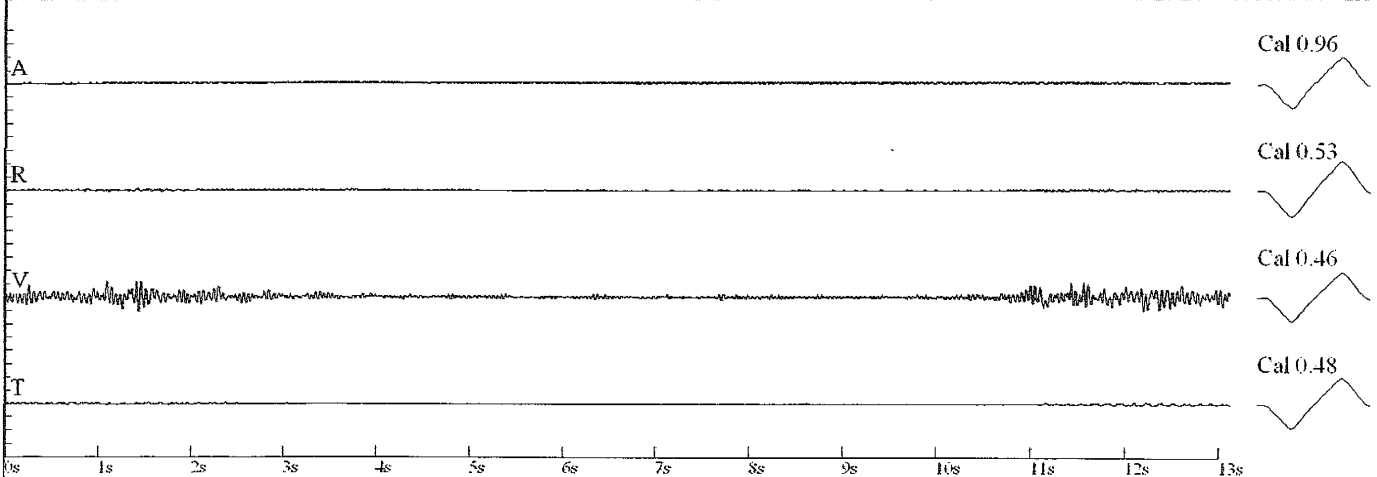
File Name: 01010006.DTB  
Number: 006  
Date: 3 23 2005  
Time: 02:13  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 100 dB /  $\hat{a}$ : 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)  
Radial: 0.01in/s 0.254mm/s /  $\hat{a}$ : 0.0Hz  
Vertical: **0.06in/s 1.524mm/s /  $\hat{a}$ : 15.0Hz**  
Transverse: 0.01in/s 0.254mm/s /  $\hat{a}$ : 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
129dB 0.56Mb (0.141Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



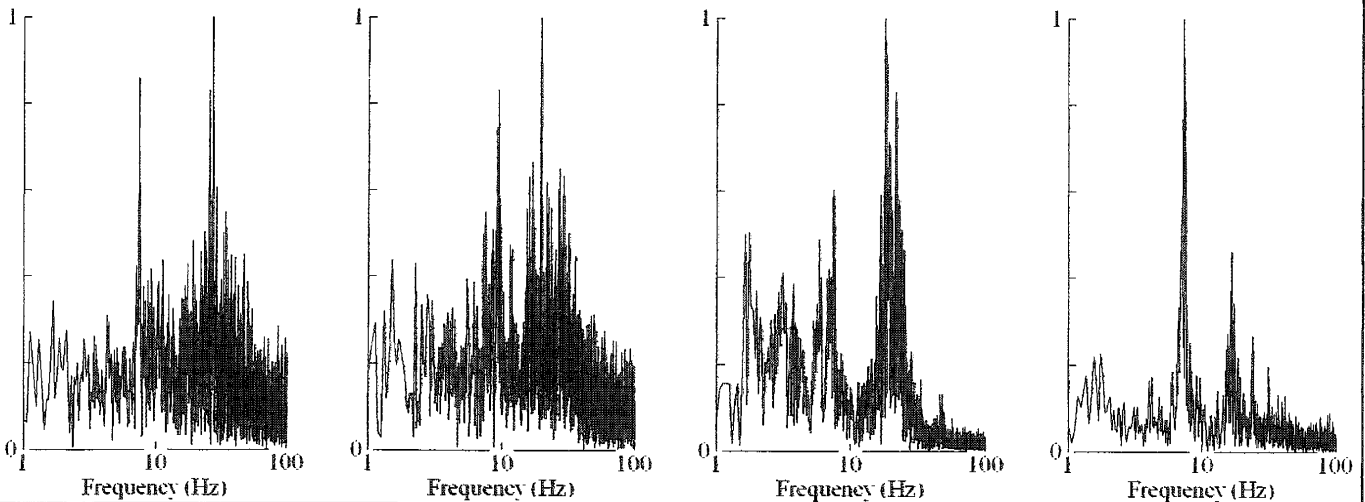
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
27.13 Hz

Radial  
19.56 Hz

Vertical  
18.00 Hz

Transverse  
7.38 Hz



# Bighorn

Upper corner

V = SW midwall; A = vertical

A channel: 1 Mb = 0.5 ips

R, V, T \* 0.60 factor

Wind

File Name: 02279005.DTB

Number: 005

Date: 3 23 2005

Time: 02:14

Serial Number: 2279

Seismic Trigger: 0.0600 in s 1.5240 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 12.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.2

## Amplitudes and Frequencies

Acoustic: 100 dB @ 0.0 Hz

(0.02Mb 0.0003psi 0.0020kPa)

Radial: 0.02in/s 0.508mm/s @ 0.0Hz

Vertical: 0.10in/s 2.54mm/s @ 17.0Hz

Transverse: 0.03in/s 0.762mm/s @ 11.6Hz

## Graph Information

Duration: 0.000s To: 13.000s

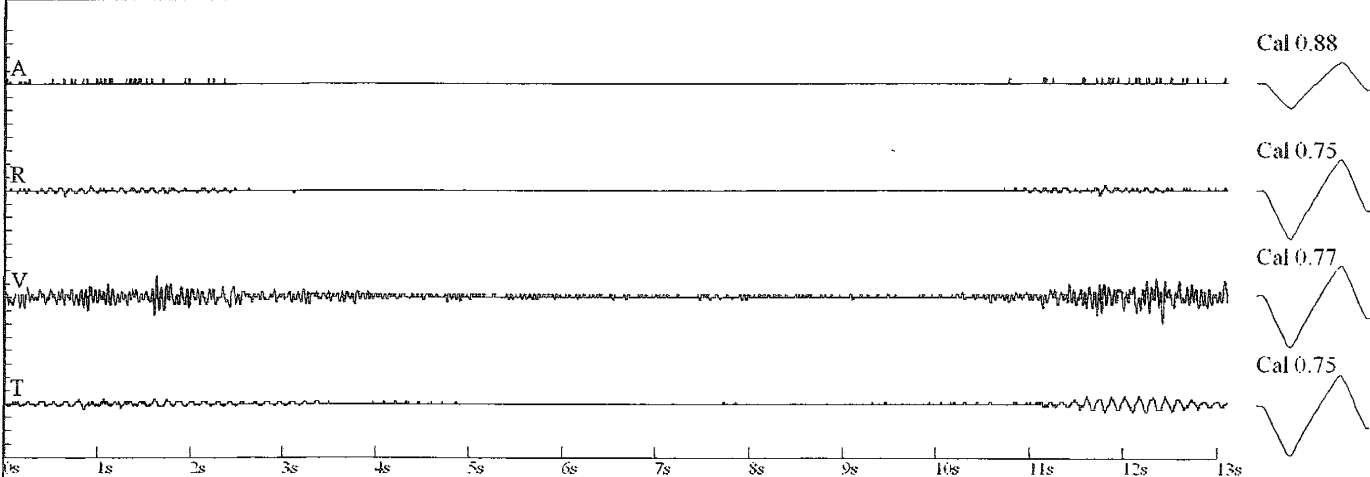
Acoustic Scale:

120dB 0.20Mb (0.050Mb/div)

Seismic Scale:

0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



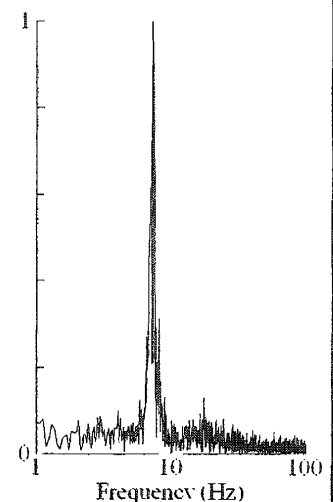
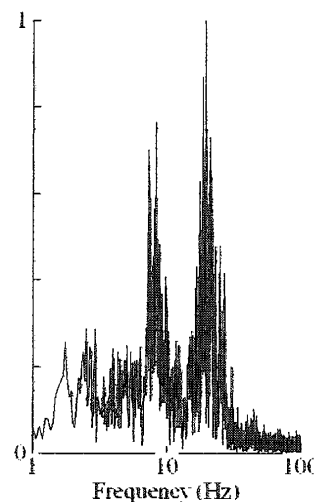
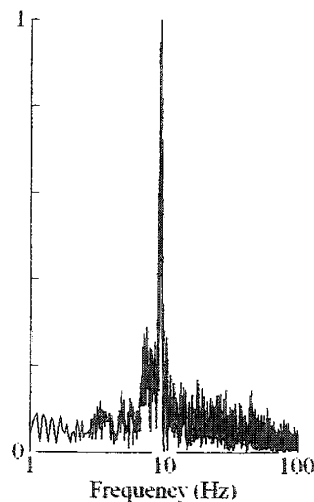
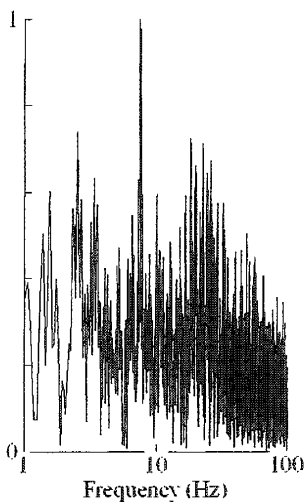
## Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
7.38 Hz

Radial  
9.38 Hz

Vertical  
19.69 Hz

Transverse  
7.38 Hz



**Bighorn Equipment  
Exterior Master**

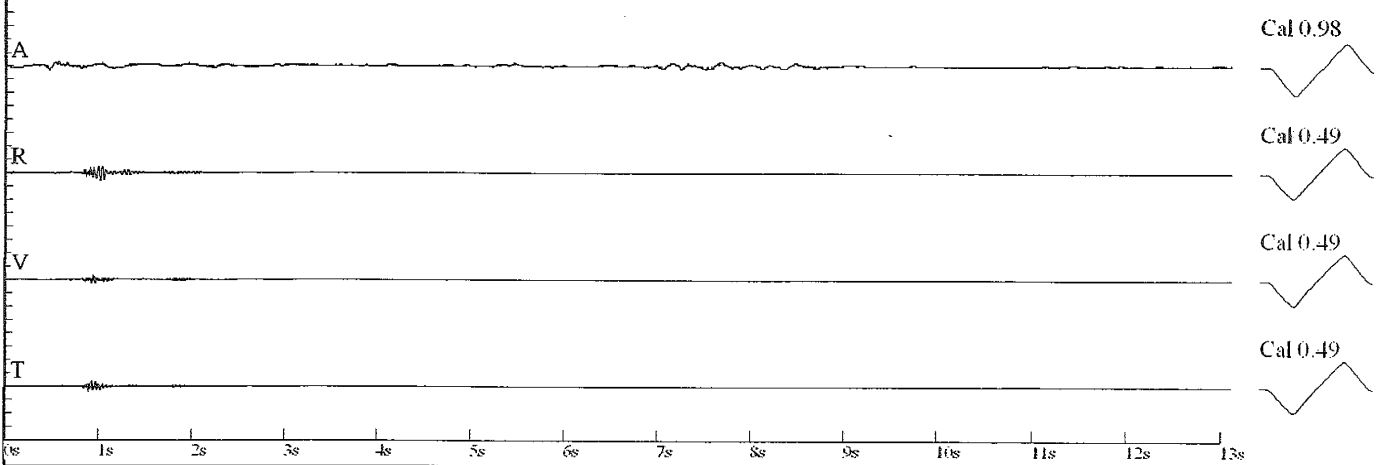
File Name: 03047008.DTB  
 Number: 008  
 Date: 3 23 2005  
 Time: 06:42  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 110 dB @ 5.3 Hz  
 (0.06Mb 0.0009psi 0.0060kPa)  
 Radial: 0.03in/s 0.762mm/s @ 28.4Hz  
 Vertical: 0.01in/s 0.254mm/s @ 0.0Hz  
 Transverse: 0.015in/s 0.381mm/s @ 32.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



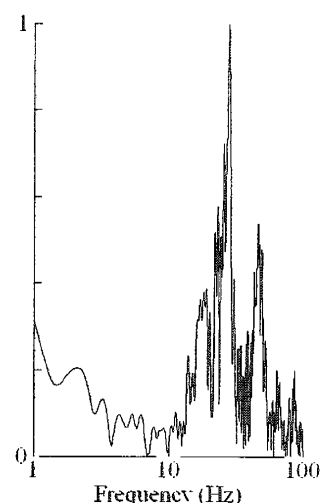
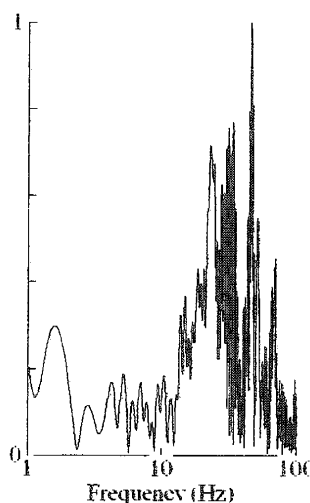
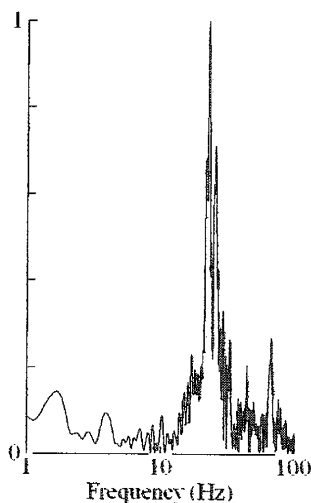
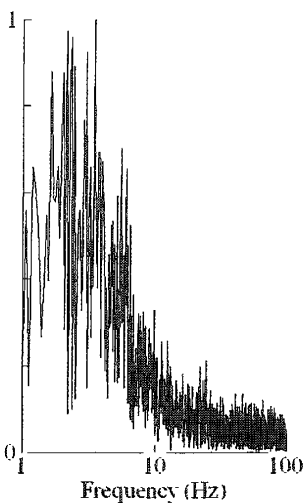
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
3.44 Hz

Radial  
22.88 Hz

Vertical  
46.00 Hz

Transverse  
28.00 Hz



**Bighorn Equipment**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

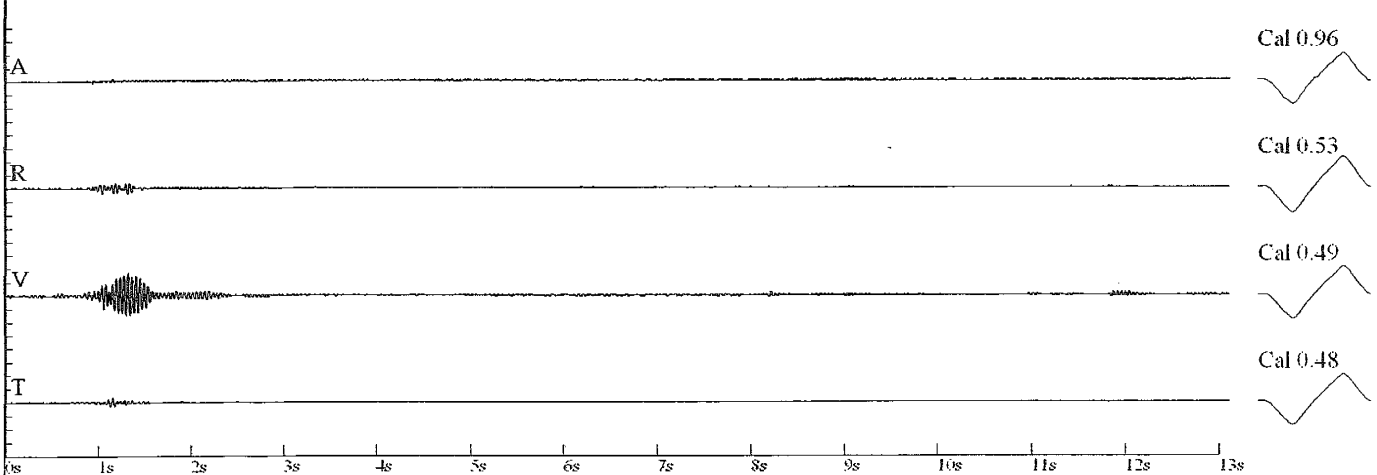
File Name: 01010007.DTB  
 Number: 007  
 Date: 3 23 2005  
 Time: 06:39  
 Serial Number: 1010  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 119 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 106 dB ( $\bar{a}$ : 0.0 Hz  
 (0.04Mb 0.0006psi 0.0040kPa)  
 Radial: 0.02in/s 0.508mm/s ( $\bar{a}$ : 28.4Hz  
 Vertical: 0.085in/s 2.159mm/s ( $\bar{a}$ : 25.6Hz  
 Transverse: 0.02in/s 0.508mm/s ( $\bar{a}$ : 25.6Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



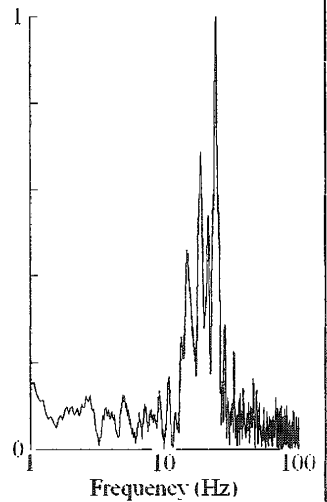
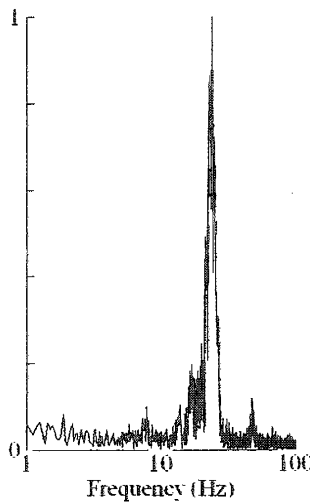
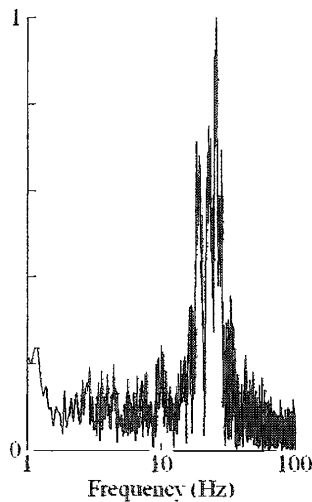
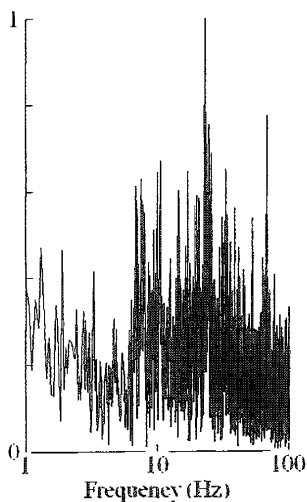
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
23.00 Hz

Radial  
25.81 Hz

Vertical  
24.38 Hz

Transverse  
24.38 Hz



**Bighorn Equipment**

**Upper corner**

**V = SW midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

**R, V, T \* 0.60 factor**

File Name: 02279006.DTB

Number: 006

Date: 3 23 2005

Time: 06:40

Serial Number: 2279

Seismic Trigger: 0.0600 in s 1.5240 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 12.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)

Radial: 0.03in/s 0.762mm/s @ 23.2Hz

Vertical: 0.19in/s 4.826mm/s @ 23.2Hz

Transverse: 0.03in/s 0.762mm/s @ 25.6Hz

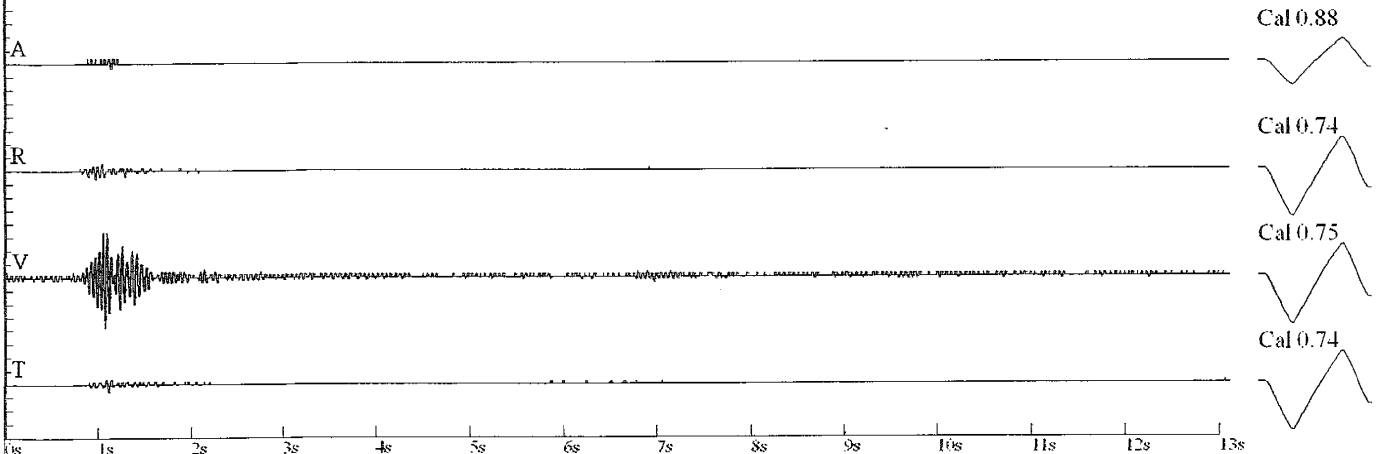
**Graph Information**

Duration: 0.000s To: 13.000s

Acoustic Scale:  
120dB 0.20Mb (0.050Mb/div)

Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



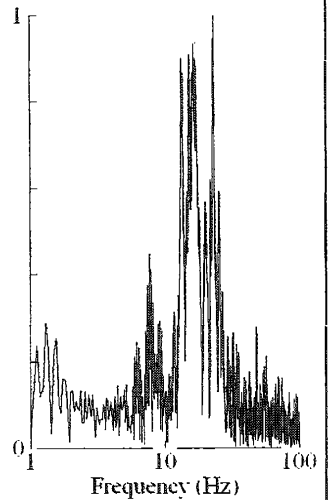
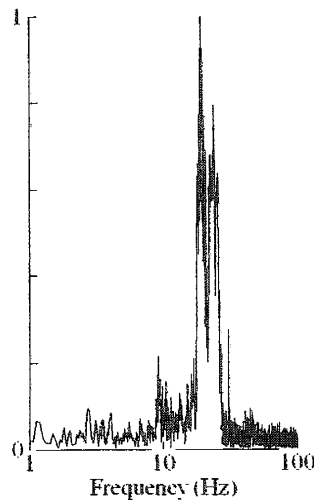
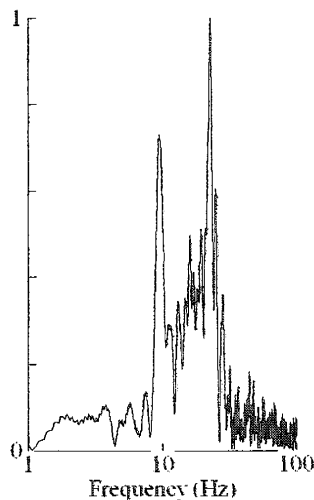
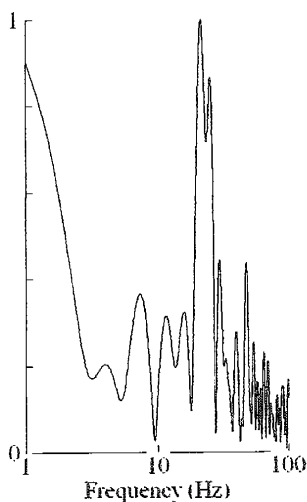
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
21.25 Hz

Radial  
22.88 Hz

Vertical  
19.38 Hz

Transverse  
23.06 Hz



**Bighorn Equipment  
Exterior Master**

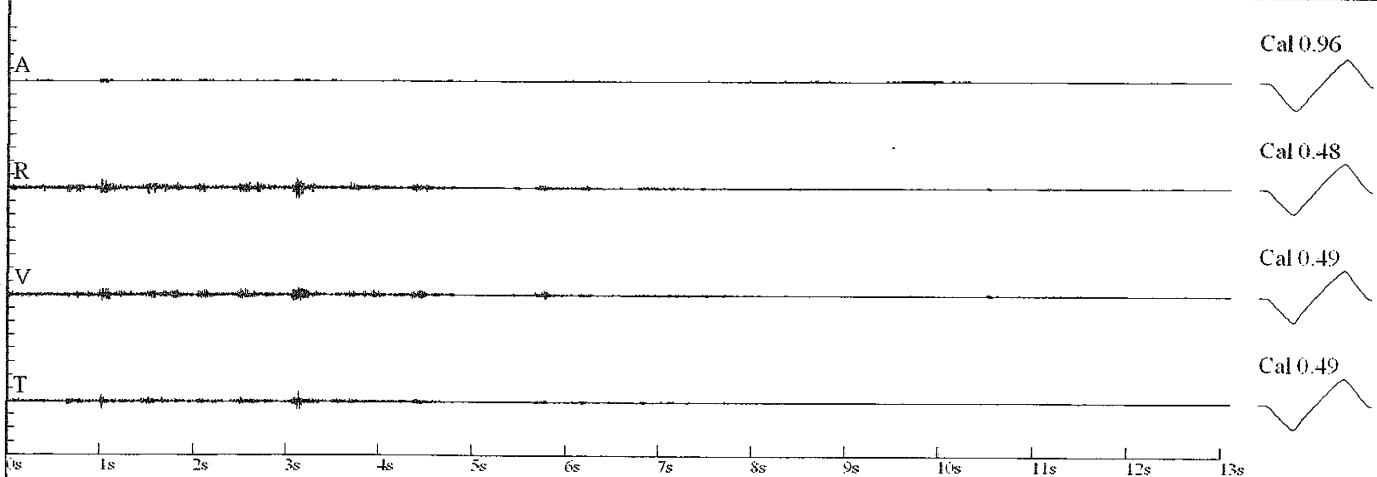
File Name: 03047009.DTB  
 Number: 009  
 Date: 3 23 2005  
 Time: 11:53  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.0

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.04in/s 1.016mm/s @ 85.3Hz  
 Vertical: 0.025in/s 0.635mm/s @ 85.3Hz  
 Transverse: 0.035in/s 0.889mm/s @ 64.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



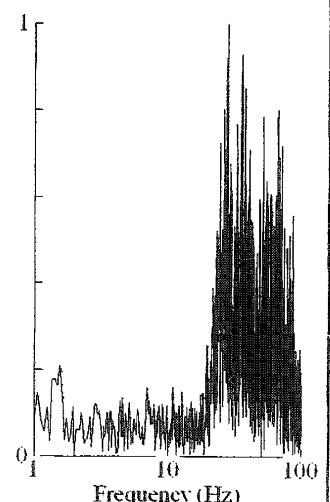
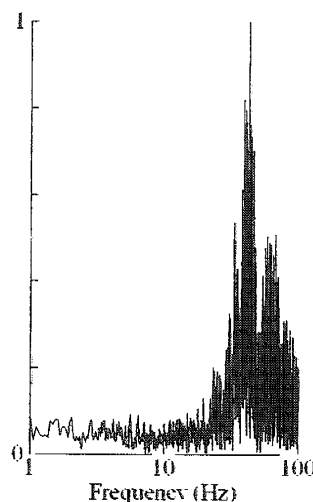
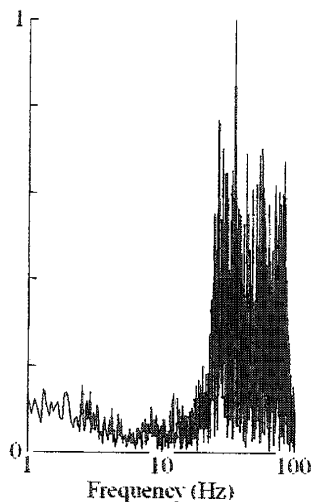
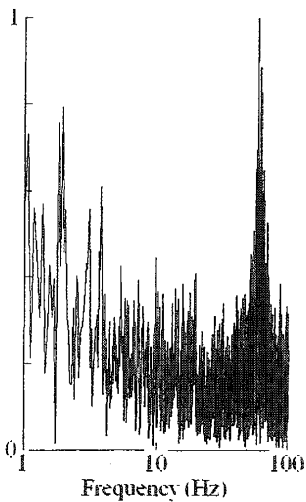
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
58.38 Hz

Radial  
35.00 Hz

Vertical  
43.50 Hz

Transverse  
27.88 Hz





**Bighorn**  
**Lower corner**  
**V = SE midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**

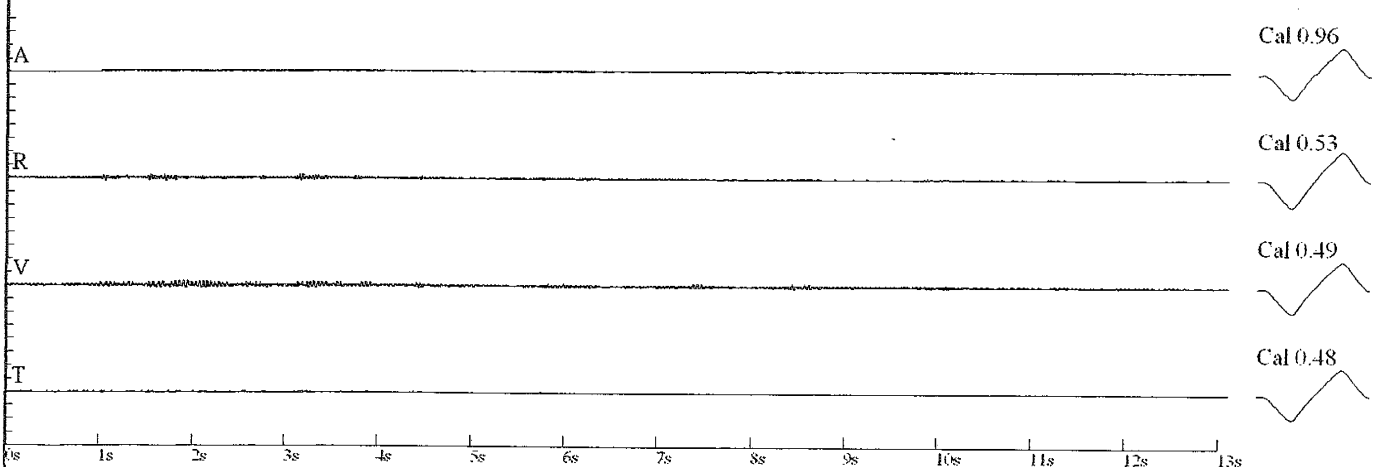
File Name: 01010008.DTB  
 Number: 008  
 Date: 3 23 2005  
 Time: 11:49  
 Serial Number: 1010  
 Seismic Trigger: 0.0400 in s 1.0160 mm s  
 Acoustic Trigger: 119 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.015in/s 0.381mm/s @ 32.0Hz  
 Vertical: 0.015in/s 0.381mm/s @ 36.5Hz  
 Transverse: 0.005in/s 0.127mm/s @ 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



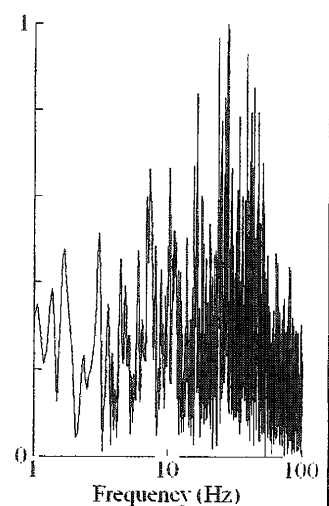
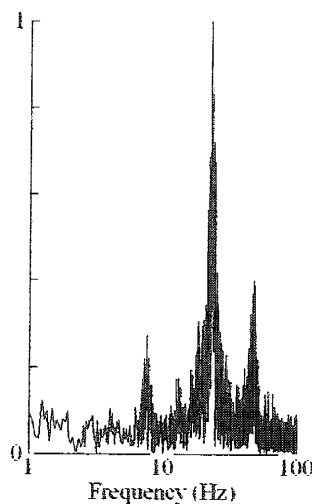
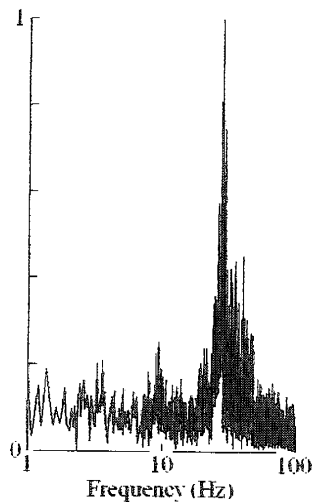
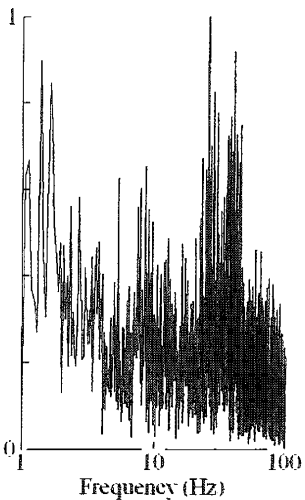
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
25.44 Hz

Radial  
28.50 Hz

Vertical  
22.81 Hz

Transverse  
27.50 Hz



**Bighorn**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

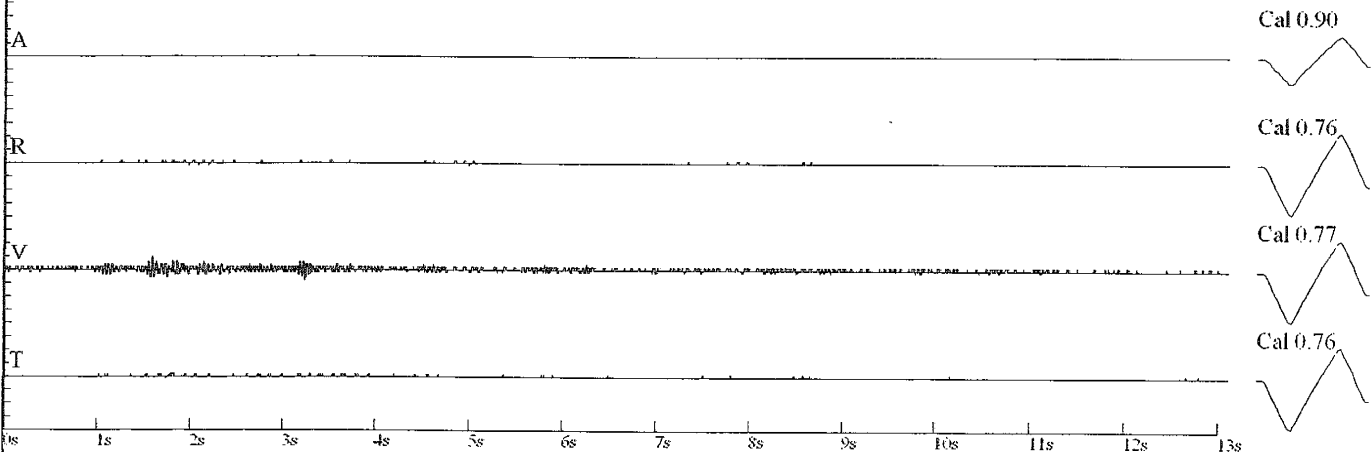
File Name: 02279007.DTB  
 Number: 007  
 Date: 3 23 2005  
 Time: 11:50  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.01in/s 0.254mm/s @ 0.0Hz  
 Vertical: **0.05in/s 1.27mm/s @ 32.0Hz**  
 Transverse: 0.01in/s 0.254mm/s @ 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 130dB 0.63Mb (0.158Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



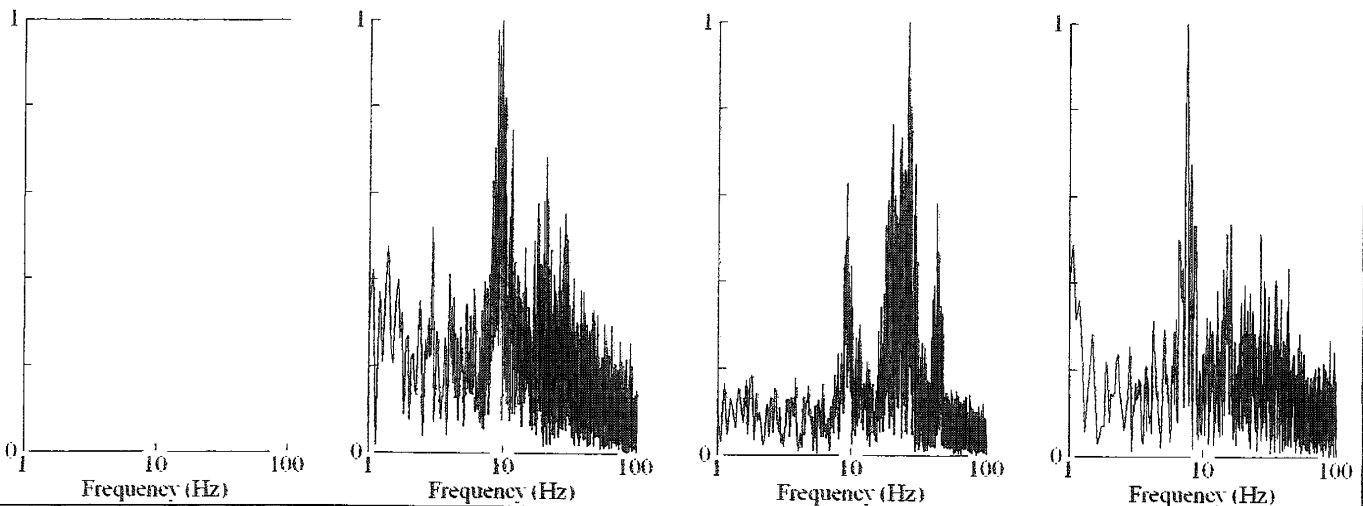
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
 9.69 Hz

Radial  
 9.69 Hz

Vertical  
 26.75 Hz

Transverse  
 7.56 Hz



**Bighorn Equipment**  
**Exterior Master**  
**(no noise)**

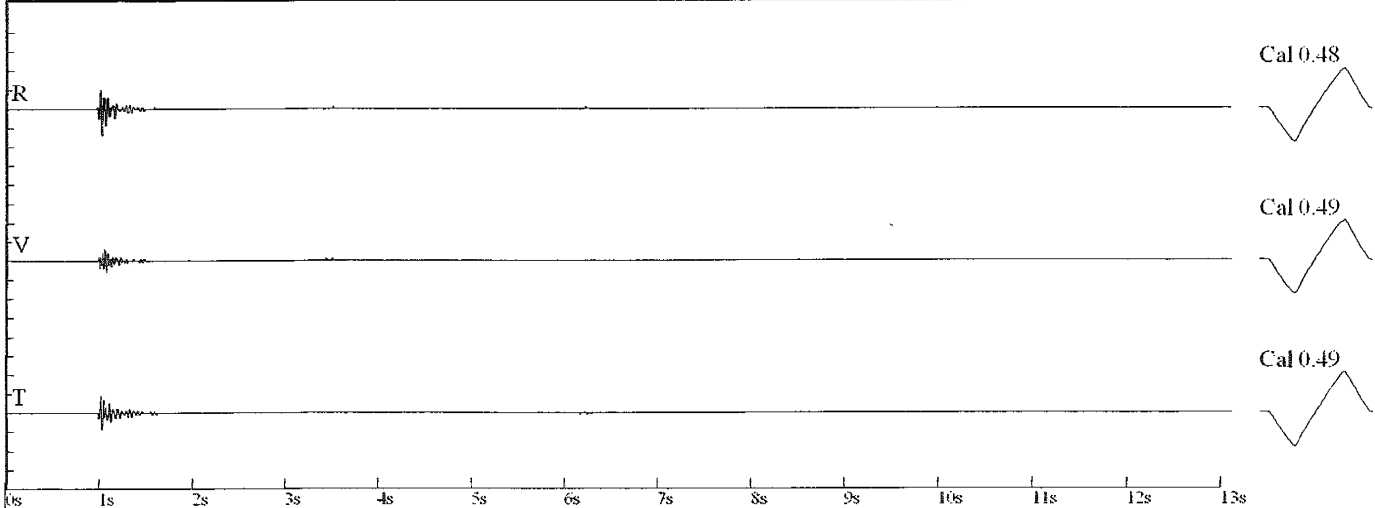
File Name: 03047065.DTB  
 Number: 065  
 Date: 4 12 2005  
 Time: 12:15  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

*Radial:* 0.07in/s 1.778mm/s @ 28.4Hz  
*Vertical:* 0.03in/s 0.762mm/s @ 42.6Hz  
*Transverse:* 0.045in/s 1.143mm/s @ 32.0Hz

**Graph Information**

*Duration:* 0.000s To: 13.000s  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s

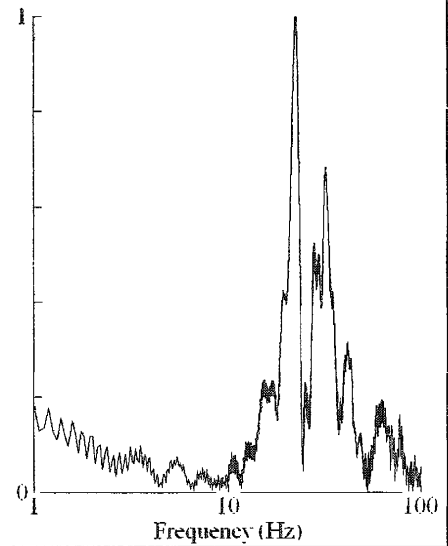
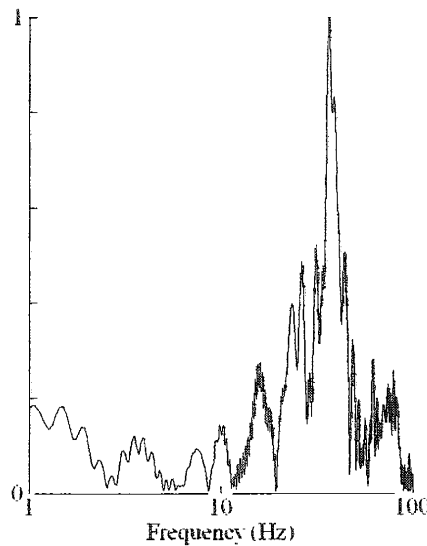
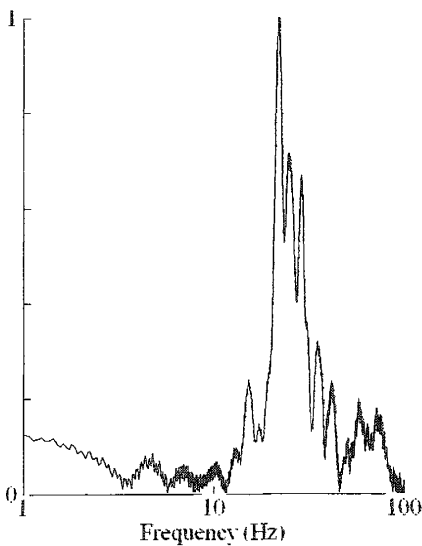


**Fourier Analysis (Power Spectrum - Box Window)**

**Radial**  
**22.06 Hz**

**Vertical**  
**36.44 Hz**

**Transverse**  
**22.44 Hz**



# Bighorn Equipment

Lower corner

V = SE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

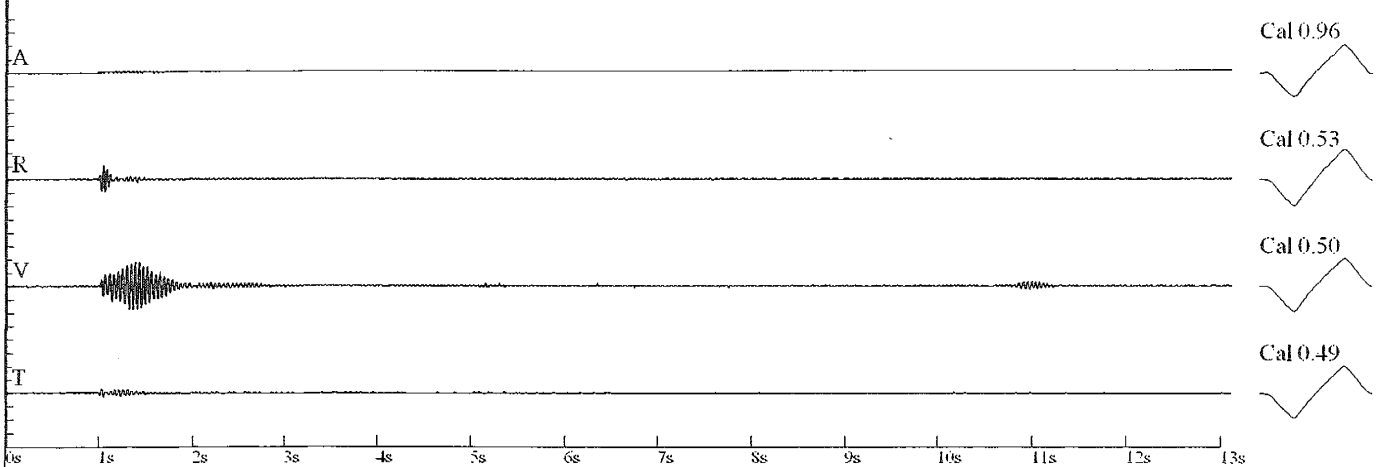
File Name: 01010059.DTB  
Number: 059  
Date: 4 12 2005  
Time: 13:10  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

## Amplitudes and Frequencies

Acoustic: 100 dB ( $\bar{a}$ : 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)  
Radial: 0.055in/s 1.397mm/s ( $\bar{a}$ : 25.6Hz  
Vertical: 0.09in/s 2.286mm/s ( $\bar{a}$ : 21.3Hz  
Transverse: 0.02in/s 0.508mm/s ( $\bar{a}$ : 28.4Hz

## Graph Information

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



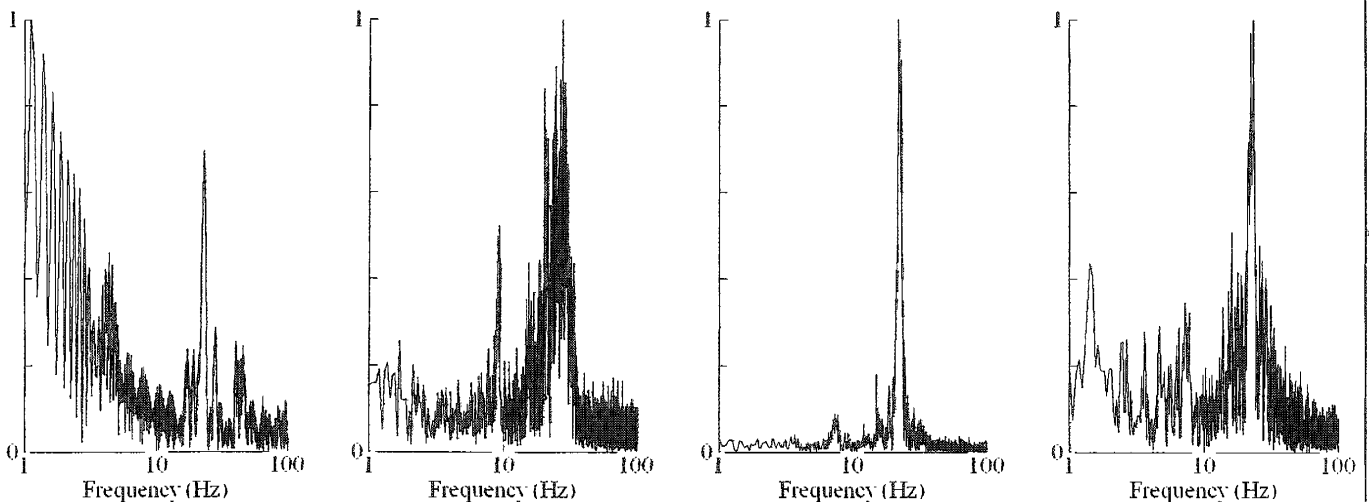
## Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
1.13 Hz

Radial  
27.63 Hz

Vertical  
22.25 Hz

Transverse  
23.19 Hz



**Bighorn Equipment**  
**Upper corner**  
**V = SW midwall; A = vertical**  
**A channel: 1 Mb = 0.5 ips**  
**R,V,T \* 0.60 factor**

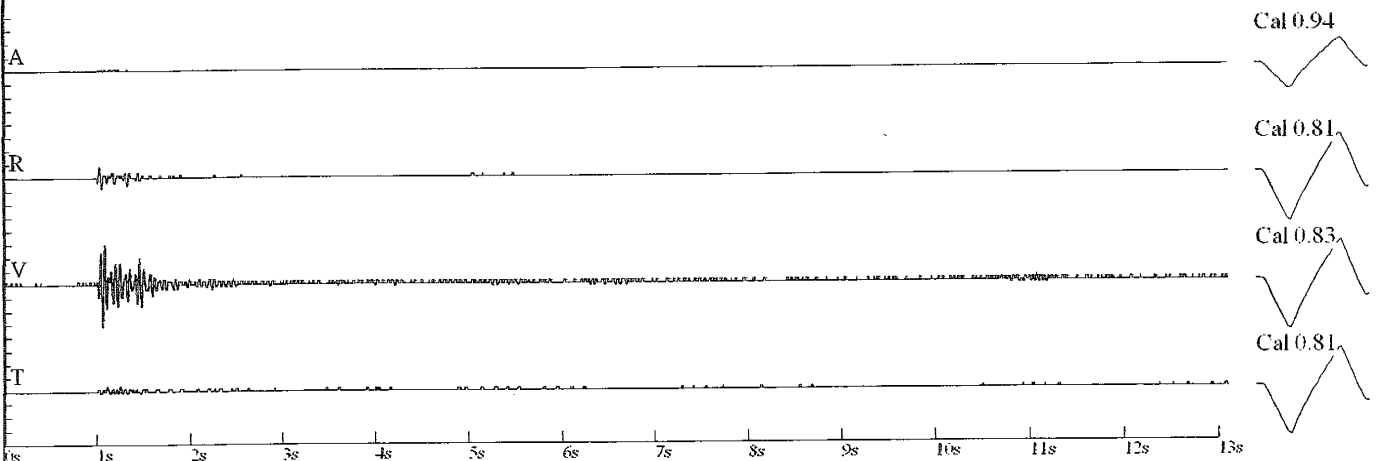
File Name: 02279061.DTB  
 Number: 061  
 Date: 4 12 2005  
 Time: 13:11  
 Serial Number: 2279  
 Seismic Trigger: 0.0600 in s 1.5240 mm s  
 Acoustic Trigger: 125 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 7.1

**Amplitudes and Frequencies**

*Acoustic:* 100 dB ( $\hat{a}$ : 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
*Radial:* 0.04in/s 1.016mm/s ( $\hat{a}$ : 25.6Hz  
*Vertical:* 0.16in/s 4.064mm/s ( $\hat{a}$ : 23.2Hz  
*Transverse:* 0.02in/s 0.508mm/s ( $\hat{a}$ : 0.0Hz

**Graph Information**

*Duration:* 0.000s To: 13.000s  
*Acoustic Scale:*  
 130dB 0.63Mb (0.158Mb/div)  
*Seismic Scale:*  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
*Time Line Intervals at:* 1.00 s



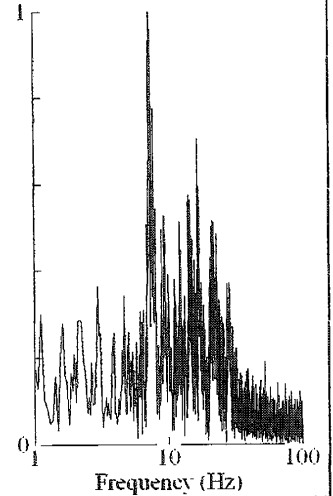
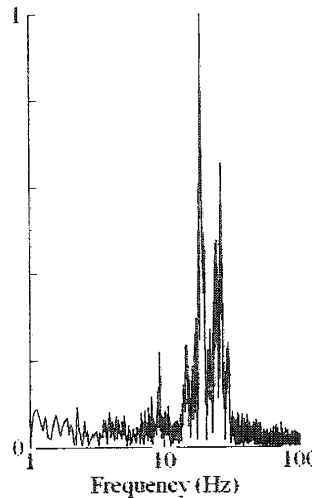
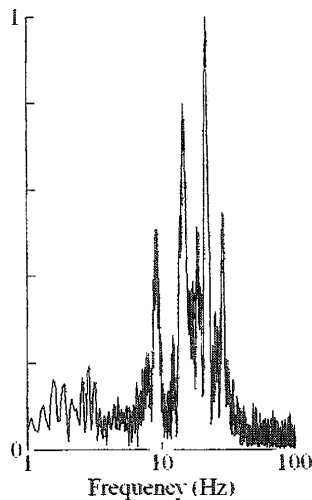
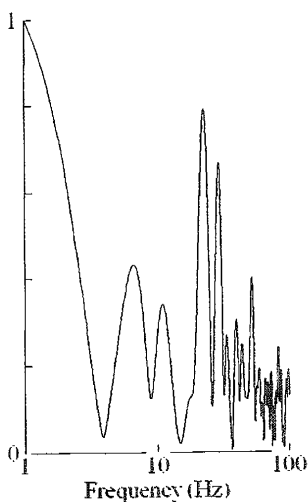
**Fourier Analysis (Power Spectrum - Box Window)**

**Acoustic**  
**1.00 Hz**

**Radial**  
**21.88 Hz**

**Vertical**  
**19.00 Hz**

**Transverse**  
**7.25 Hz**



**Bighorn Equipment  
Exterior Master**

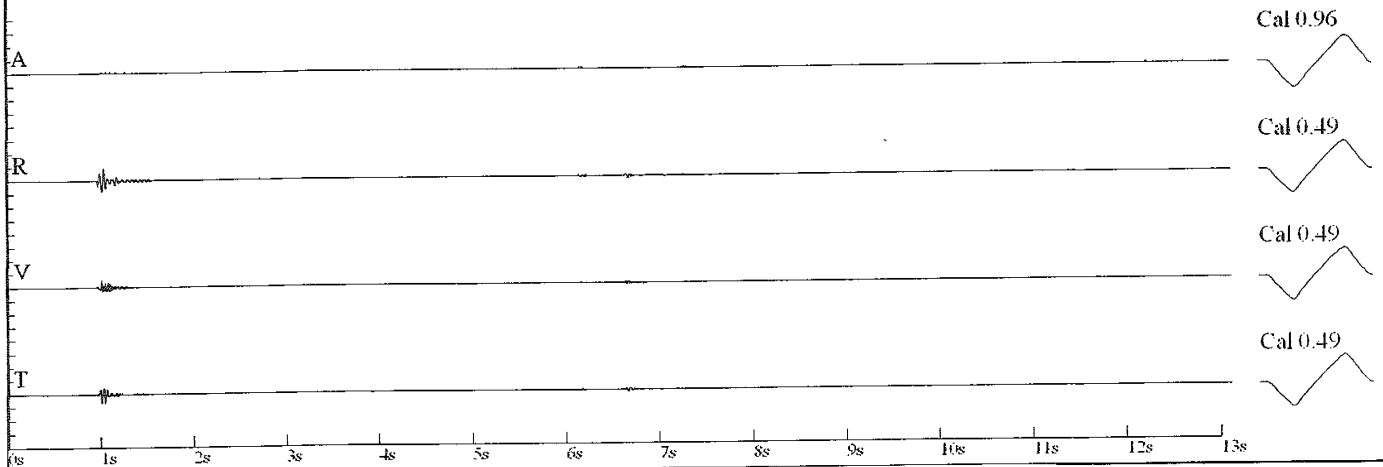
File Name: 03047066.DTB  
 Number: 066  
 Date: 4 13 2005  
 Time: 10:46  
 Serial Number: 3047  
 Seismic Trigger: 0.0300 in s 0.7620 mm s  
 Acoustic Trigger: 133 dB  
 Sample Rate: 512  
 Record Duration: 12.0 Seconds  
 Pre-Trigger: 1.00 Seconds  
 Sensor Gain: 2x  
 Battery: 6.9

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
 (0.02Mb 0.0003psi 0.0020kPa)  
 Radial: 0.045in/s 1.143mm/s @ 32.0Hz  
 Vertical: 0.025in/s 0.635mm/s @ 51.2Hz  
 Transverse: 0.035in/s 0.889mm/s @ 32.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
 Acoustic Scale:  
 129dB 0.56Mb (0.141Mb/div)  
 Seismic Scale:  
 0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
 Time Line Intervals at: 1.00 s



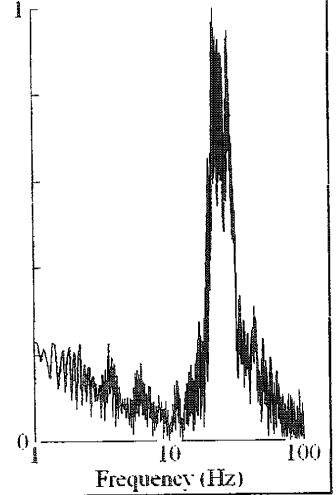
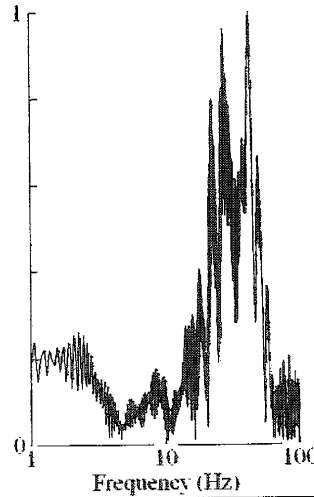
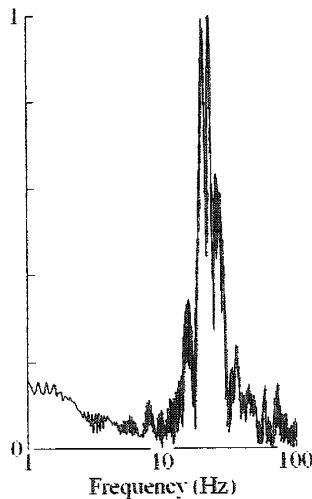
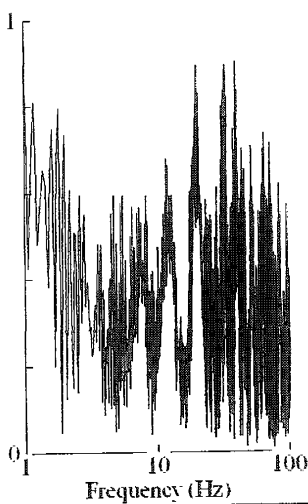
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.00 Hz

Radial  
23.19 Hz

Vertical  
43.25 Hz

Transverse  
22.13 Hz



**Bighorn Equipment**

**Lower corner**

**V = SE midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

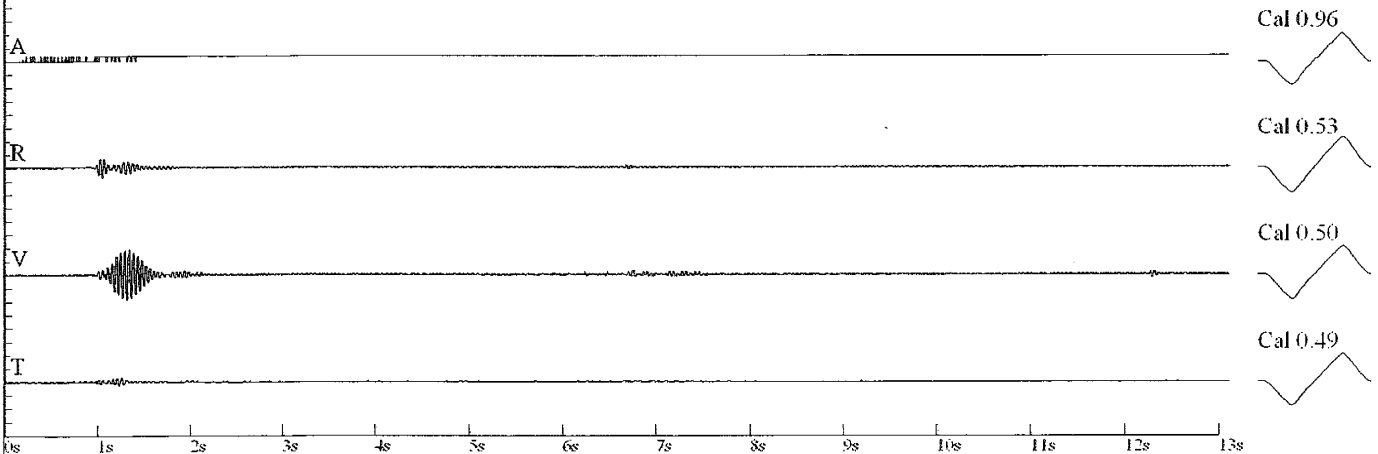
File Name: 01010060.DTB  
Number: 060  
Date: 4 13 2005  
Time: 11:41  
Serial Number: 1010  
Seismic Trigger: 0.0400 in s 1.0160 mm s  
Acoustic Trigger: 119 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)  
Radial: 0.035in/s 0.889mm/s @ 23.2Hz  
Vertical: 0.095in/s 2.413mm/s @ 21.3Hz  
Transverse: 0.02in/s 0.508mm/s @ 21.3Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
120dB 0.20Mb (0.050Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



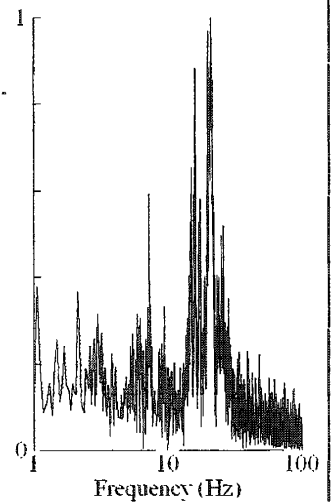
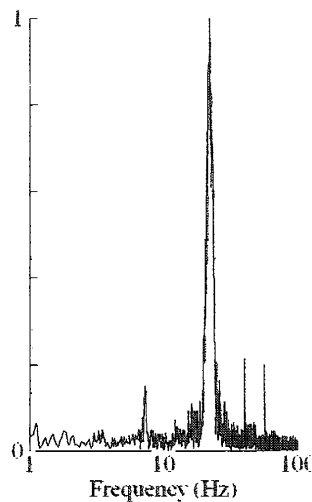
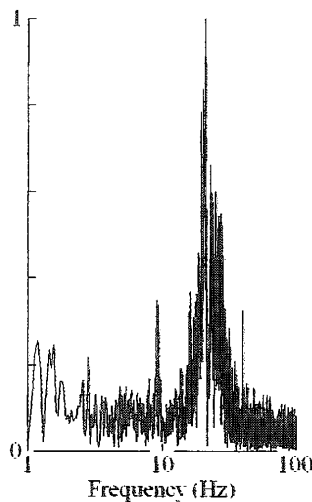
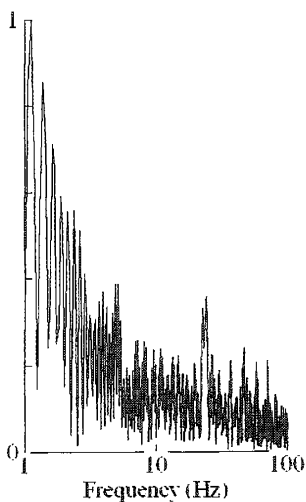
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.13 Hz

Radial  
21.06 Hz

Vertical  
22.06 Hz

Transverse  
21.06 Hz



**Bighorn Equipment**

**Upper corner**

**V = SW midwall; A = vertical**

**A channel: 1 Mb = 0.5 ips**

**R,V,T \* 0.60 factor**

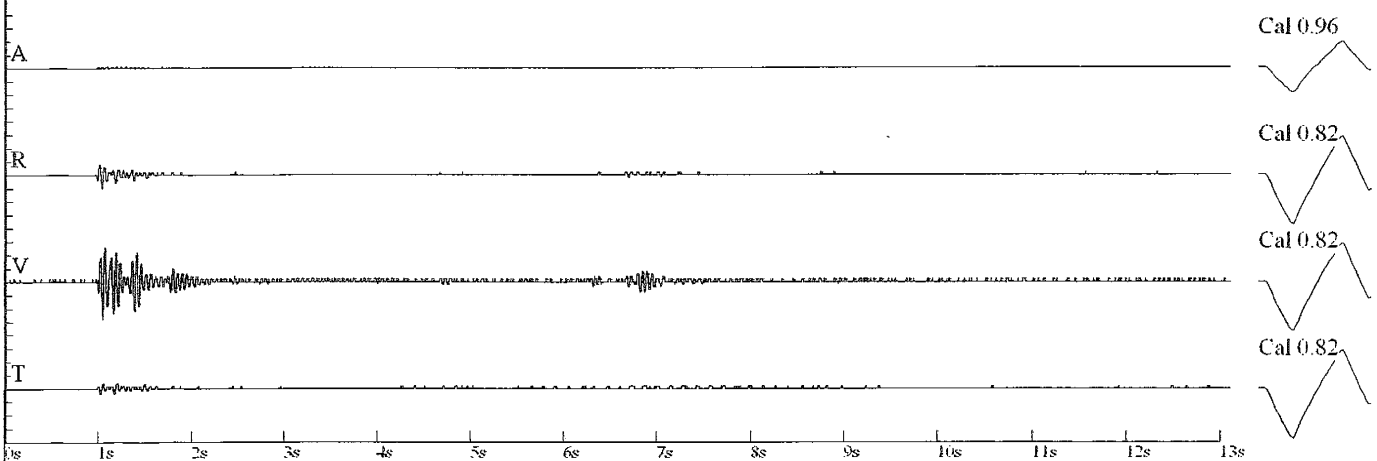
File Name: 02279062.DTB  
Number: 062  
Date: 4 13 2005  
Time: 11:42  
Serial Number: 2279  
Seismic Trigger: 0.0600 in s 1.5240 mm s  
Acoustic Trigger: 125 dB  
Sample Rate: 512  
Record Duration: 12.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 100 dB @ 0.0 Hz  
(0.02Mb 0.0003psi 0.0020kPa)  
Radial: 0.05in/s 1.27mm/s @ 25.6Hz  
Vertical: 0.14in/s 3.556mm/s @ 23.2Hz  
Transverse: 0.02in/s 0.508mm/s @ 0.0Hz

**Graph Information**

Duration: 0.000s To: 13.000s  
Acoustic Scale:  
129dB 0.56Mb (0.141Mb/div)  
Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)  
Time Line Intervals at: 1.00 s



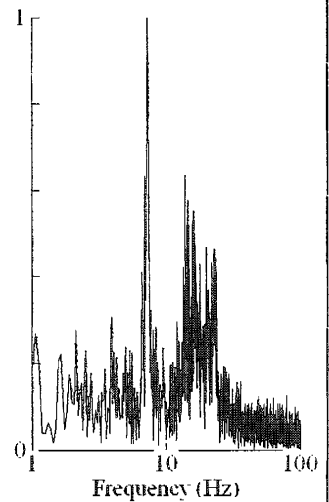
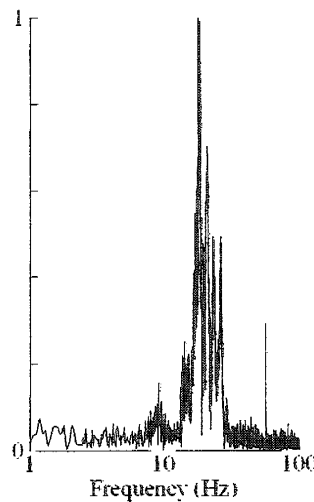
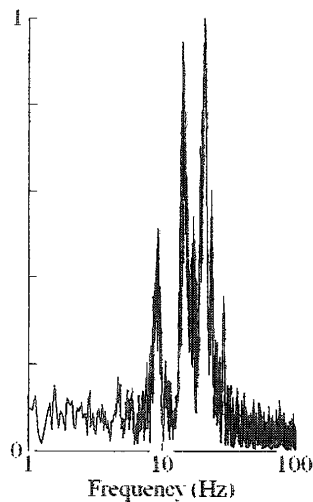
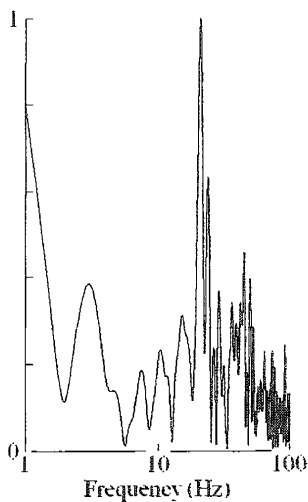
**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
20.81 Hz

Radial  
20.88 Hz

Vertical  
18.19 Hz

Transverse  
7.31 Hz





**High Mesa Thunder storm and wind  
Exterior Master**

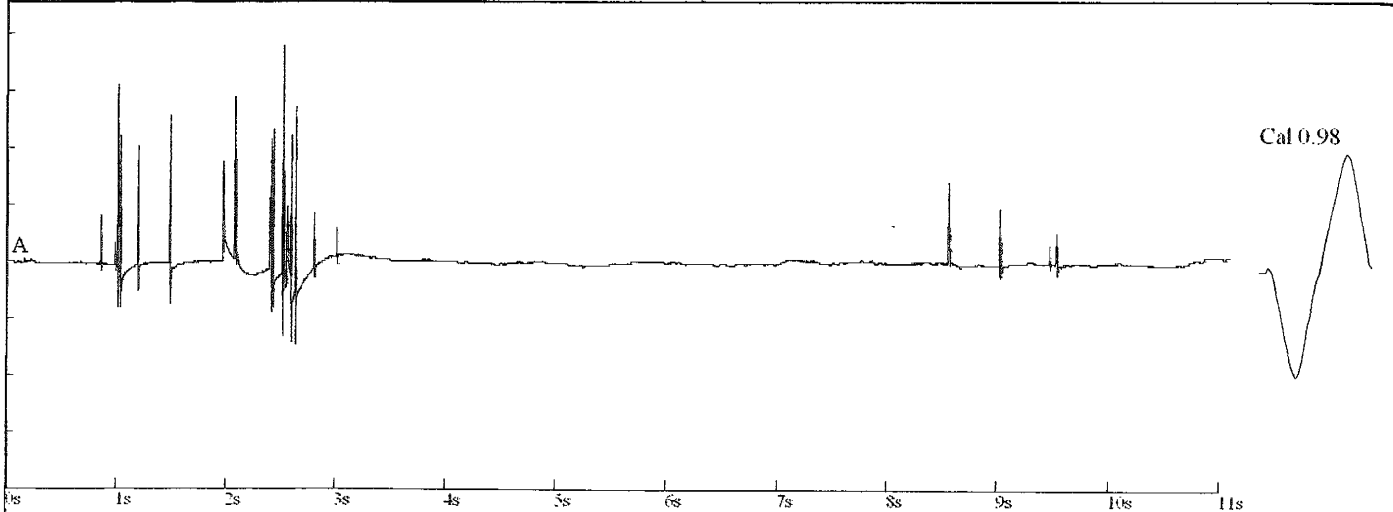
File Name: 01258069.DTB  
Number: 069  
Date: 3 22 2005  
Time: 23:52  
Serial Number: 1258  
Seismic Trigger: 0.0250 in s 0.6350 mm s  
Acoustic Trigger: 125 dB  
Sample Rate: 512  
Record Duration: 10.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.2

**Amplitudes and Frequencies**

Acoustic: 141 dB @ 85.3 Hz  
(2.12Mb 0.0307psi 0.2120kPa)

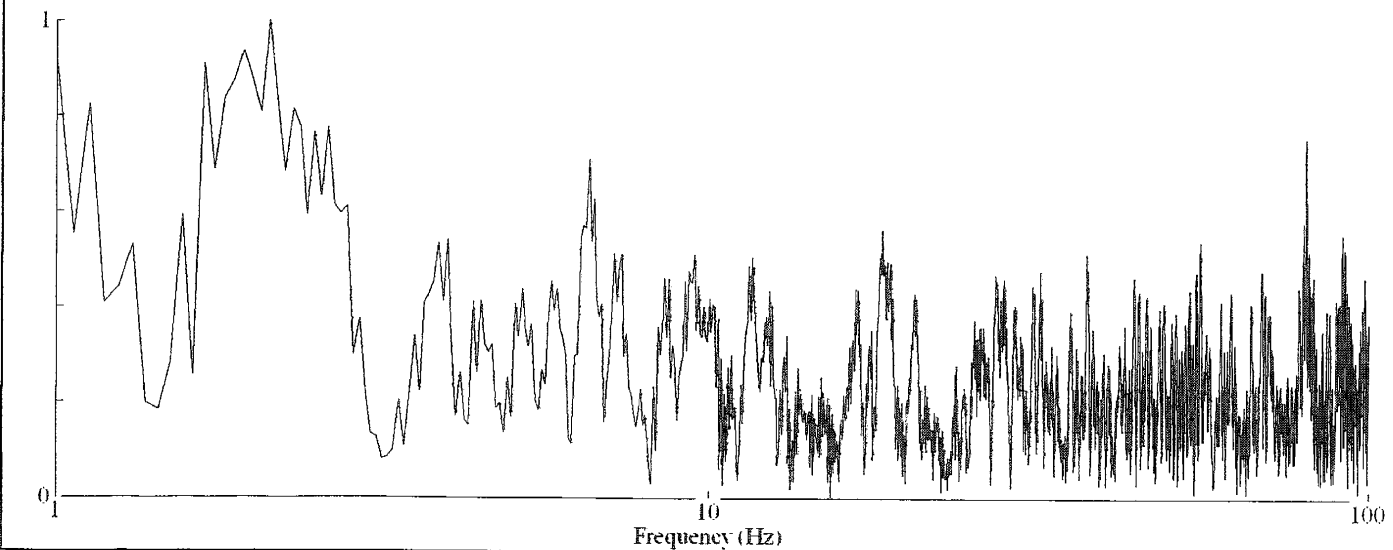
**Graph Information**

Duration: 0.000s To: 11.000s  
Acoustic Scale:  
141dB 2.24Mb (0.561Mb/div)  
Time Line Intervals at: 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
2.13 Hz



# High Mesa Thunder storm and wind

Upper corner

V = NE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

File Name: 02276310.DTB

Number: 310

Date: 3 22 2005

Time: 23:53

Serial Number: 2276

Seismic Trigger: 0.0300 in s 0.7620 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 10.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.2

## Amplitudes and Frequencies

Acoustic: <100 dB

Radial: 0.01in/s 0.254mm/s @ 0.0Hz

Vertical: 0.03in/s 0.762mm/s @ 13.4Hz

Transverse: 0.01in/s 0.254mm/s @ 0.0Hz

## Graph Information

Duration: 0.000s To: 11.000s

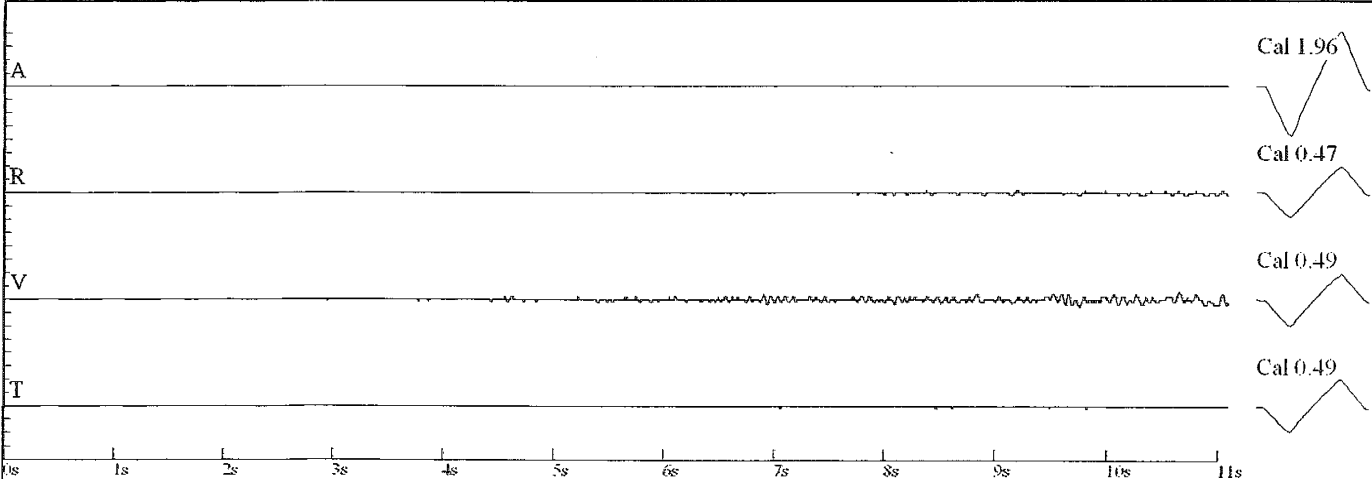
Acoustic Scale:

120dB 0.20Mb (0.050Mb/div)

Seismic Scale:

0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



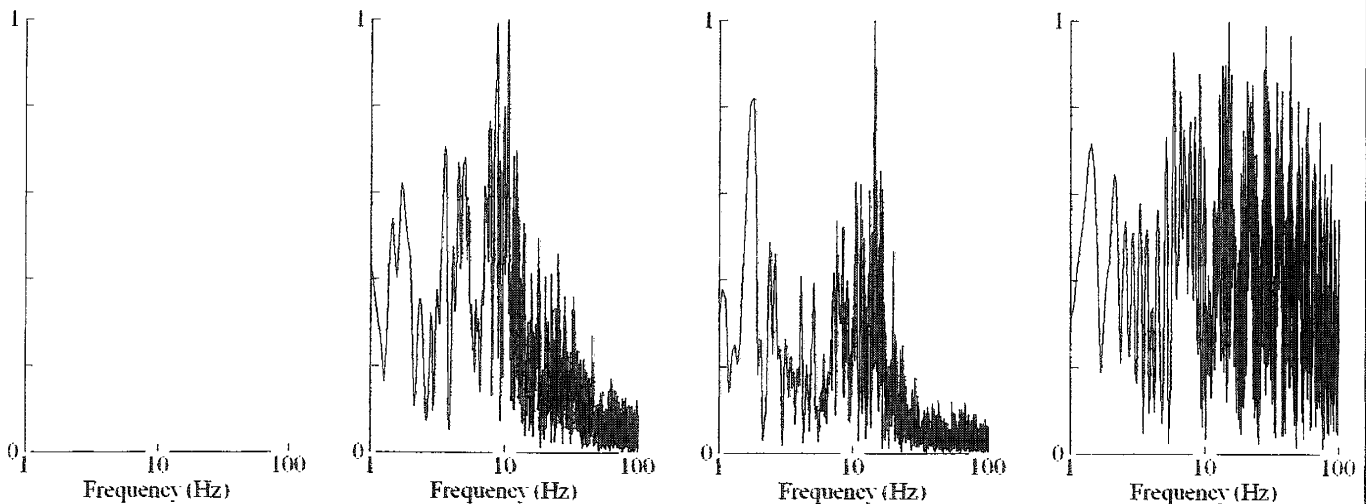
## Fourier Analysis (Power Spectrum - Box Window)

Acoustic

Radial  
10.44 Hz

Vertical  
14.63 Hz

Transverse  
15.00 Hz



**High Mesa Thunder storm and wind  
Exterior Master**

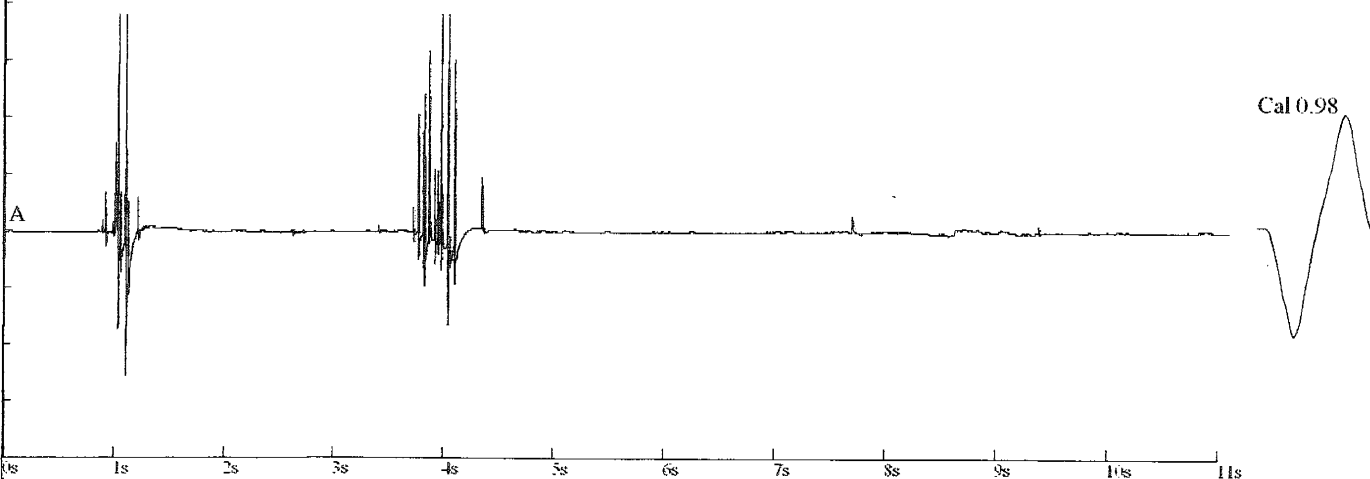
File Name: 01258065.DTB  
Number: 065  
Date: 3/22/2005  
Time: 23:50  
Serial Number: 1258  
Seismic Trigger: 0.0250 in s 0.6350 mm s  
Acoustic Trigger: 125 dB  
Sample Rate: 512  
Record Duration: 10.0 Seconds  
Pre-Trigger: 1.00 Seconds  
Sensor Gain: 2x  
Battery: 7.1

**Amplitudes and Frequencies**

Acoustic: 141 dB @ 85.3 Hz  
(2.12Mb 0.0307psi 0.2120kPa)

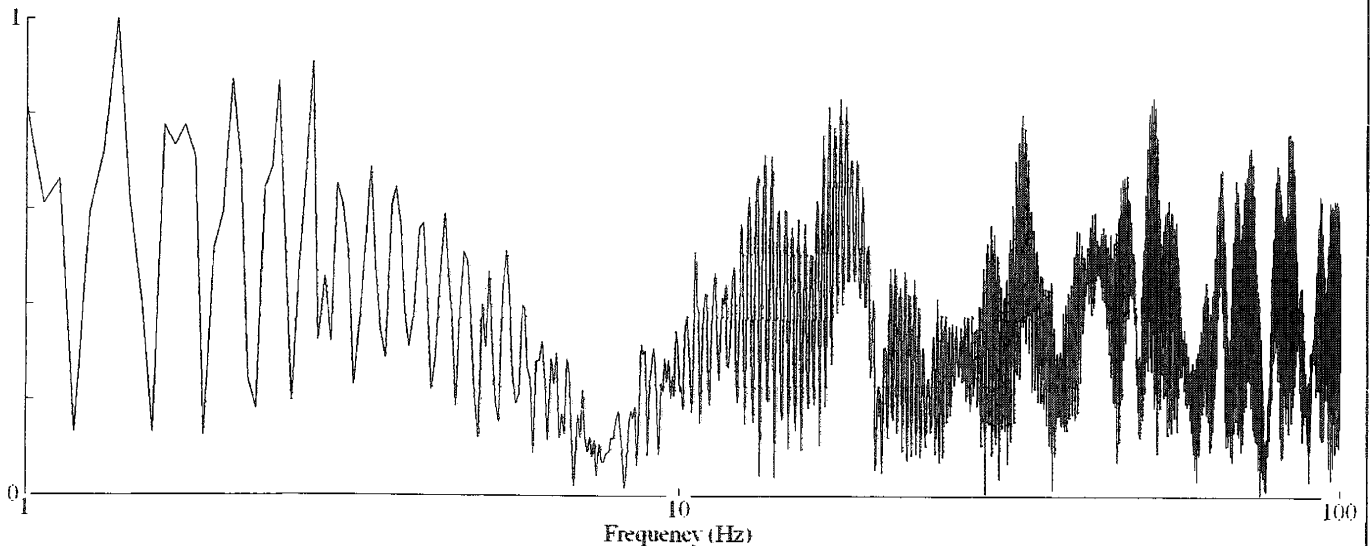
**Graph Information**

Duration: 0.000s To: 11.000s  
Acoustic Scale:  
141dB 2.24Mb (0.561Mb/div)  
Time Line Intervals at: 1.00 s



**Fourier Analysis (Power Spectrum - Box Window)**

Acoustic  
1.38 Hz



# High Mesa Thunder storm and wind

Upper corner

V = NE midwall; A = vertical

A channel: 1 Mb = 0.5 ips

File Name: 02276306.DTB

Number: 306

Date: 3 22 2005

Time: 23:51

Serial Number: 2276

Seismic Trigger: 0.0300 in s 0.7620 mm s

Acoustic Trigger: 125 dB

Sample Rate: 512

Record Duration: 10.0 Seconds

Pre-Trigger: 1.00 Seconds

Sensor Gain: 2x

Battery: 7.1

## Amplitudes and Frequencies

Acoustic: 106 dB @ 0.0 Hz  
(0.04Mb 0.0006psi 0.0040kPa)

Radial: 0.01in/s 0.254mm/s @ 0.0Hz

Vertical: 0.04in/s 1.016mm/s @ 128.0Hz

Transverse: 0.01in/s 0.254mm/s @ 0.0Hz

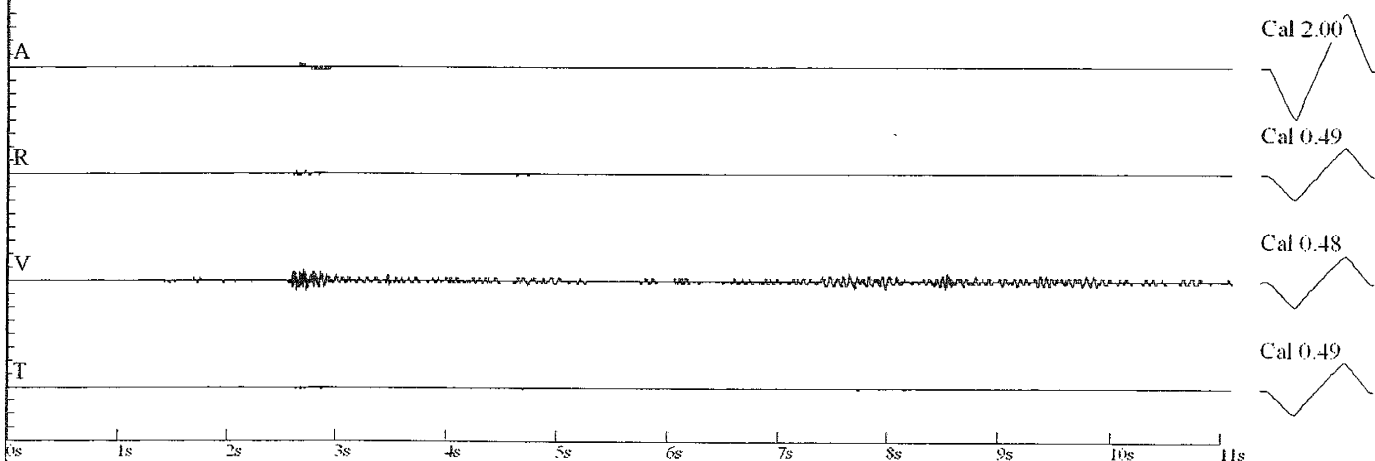
## Graph Information

Duration: 0.000s To: 11.000s

Acoustic Scale:  
130dB 0.63Mb (0.158Mb/div)

Seismic Scale:  
0.20in/s (0.050in/s/div) 5.08mm/s (1.270mm/s/div)

Time Line Intervals at: 1.00 s



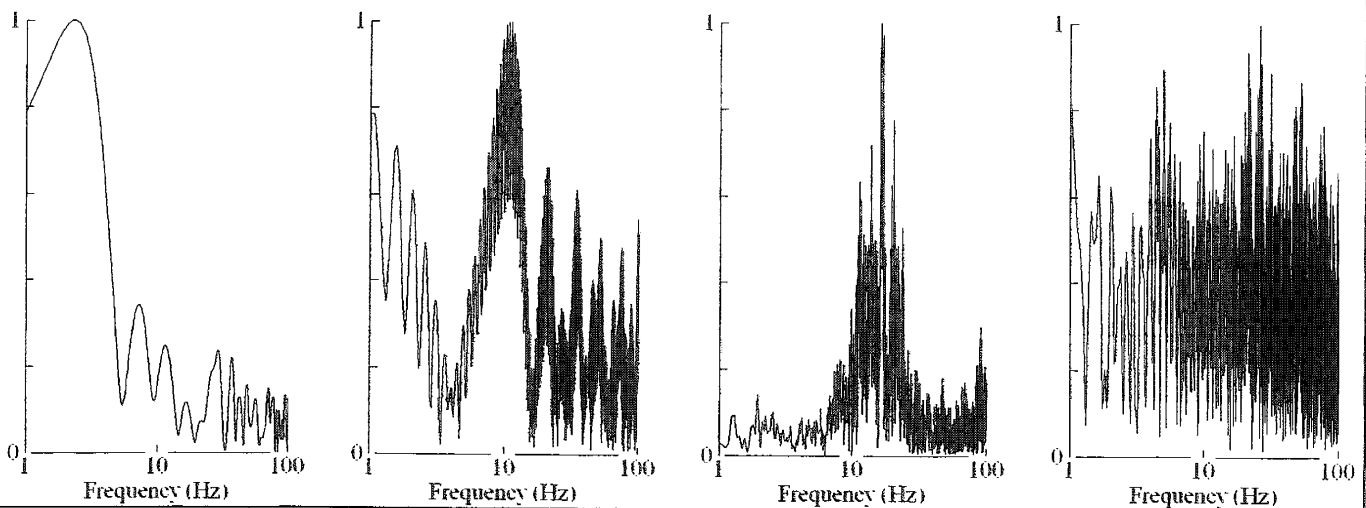
## Fourier Analysis (Power Spectrum - Box Window)

Acoustic  
2.31 Hz

Radial  
11.25 Hz

Vertical  
16.44 Hz

Transverse  
25.88 Hz



## Appendix D

### Summary of seismograph data





Table D-1 Summary of seismograph records for Bighorn residence

Shot date and time	Unit	Structure location	Location of transducer	Transverse (northeast) (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Vertical (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Radial (southwest) (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Airblast (psi)	
													(dB)	(psi)
4/7/05 12:33	3047	master	ground	nt										
	1010	S corner	S1											
	2279	SE wall	SE mid-wall											
4/8/05 11:15	3047	master	ground	nt										
	1010	S corner	S1											
	2279	SE wall	SE mid-wall											
4/12/05 2:21	3047	master	ground	nt										
	1010	S corner	S1											
	2279	SE wall	SE mid-wall											
4/13/05 3:40	3047	master	ground	nt										
	1010	S corner	S1											
	2279	SE wall	SE mid-wall											
4/14/05 4:00	3047	master	ground	0.040	7.1	7.4	0.030	10.6	6.8	0.035	10.2	6.8	7.8	106
	1010	S corner	S1	0.095	9.8	6.8	0.040	9.4	6.8	0.050	7.7	6.8	7.9	0.0006
	2279	SE wall	SE mid-wall	0.200	7.3	6.8	0.040	14.2	6.8	0.157	8.8	6.8	7.8	
	2279	S corner	S2	0.313	7.7	6.8	0.040			0.190	9.1	7.9		
	2279	SW wall	SW mid-wall											

nt - no trigger; ground motion below seismograph trigger level

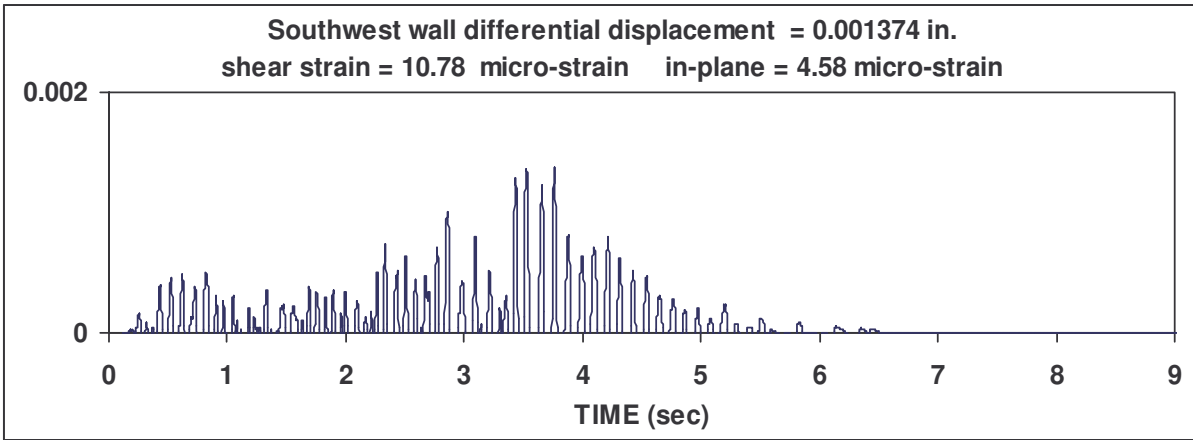
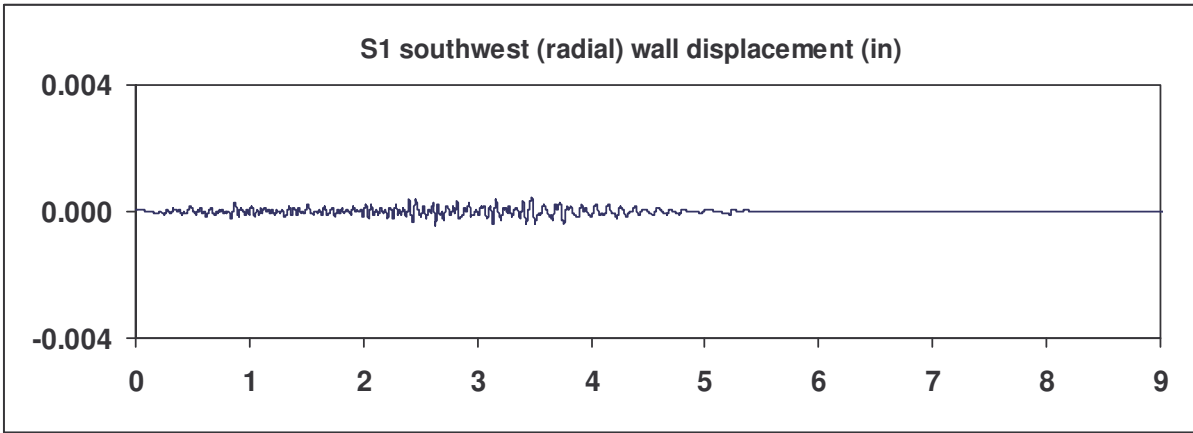
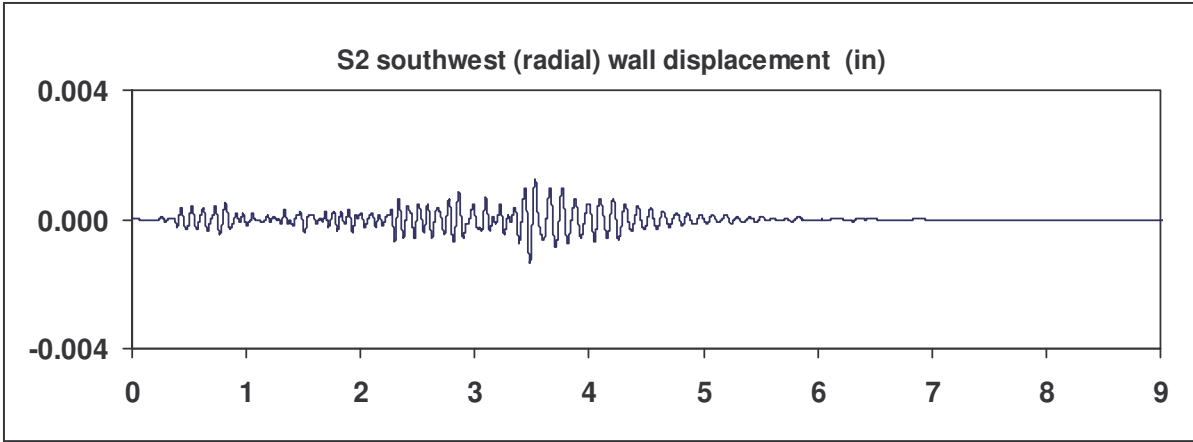




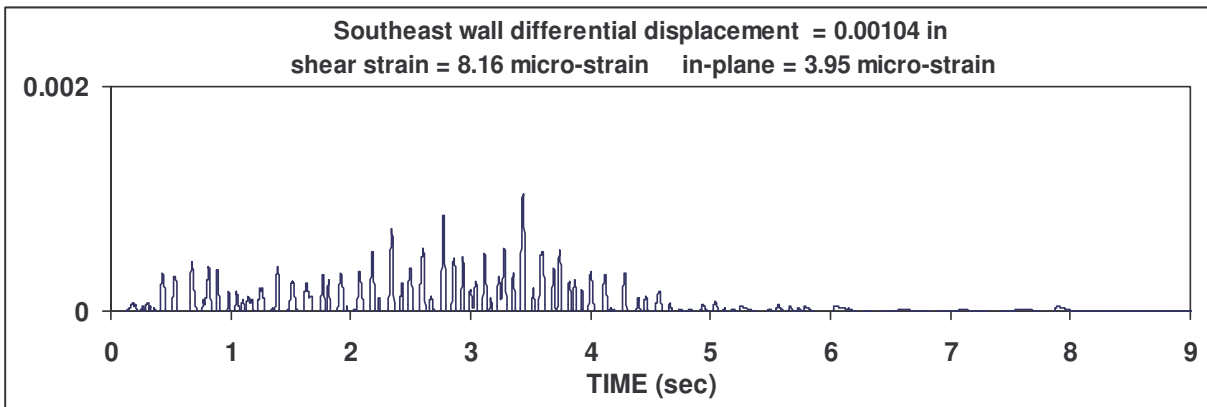
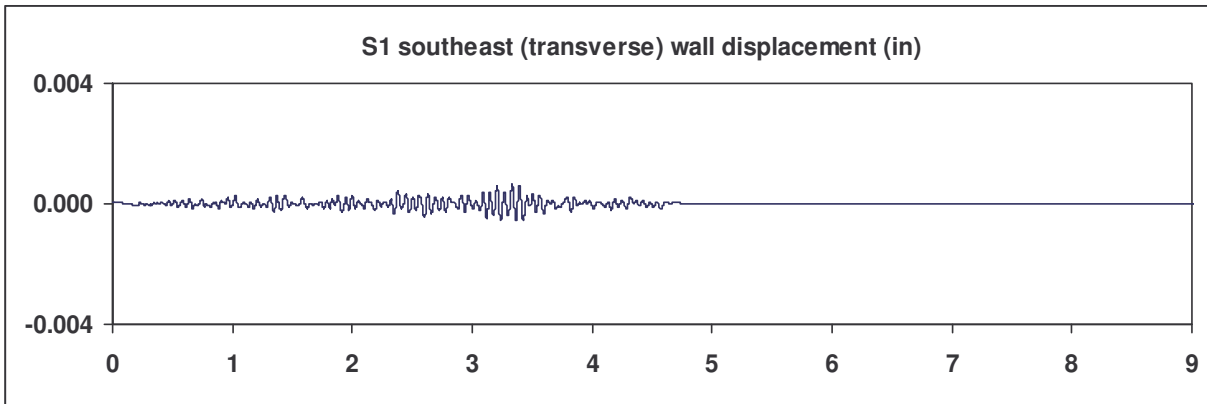
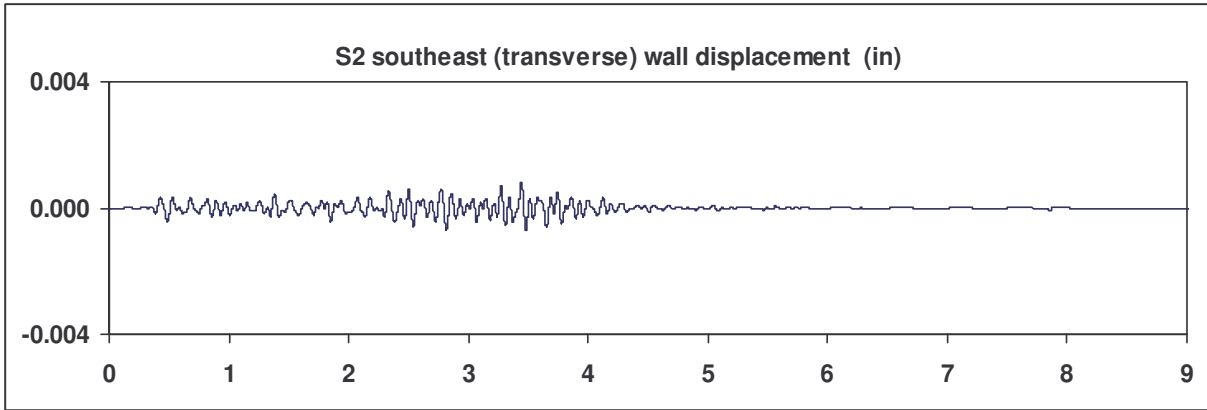
Table D-2 Summary of seismograph records for High Mesa residence

Shot date and time	Unit	Structure location	Location of transducer	Transverse (southeast) (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Vertical (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Radial (northeast) (in/s)	Peak Frequency (Hz)	FFT Frequency (Hz)	Airblast	
													(dB)	(psi)
4/8/05	1258	master	ground	0.070	42.6	37.6	0.055	25.6	33.5	0.075	32.0	37.9	106	0.0006
11:15	903	E corner	S1	0.050	21.3	11.0	0.120	32.0	33.4	0.065	32.0	33.1		
	903	SE wall	MW	0.170	21.3	15.0								
	2276	E corner	S2	fell off well			0.120	32.0	33.4	0.035	8.2	8.0		
	2276	NE wall	MW							0.170	23.2	15.4		
4/12/05	1258	master	ground	0.020	32.0	3.3	0.025	8.5	6.9	0.025	12.8	39.1	106	0.0006
2:21	903	E corner	S1	0.025	28.4	34.4	0.030	36.5	29.4	0.020	36.5	29.1		
	903	SE wall	MW	0.045	23.2	16.4								
	2276	E corner	S2	0.030	21.3	15.4	0.030	32.0	29.4	0.025	14.2	9.1		
	2276	NE wall	MW							0.1	23.2	15.4		
4/13/05	1258	master	ground	0.025	7.3	4.5	0.030	6.5	4.8	0.030	36.5	5.4	106	0.0006
11:00	903	E corner	S1	0.025	25.6	5.4	0.040	42.6	41.1	0.025	5.9	4.6		
	903	SE wall	MW	0.080	19.6	15.8								
	2276	E corner	S2	0.045	17.0	11.8	0.040	28.4	41.3	0.065	8.8	8.5		
	2276	NE wall	MW							0.080	9.4	15.7		
4/14/05	1258	master	ground	0.035	11.6	4.3	0.040	10.6	6.6	0.030	25.6	7.1	112	0.0012
3:07	903	E corner	S1	0.025	10.1	6.6	0.000	14.2	6.6	0.025	16.0	4.4		
	903	SE wall	MW	0.085	15.0	16.1								
	2276	E corner	S2	0.055	13.4	16.1	0.045	12.1	6.5	0.050	8.8	8.8		
	2276	NE wall	MW							0.160	15.0	16.1		

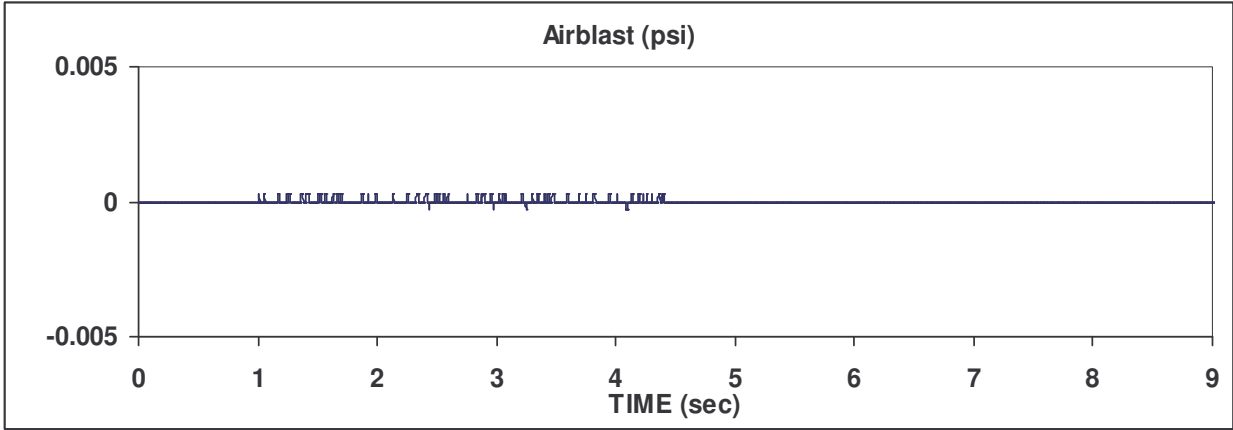
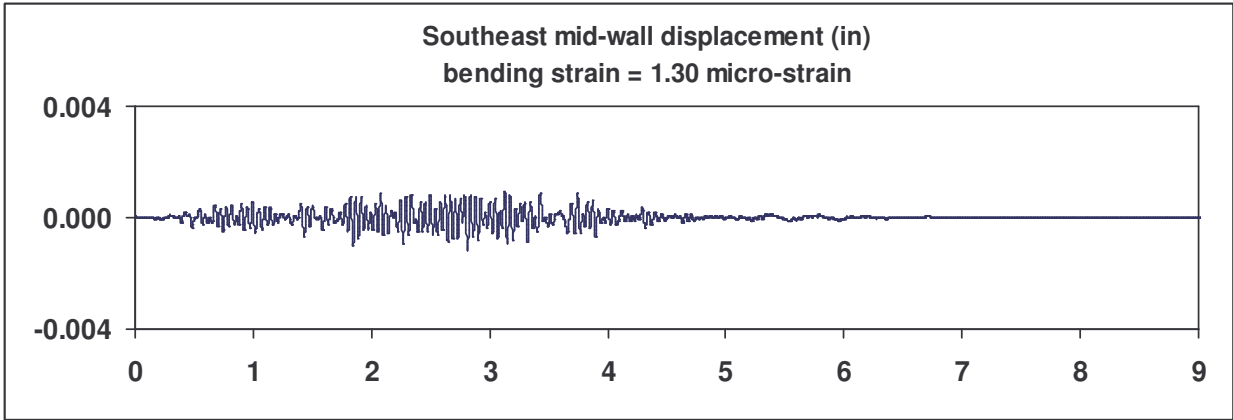
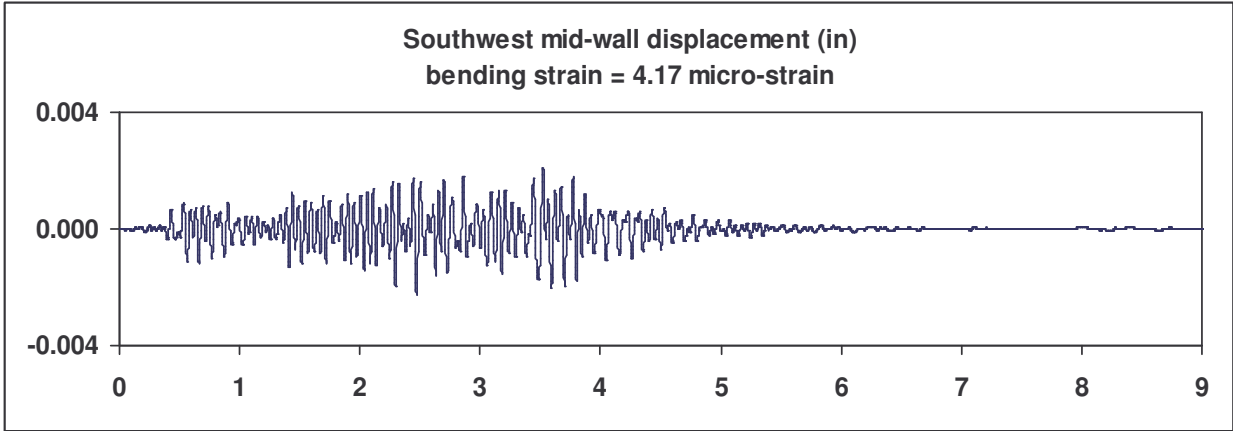
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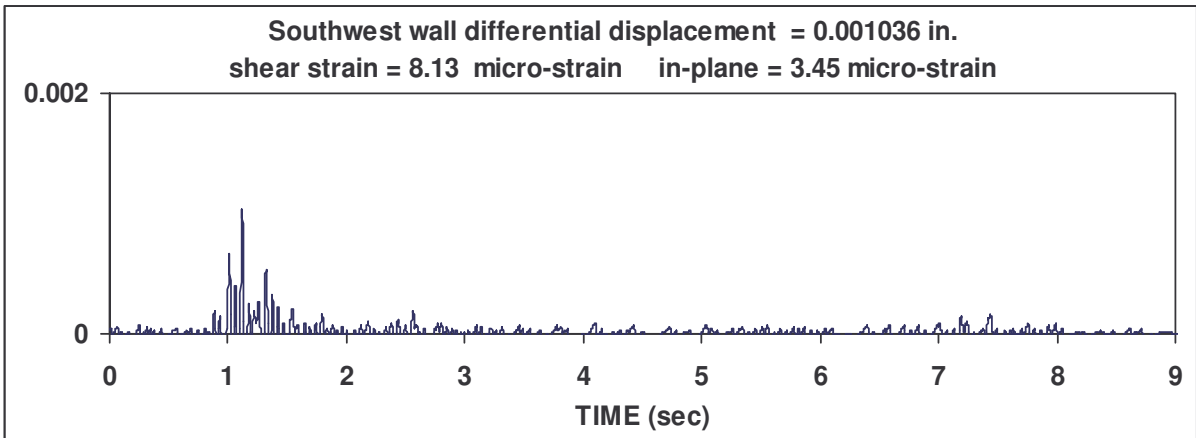
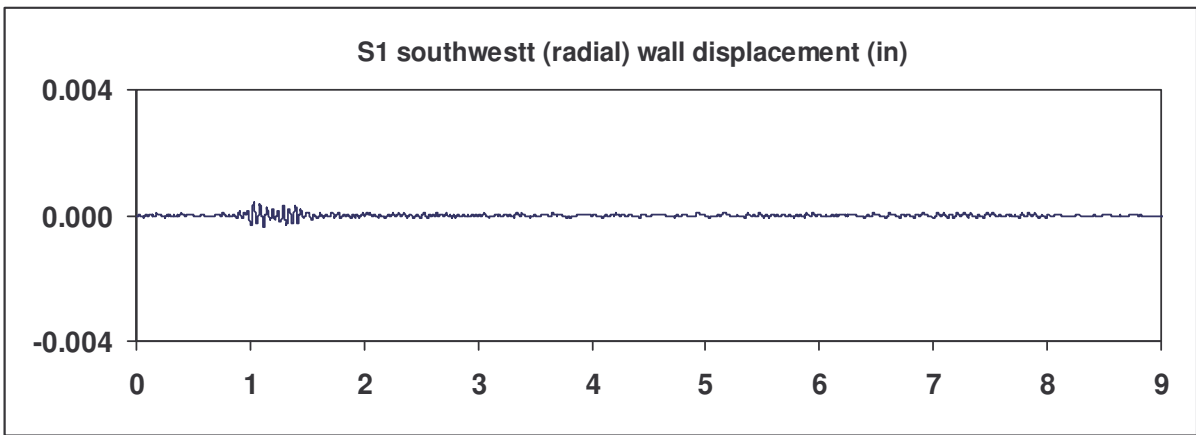
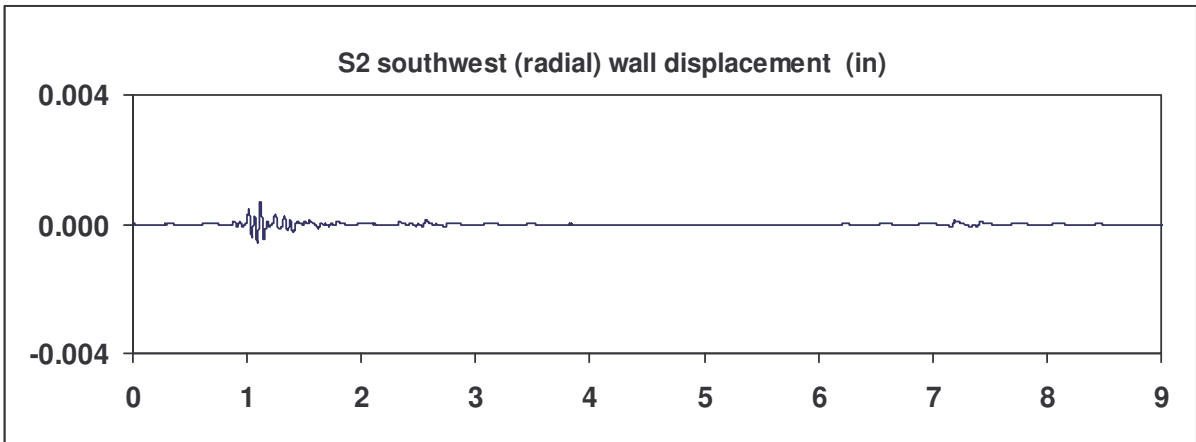
3/15/05a Bighorn



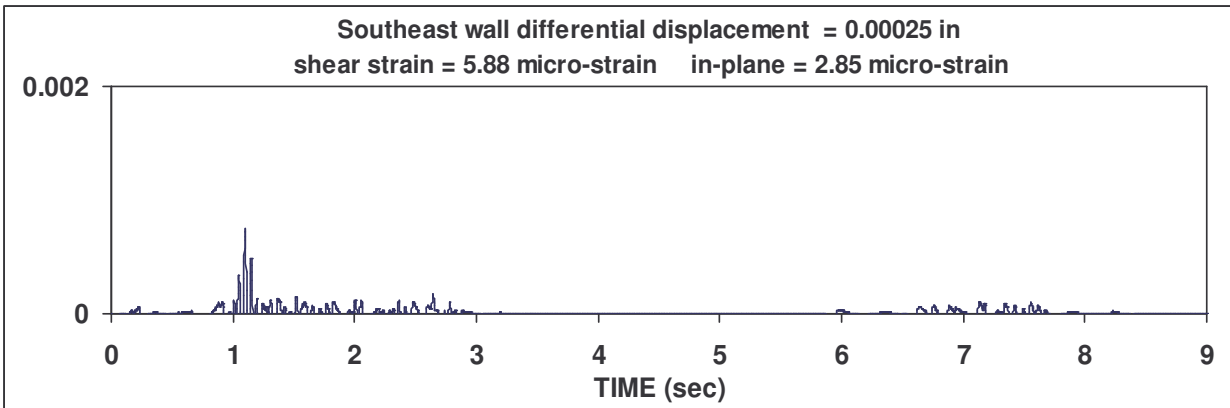
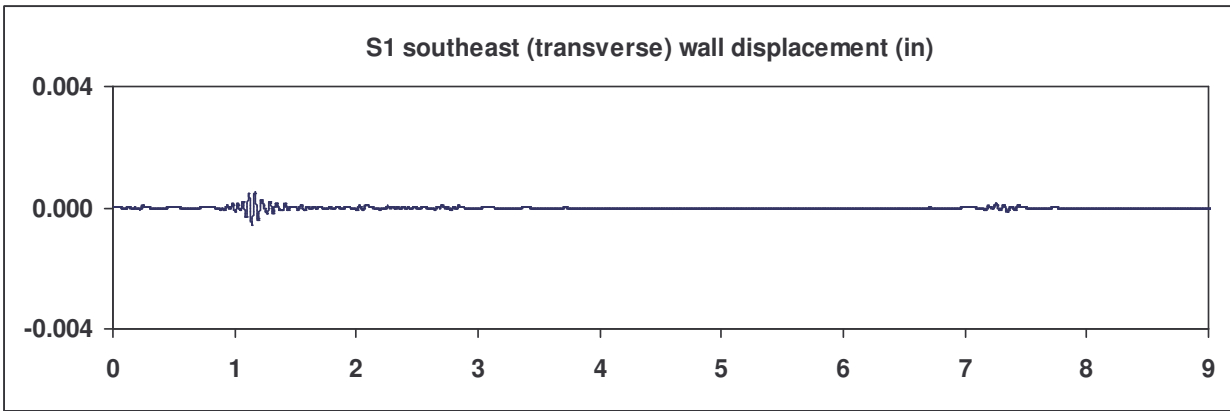
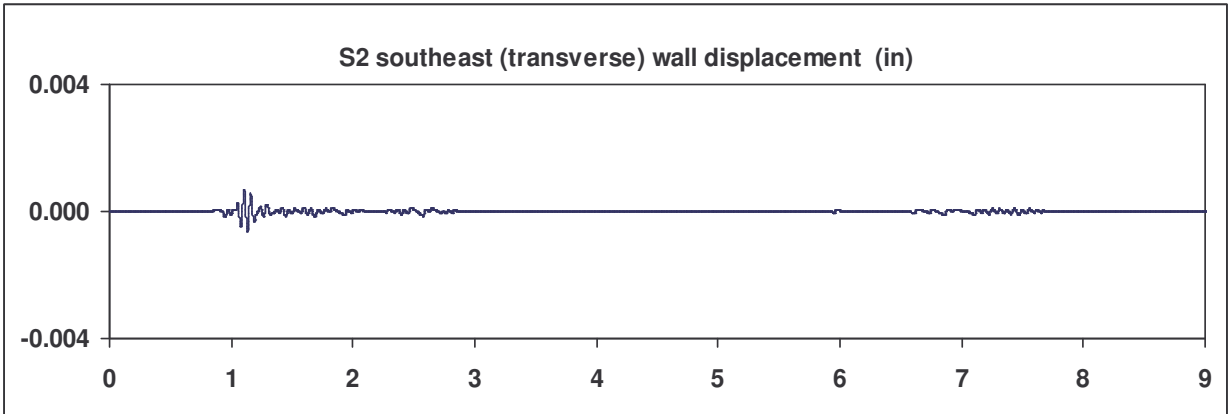
3/15/05a Bighorn



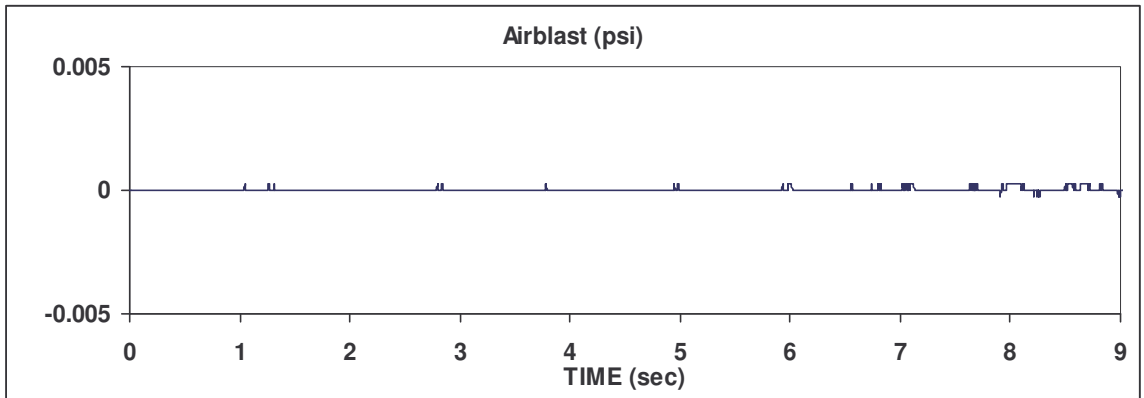
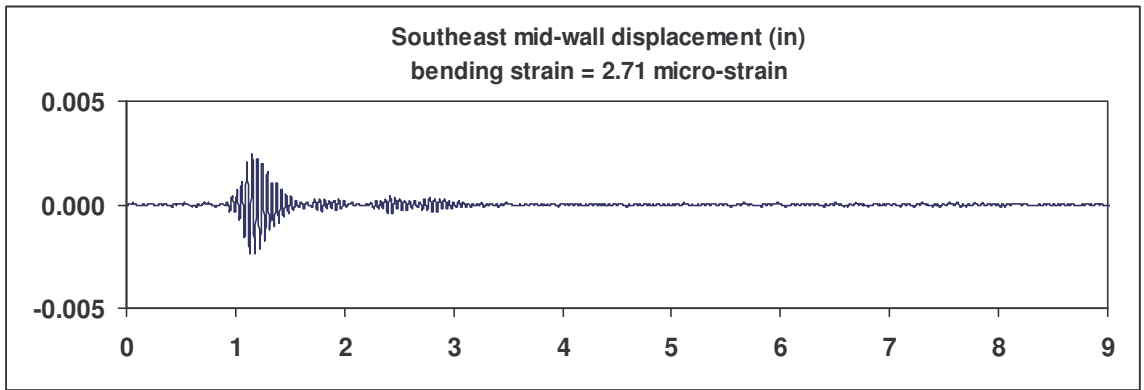
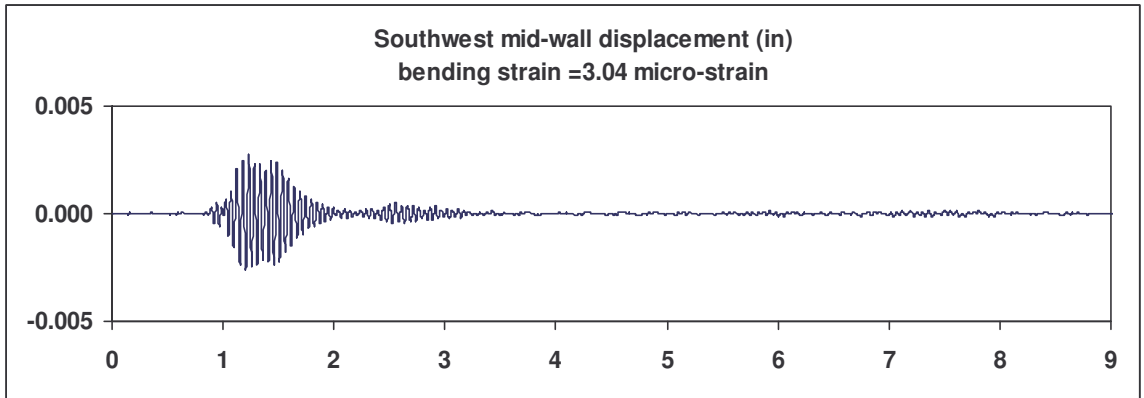
3/15/05a Bighorn



3/21/05 Bighorn

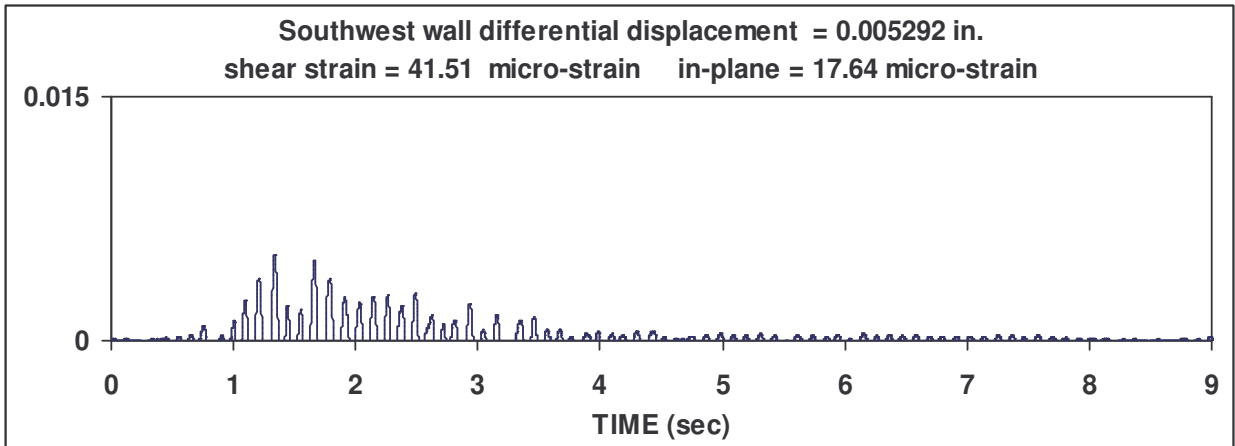
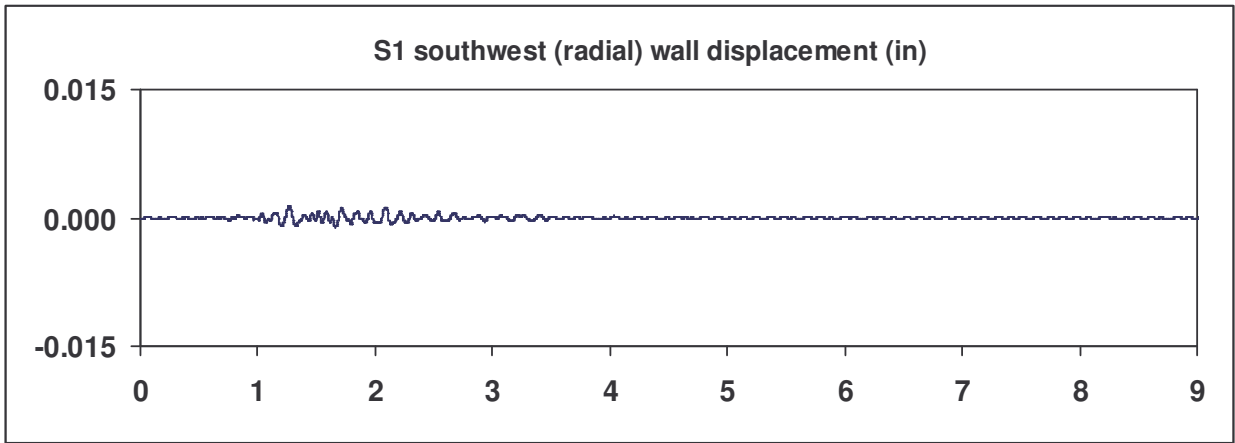
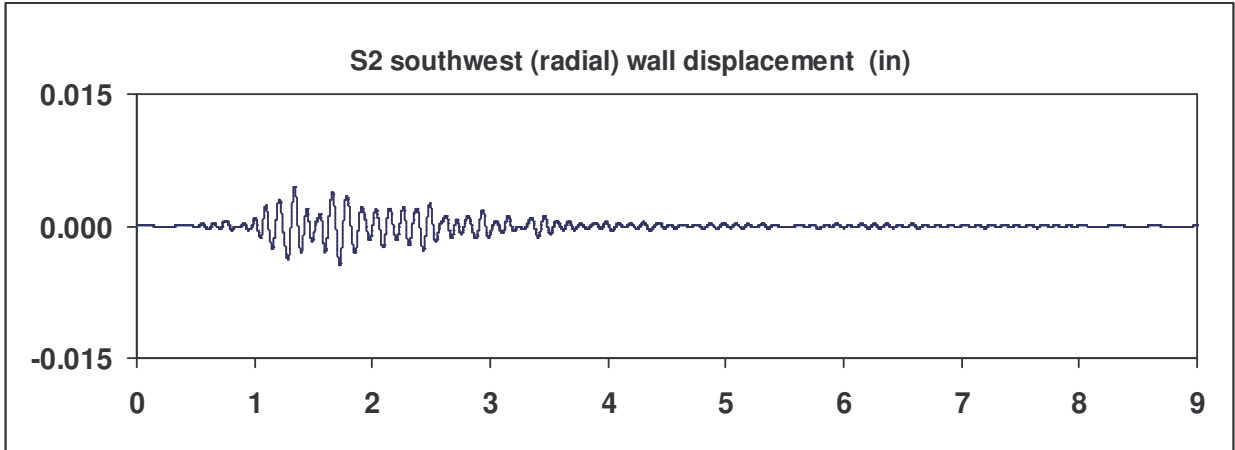


3/21/05 Bighorn

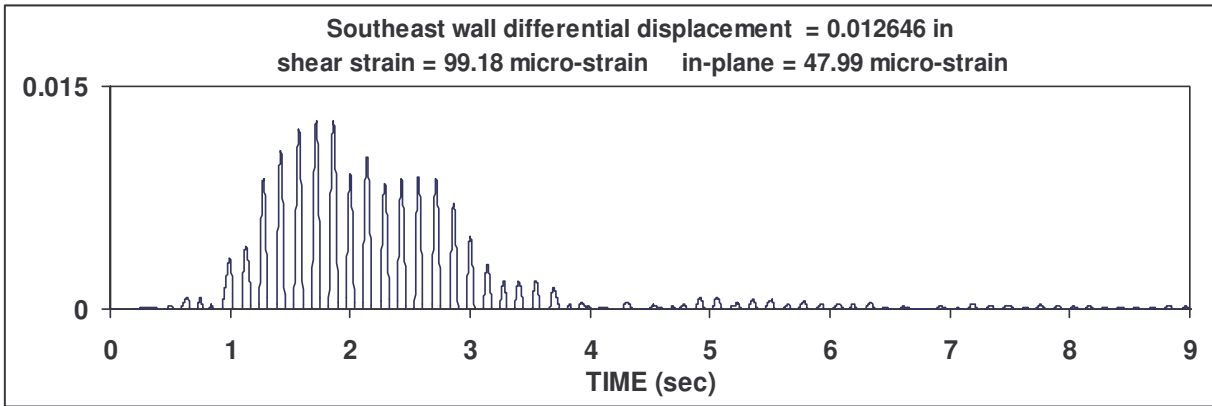
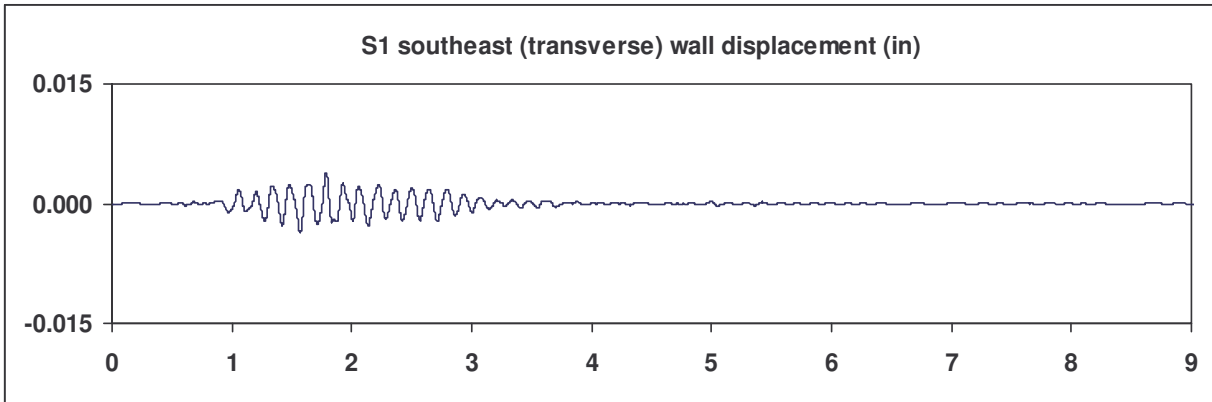
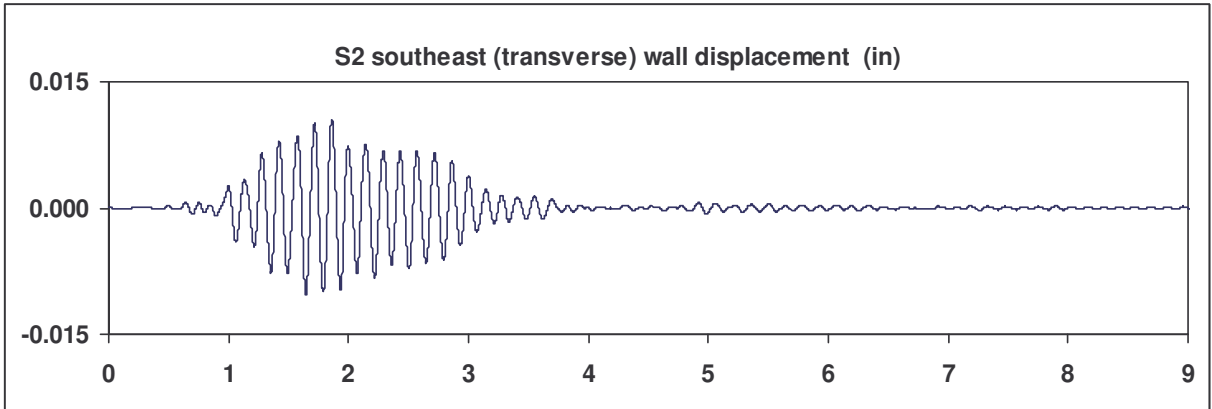


3/21/05 Bighorn

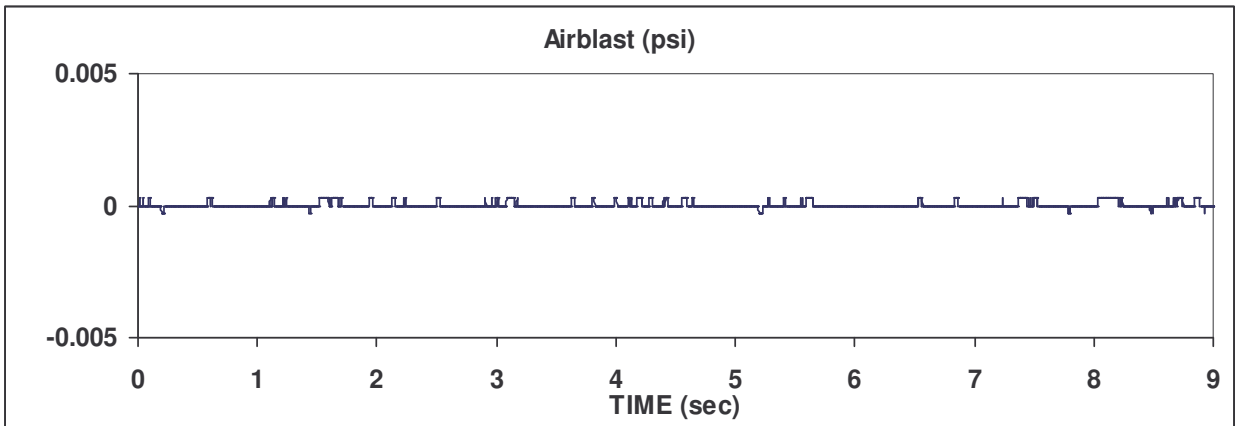
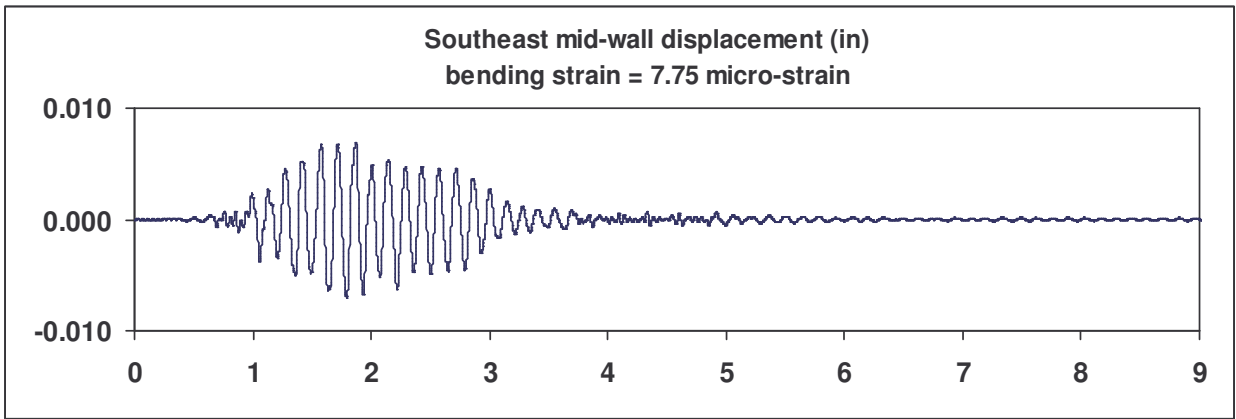
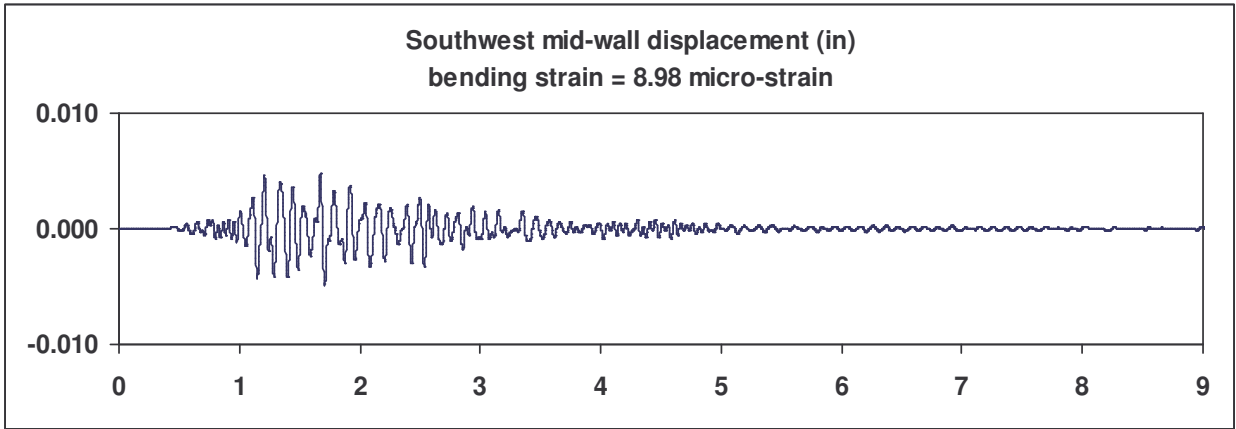




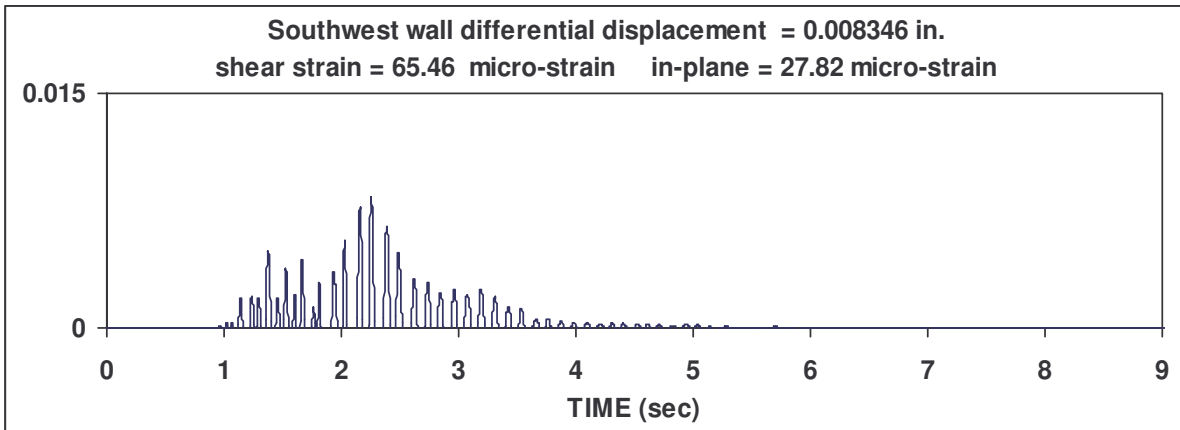
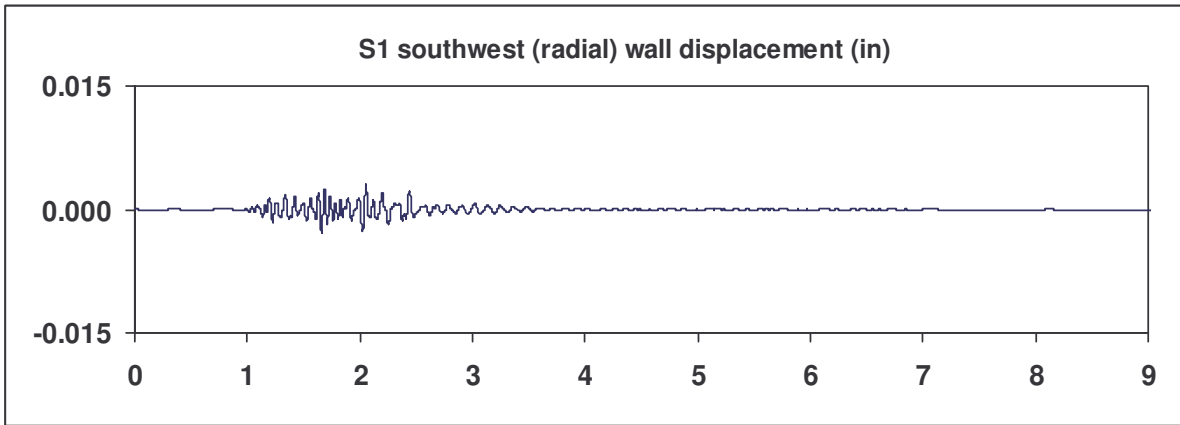
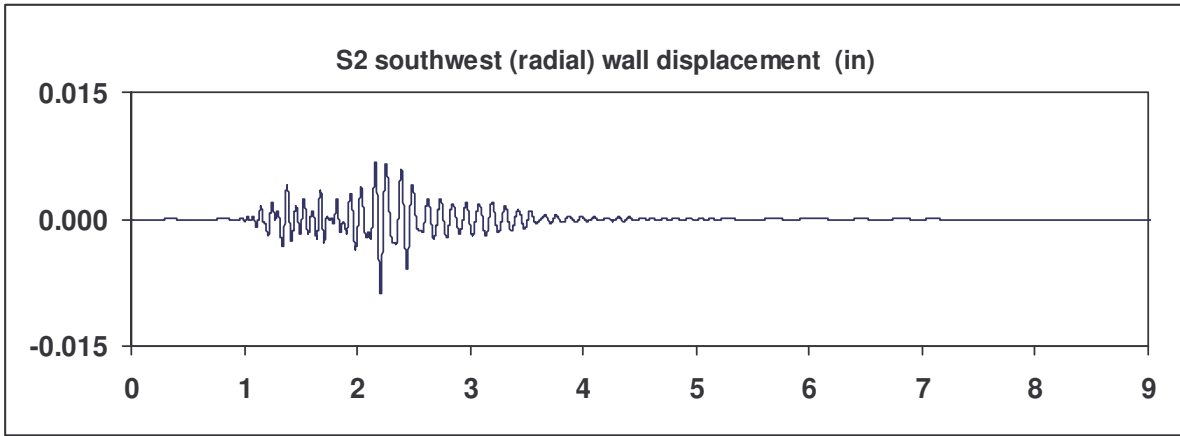
3/22/05 Bighorn



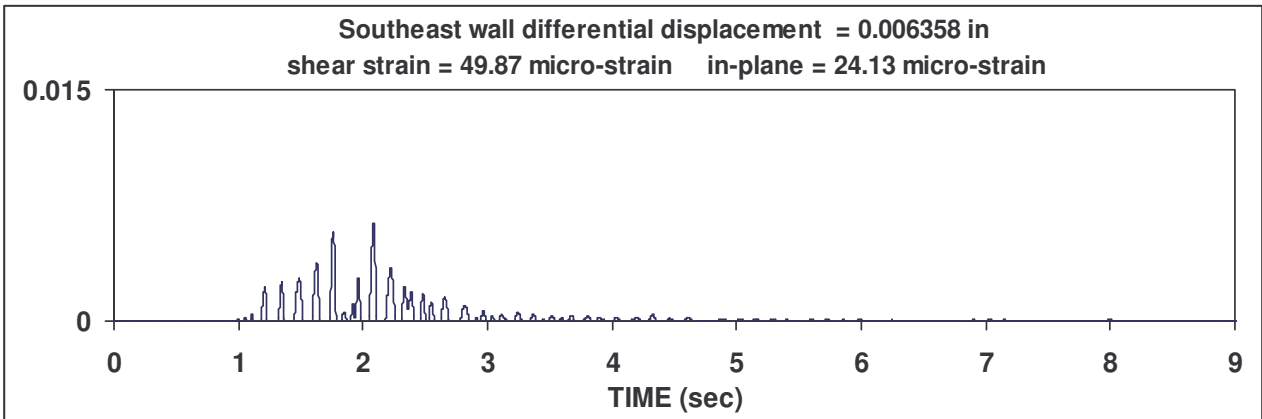
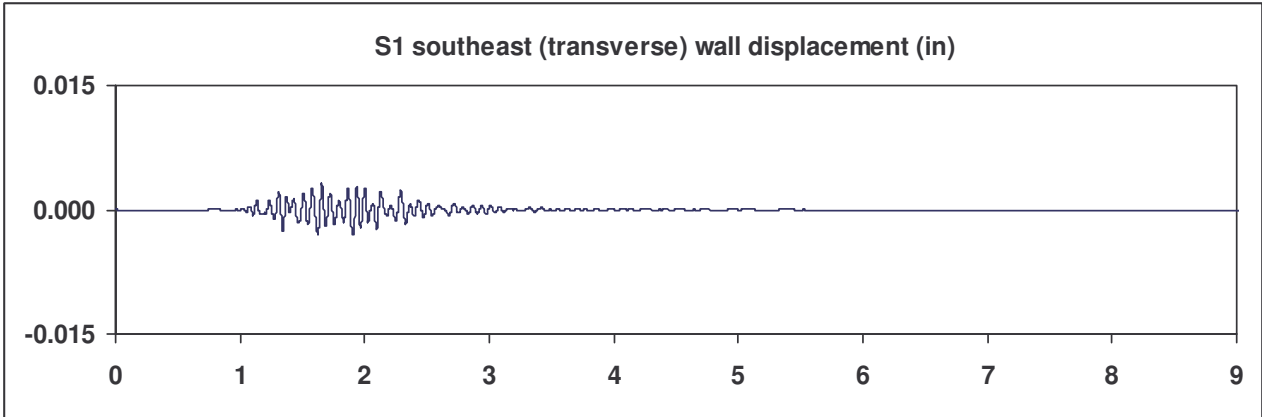
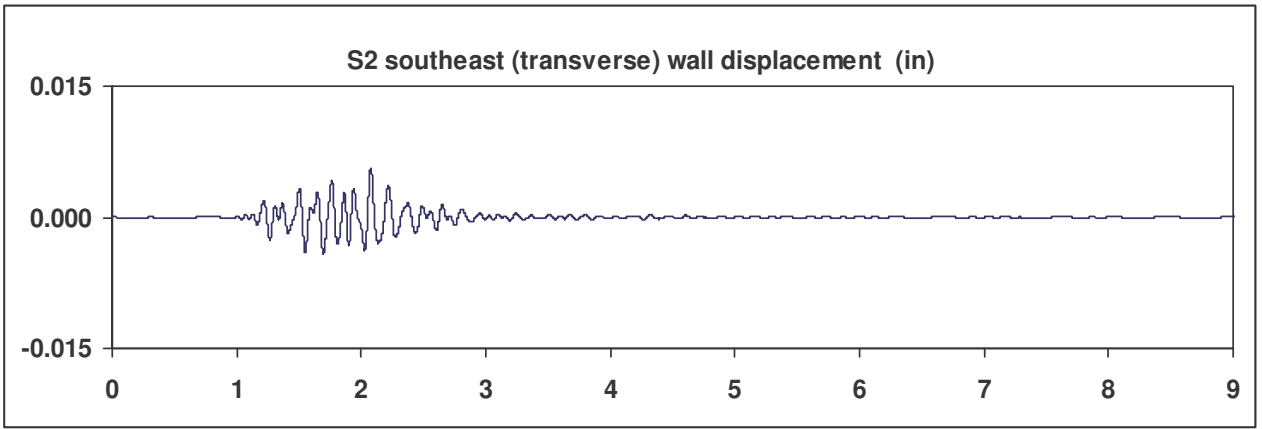
3/22/05 Bighorn



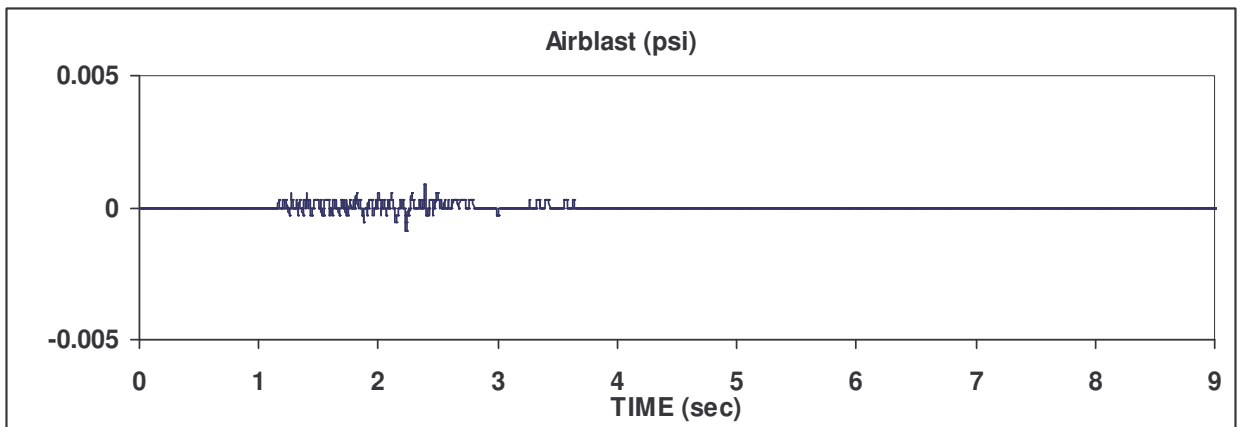
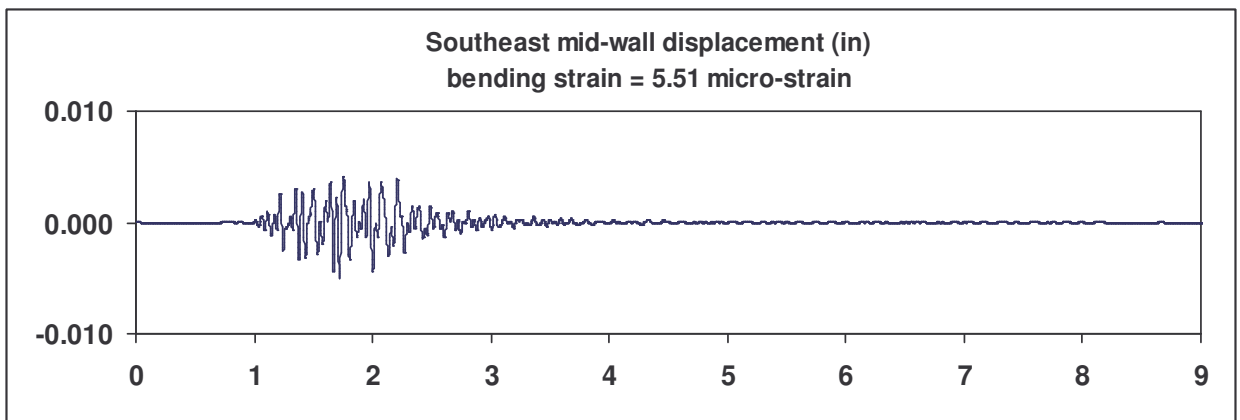
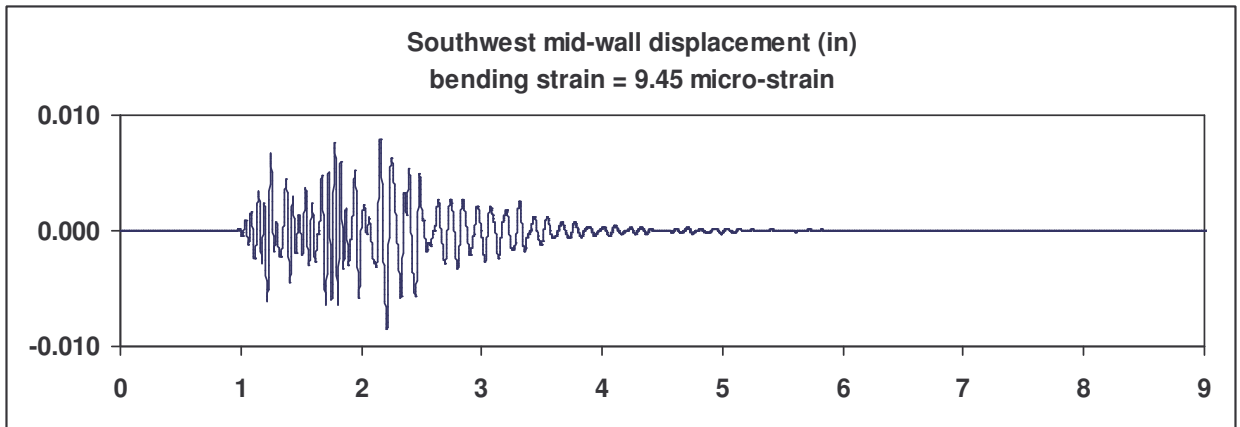
3/22/05 Bighorn



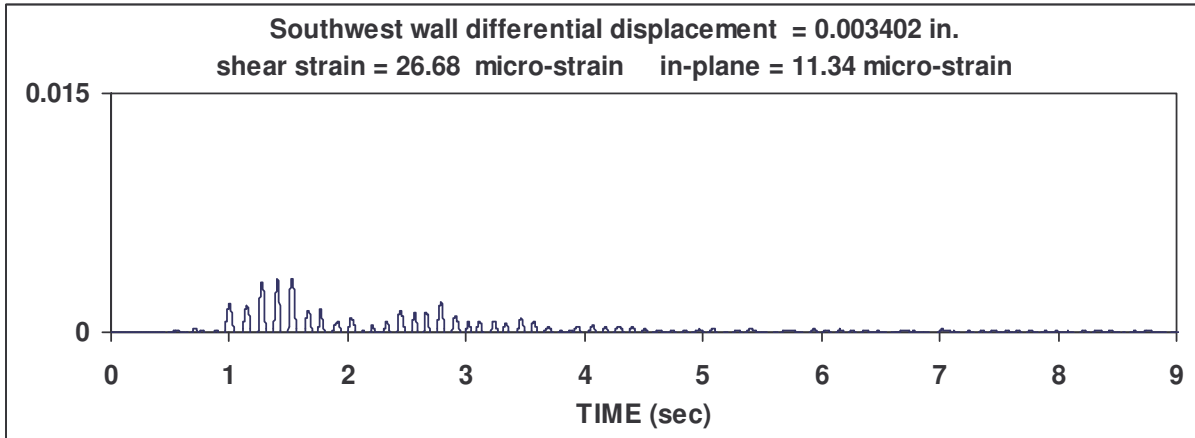
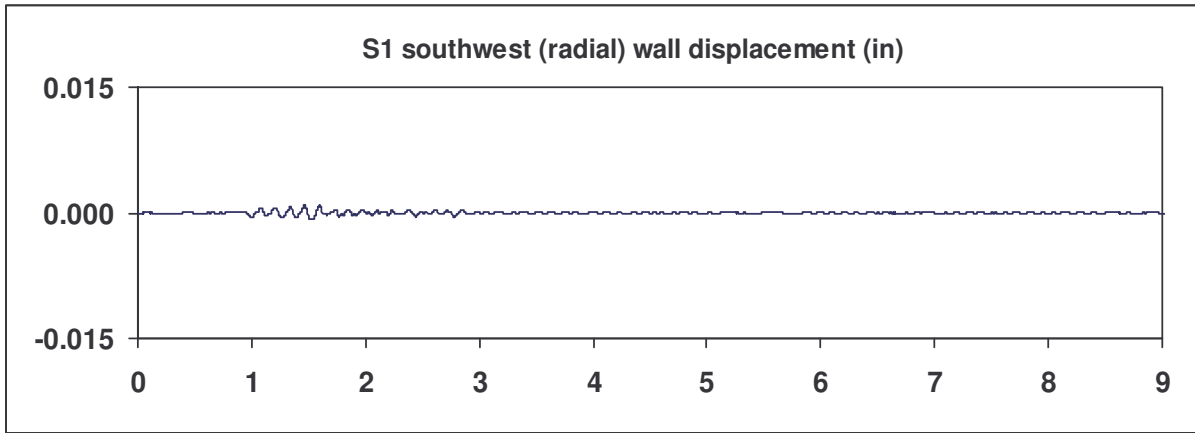
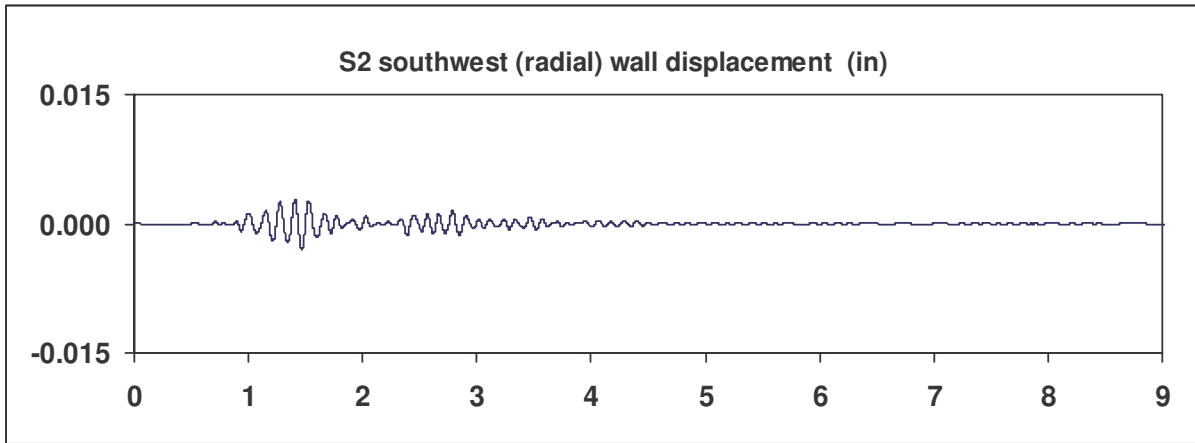
3/23/05b Bighorn

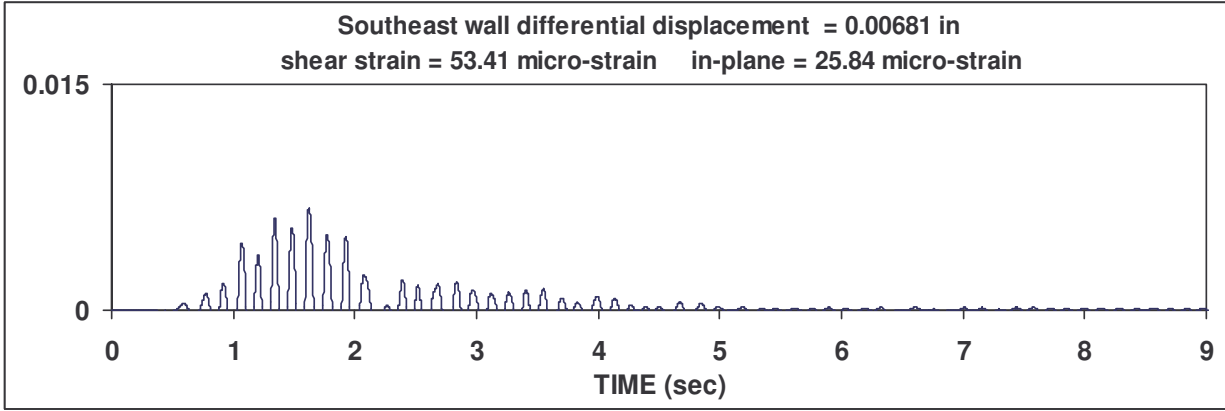
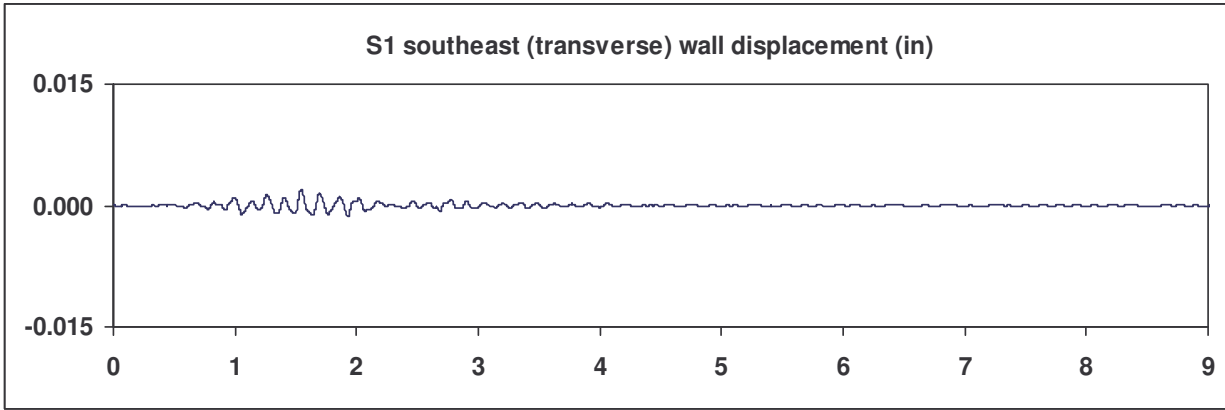
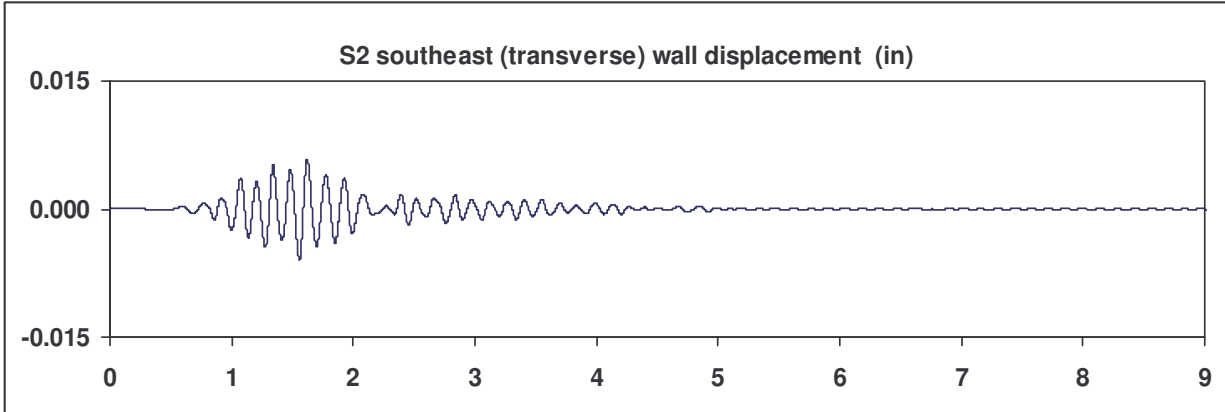


3/23/05b Bighorn



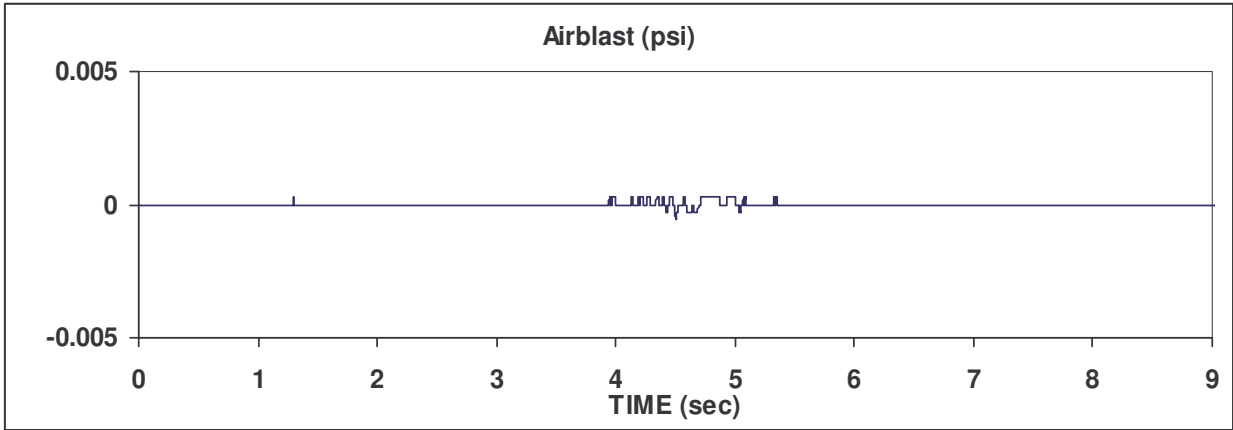
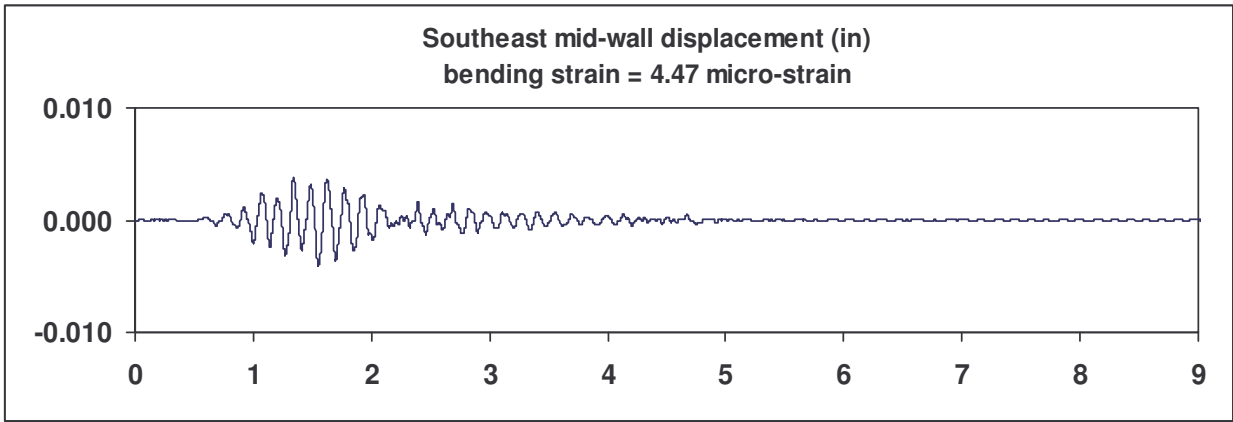
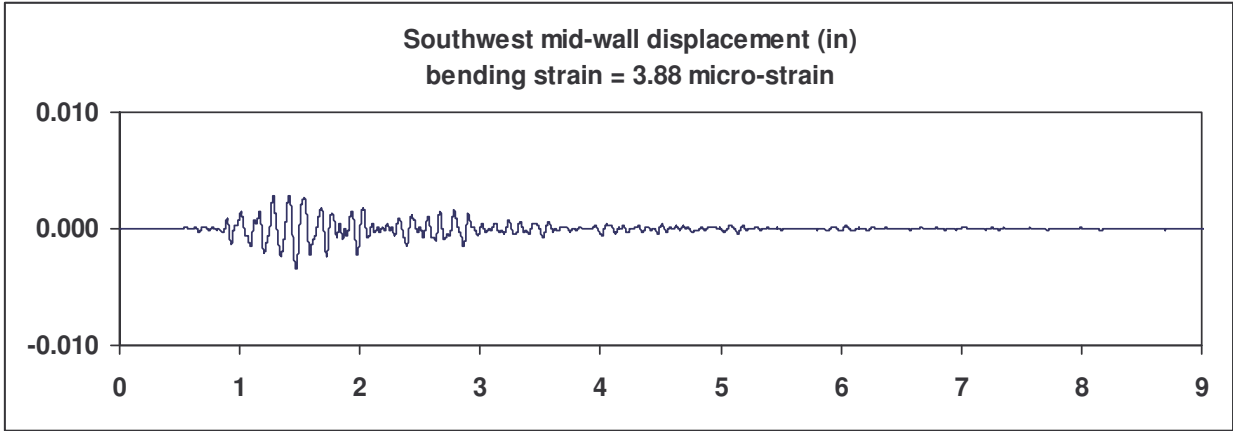
3/23/05b Bighorn



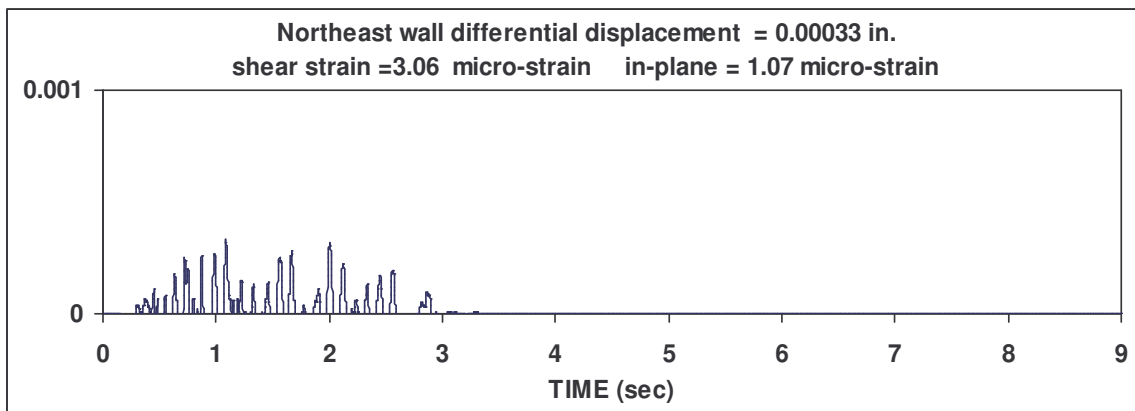
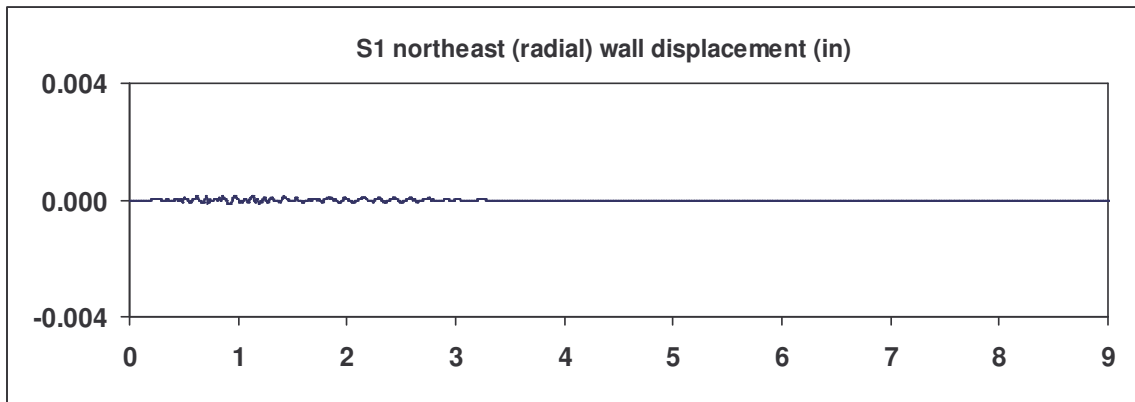
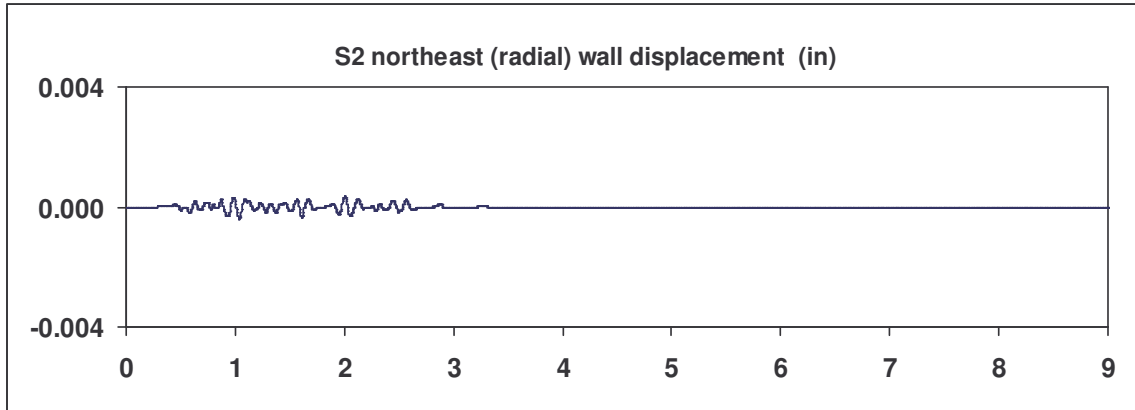


4/14/05 Bighorn

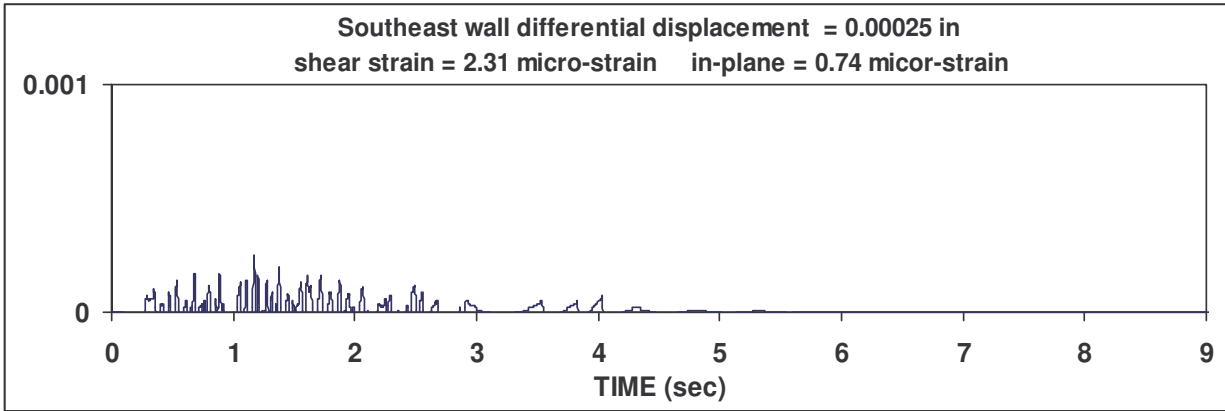
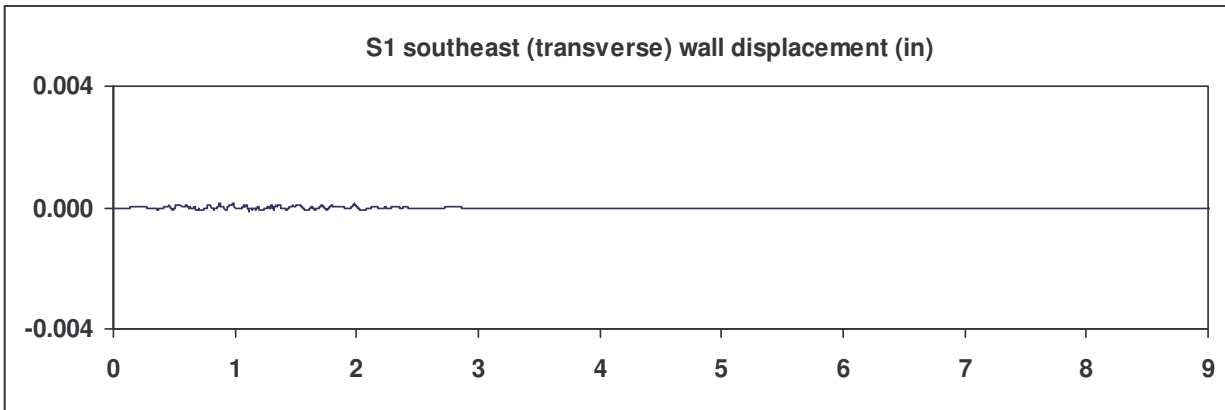
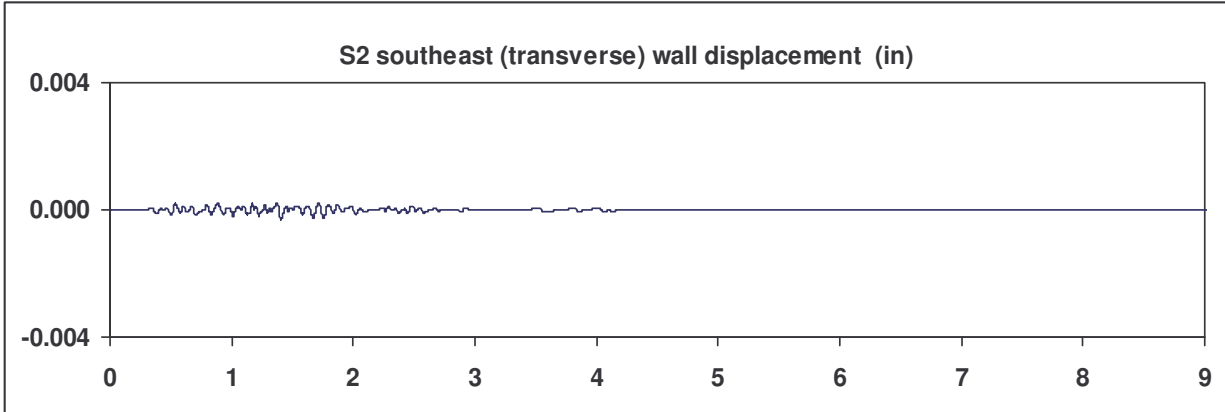




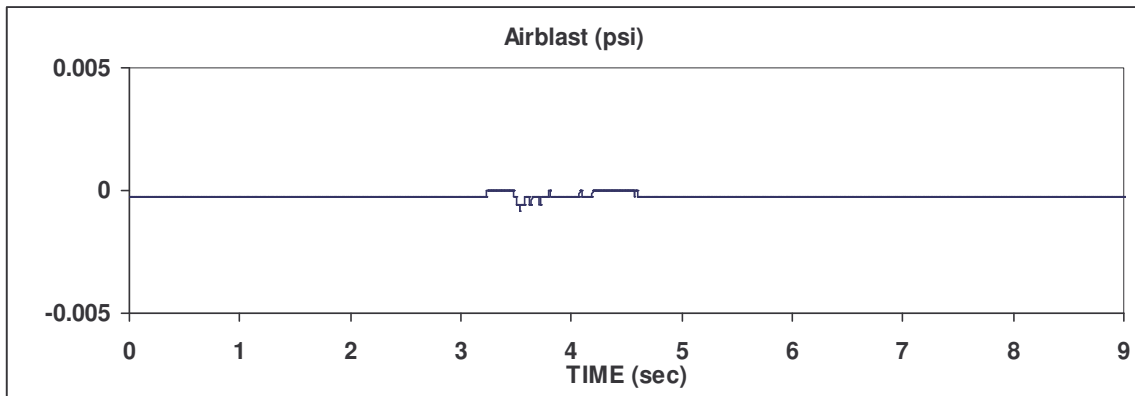
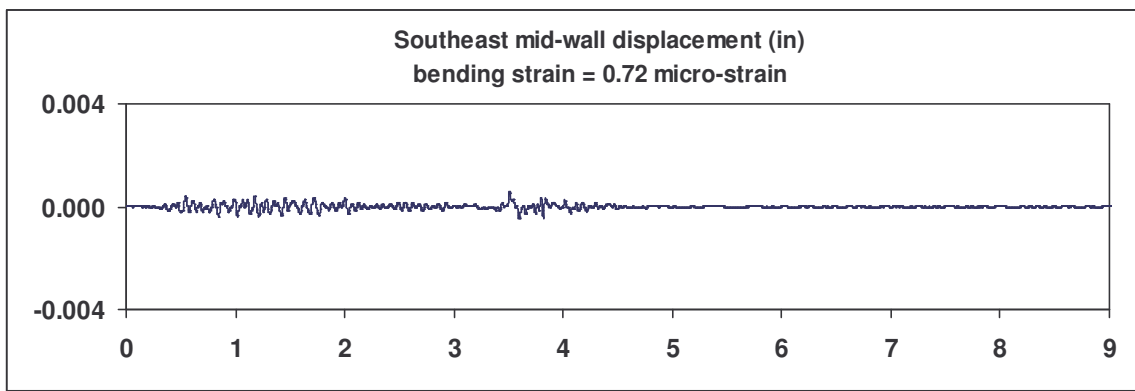
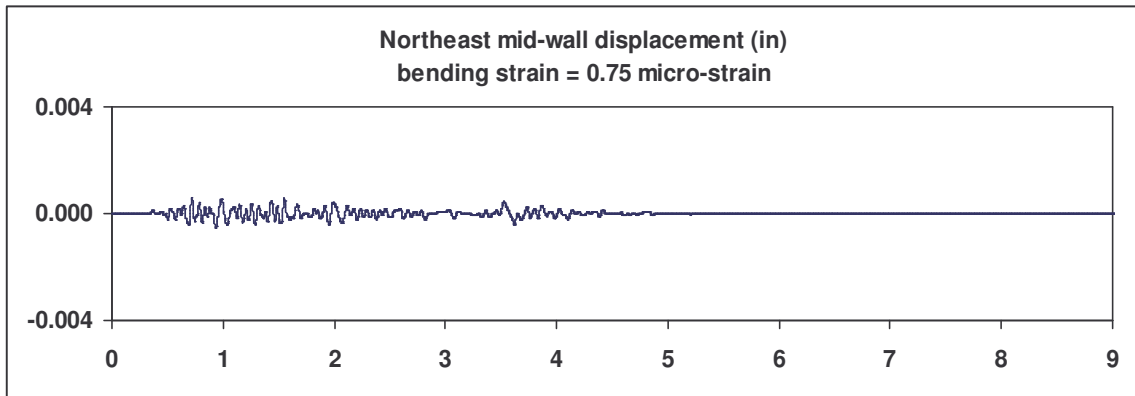
4/14/05 Bighorn



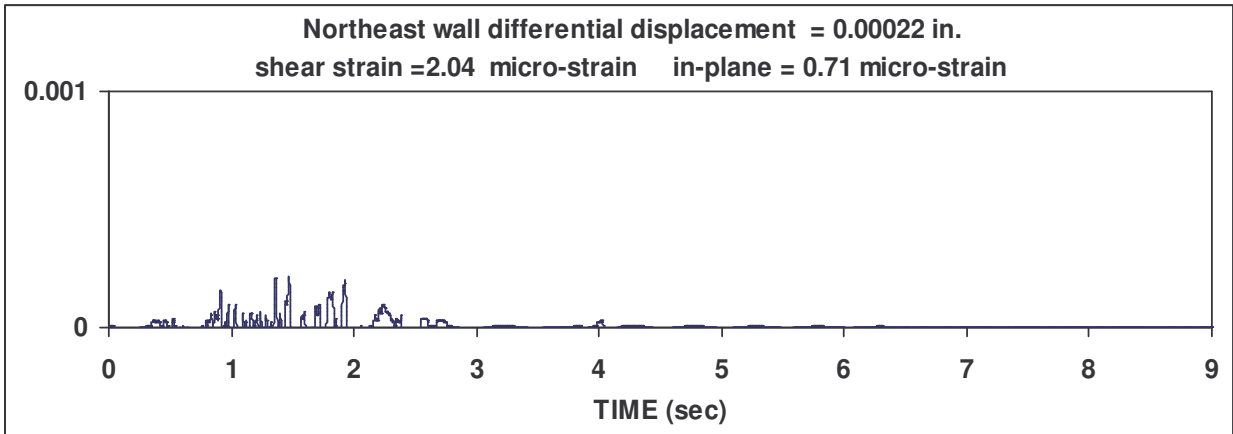
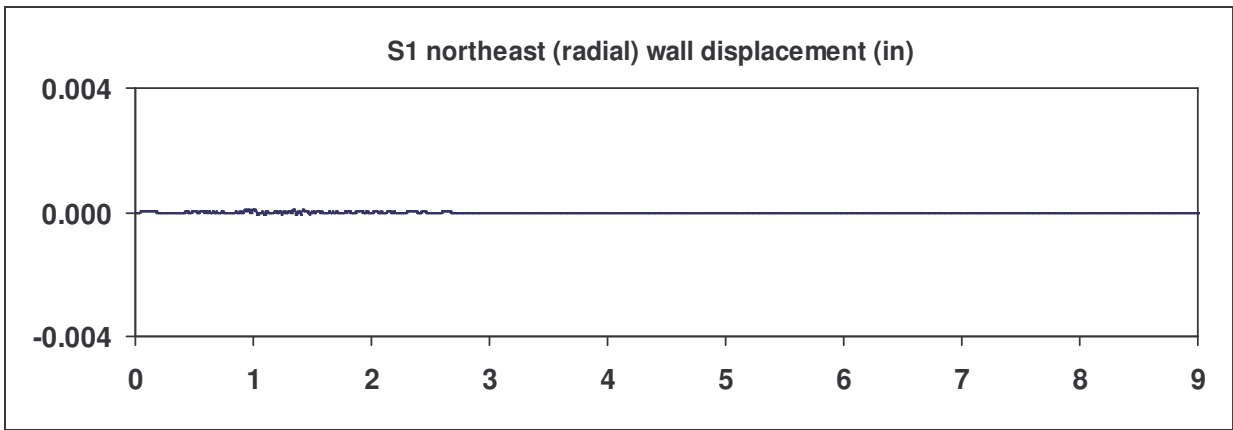
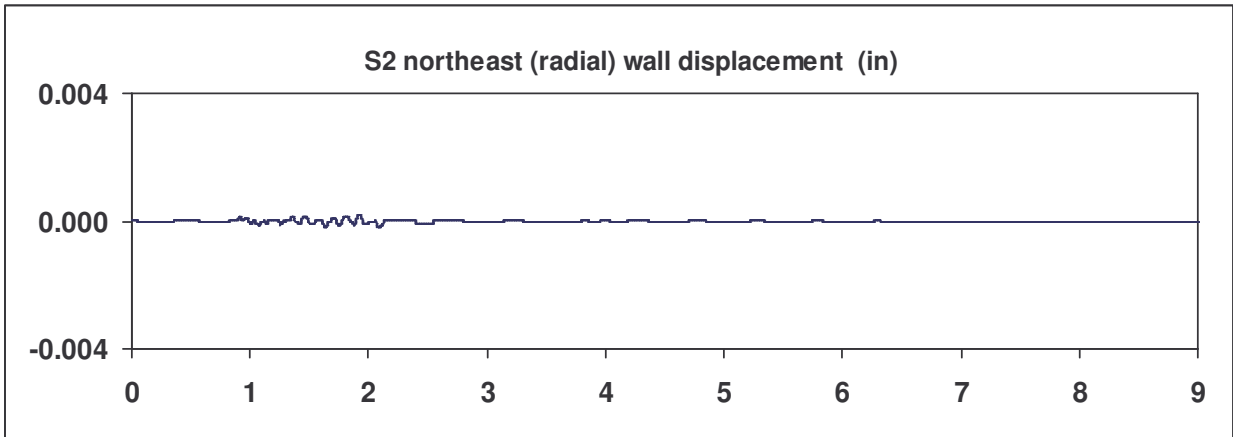
3/15/05b High Mesa



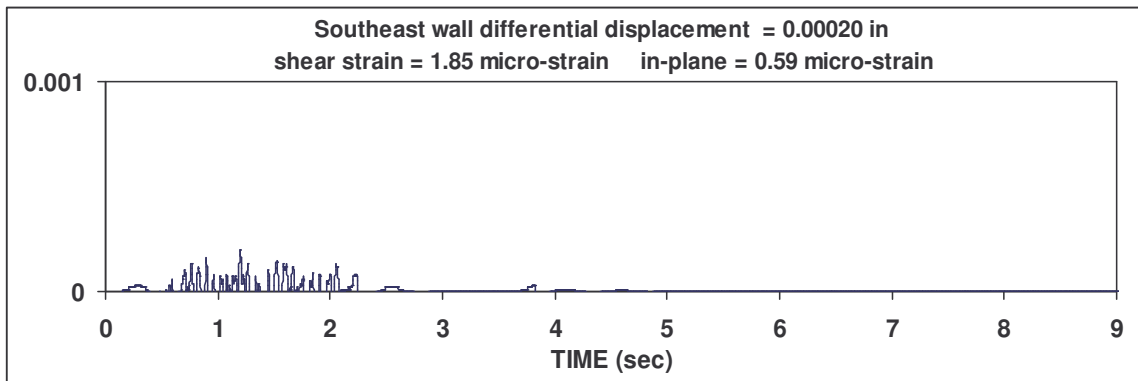
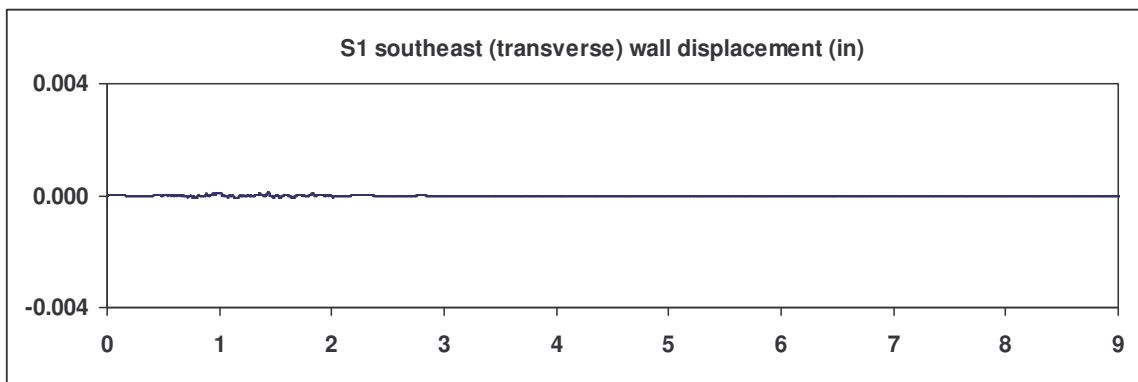
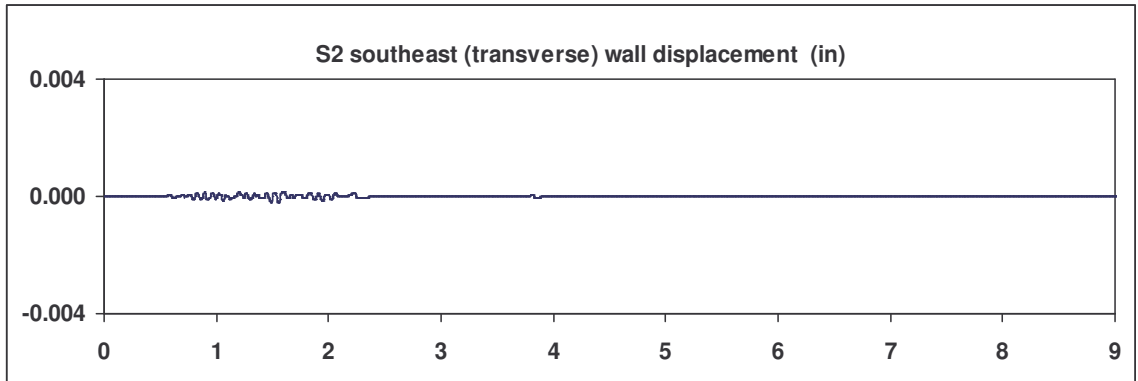
3/15/05b High Mesa



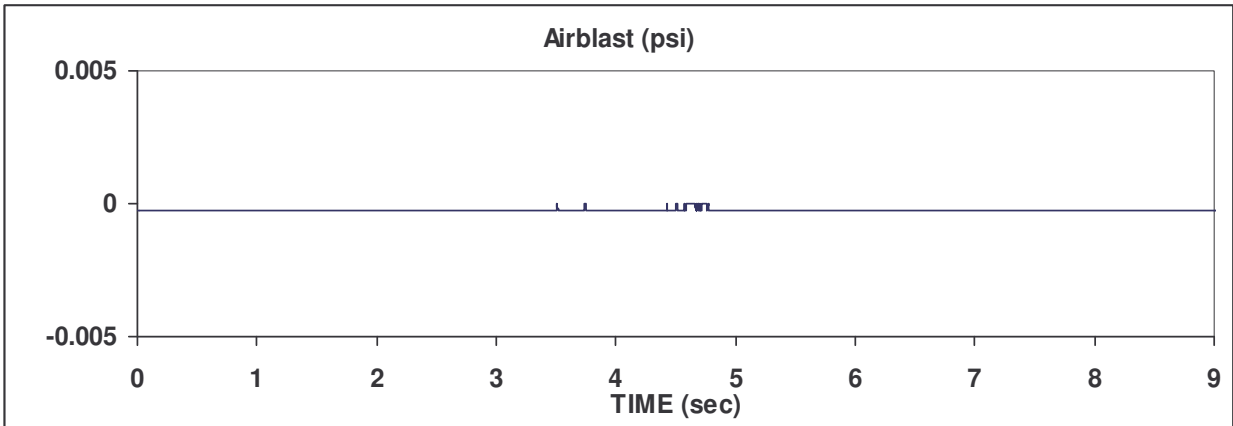
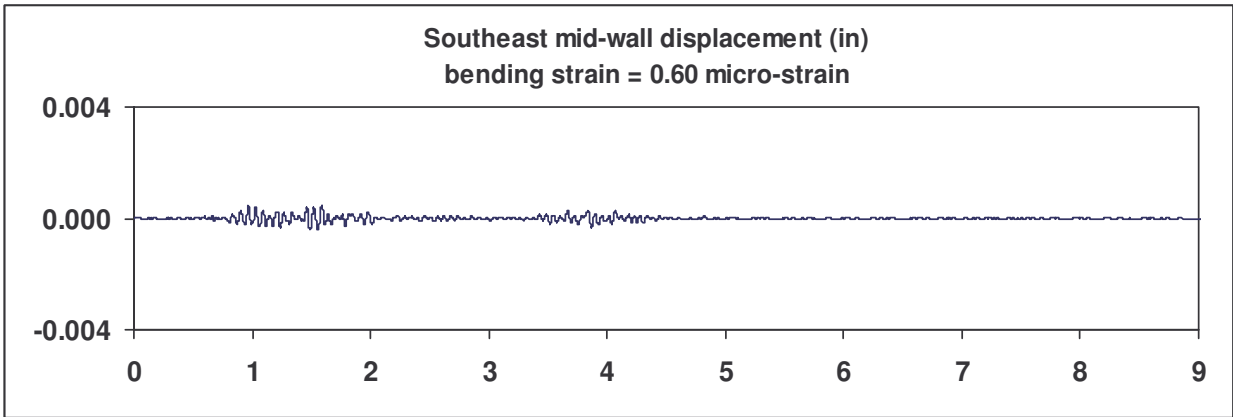
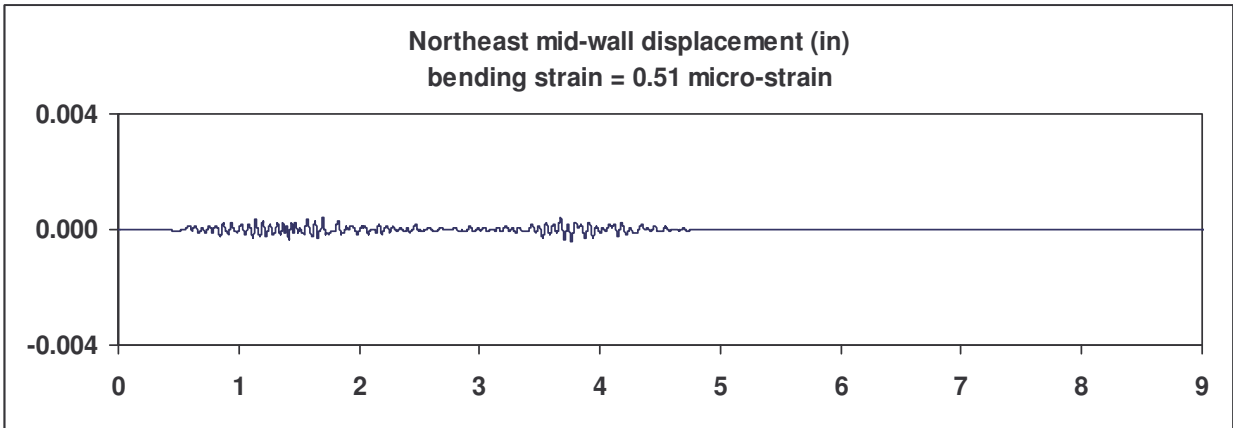
3/15/05b High Mesa



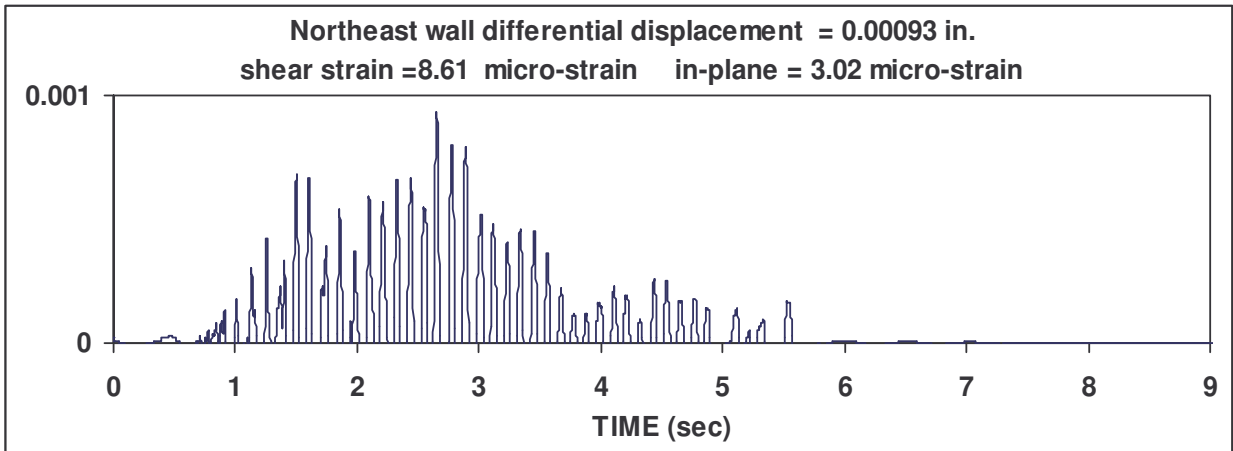
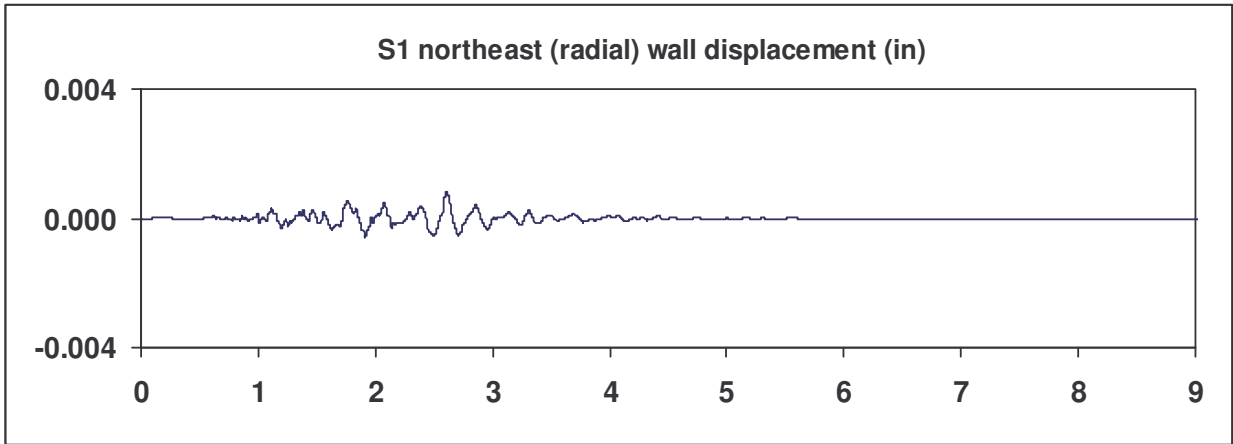
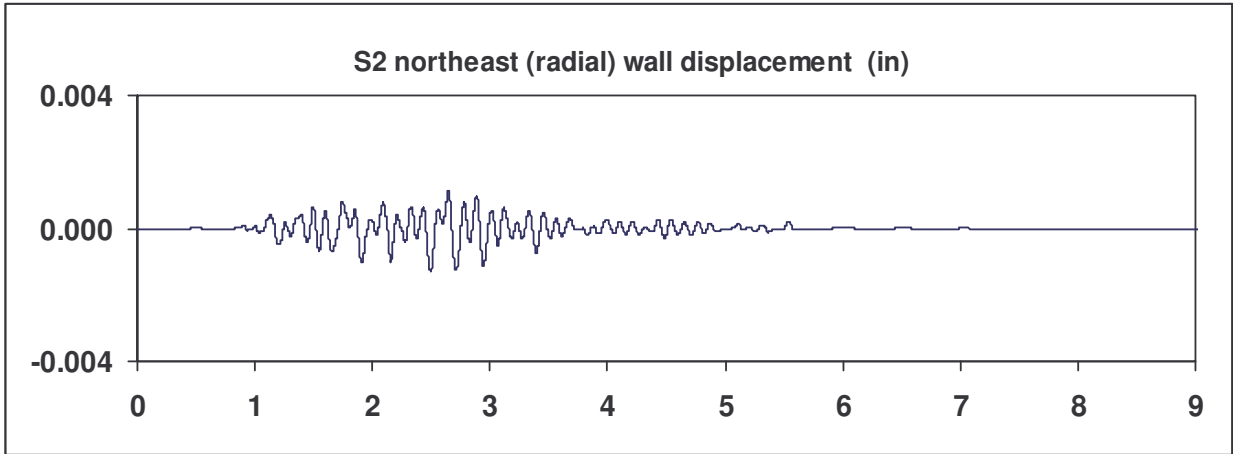
3/16/05a High Mesa



3/16/05a High Mesa

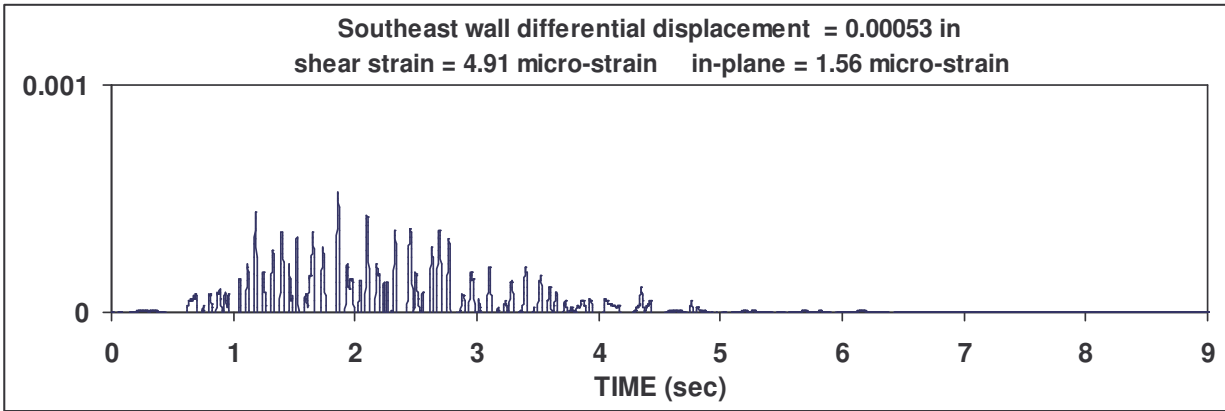
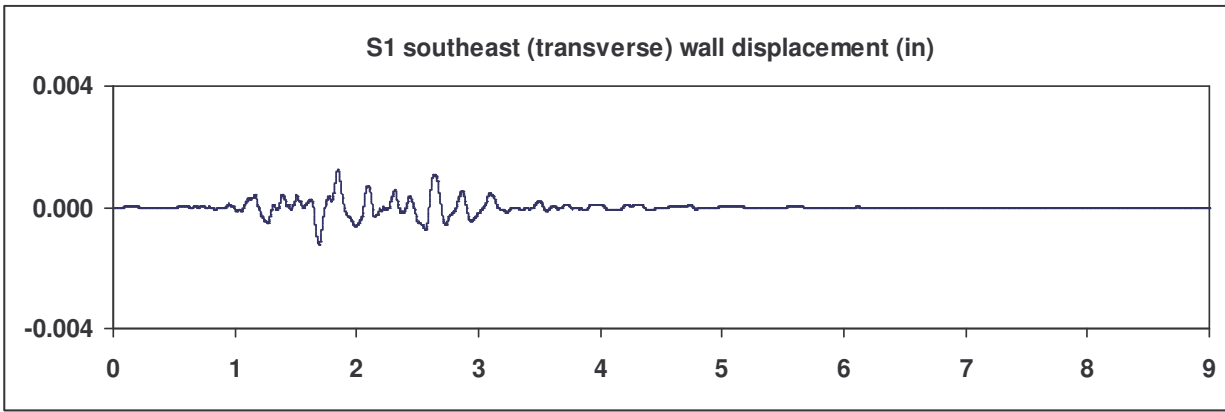
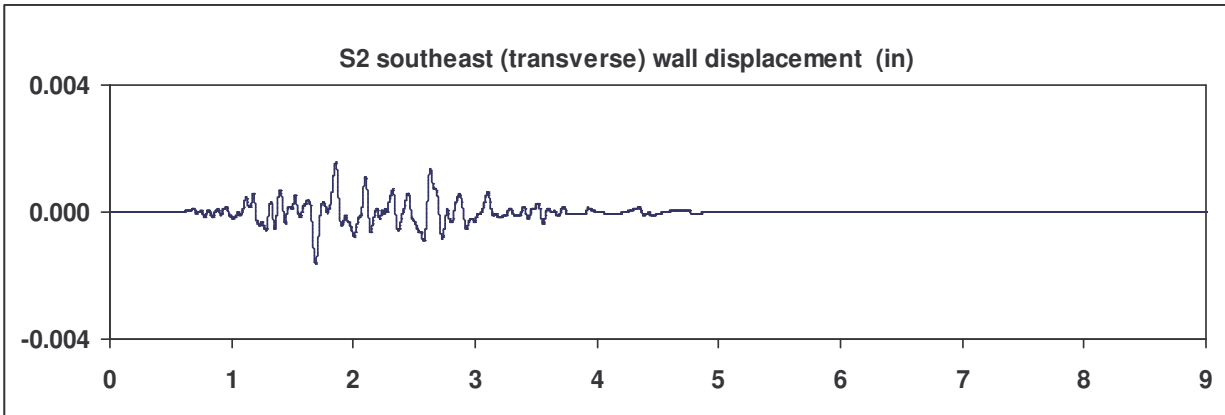


3/16/05a High Mesa

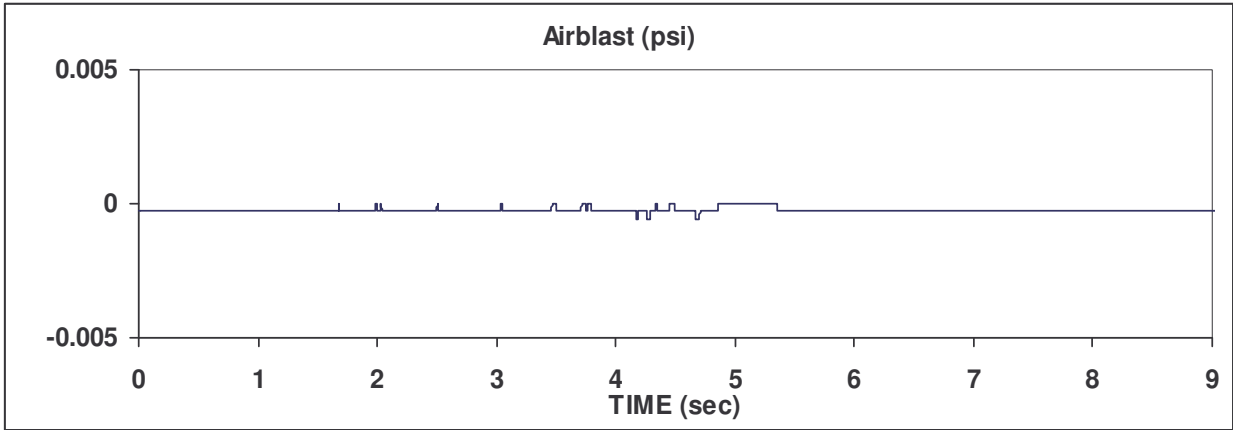
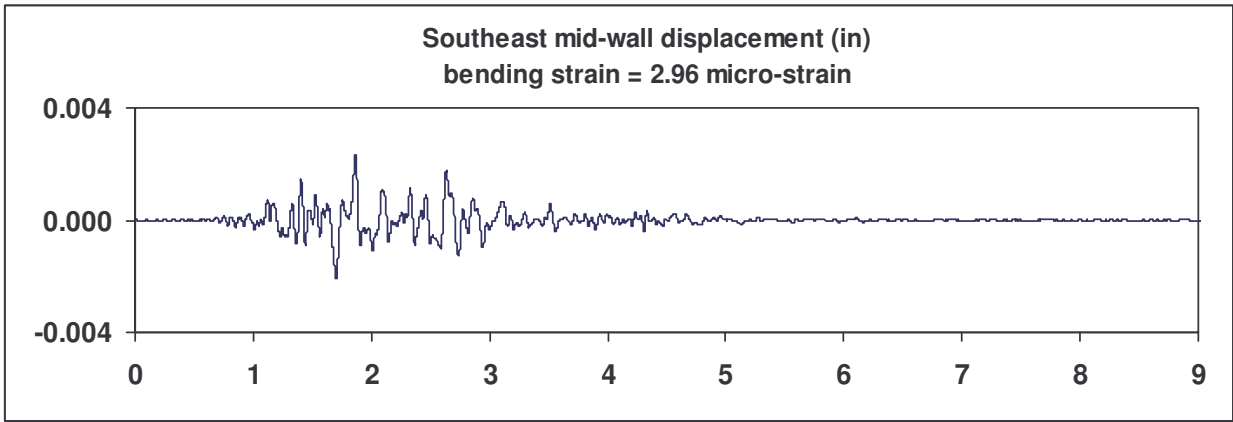
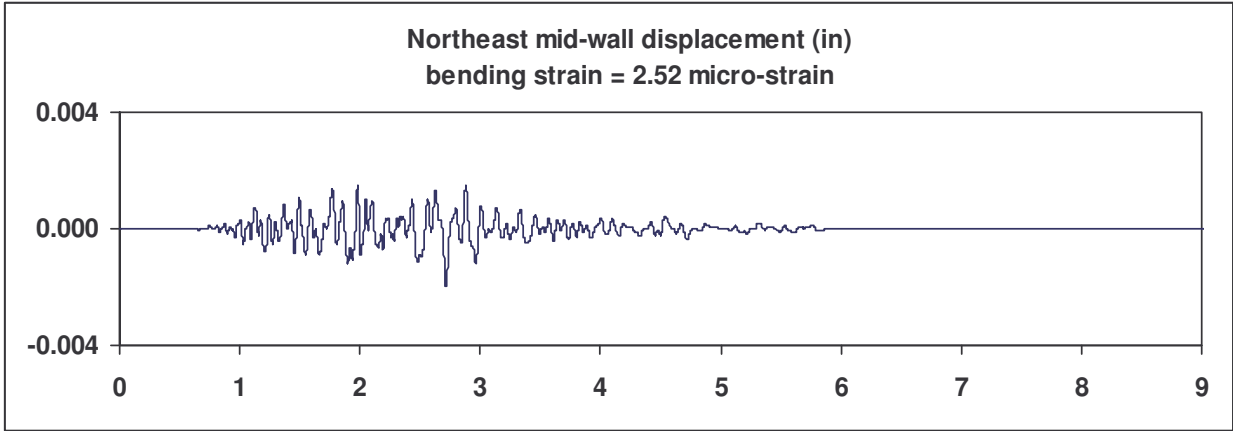


3/16/05b High Mesa

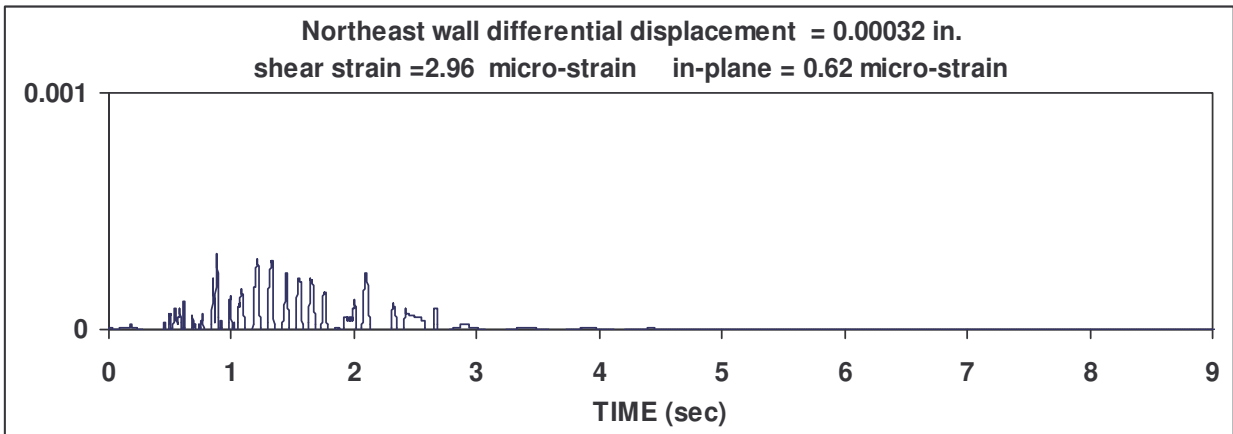
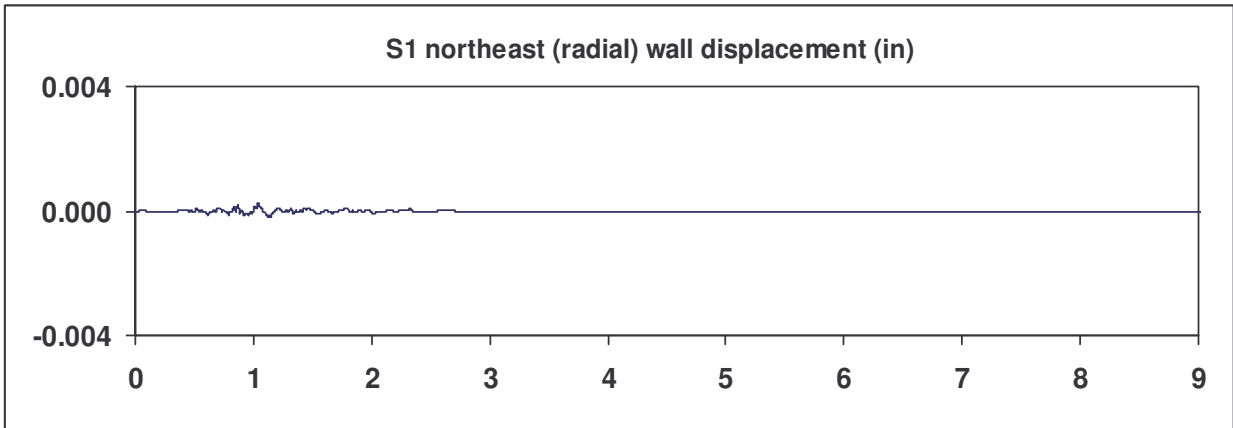
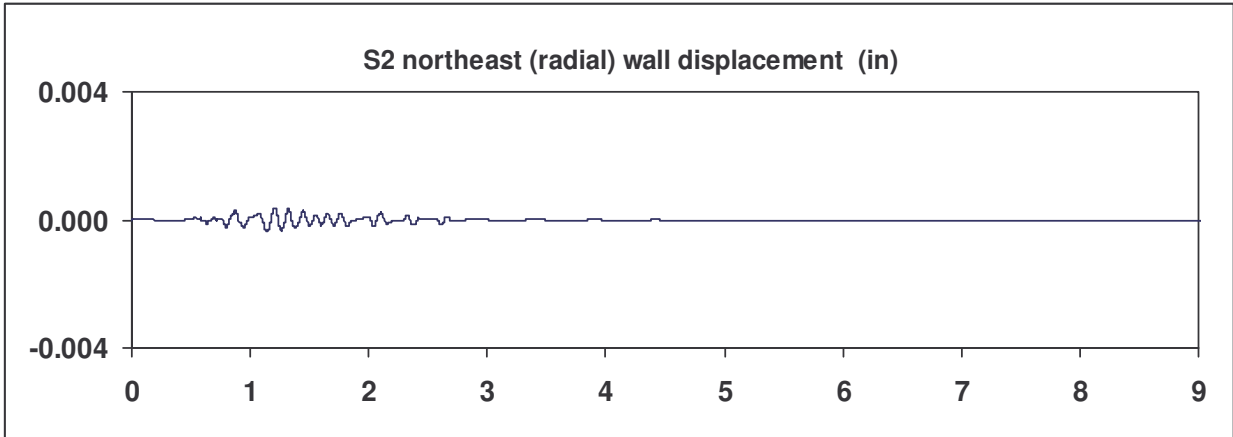




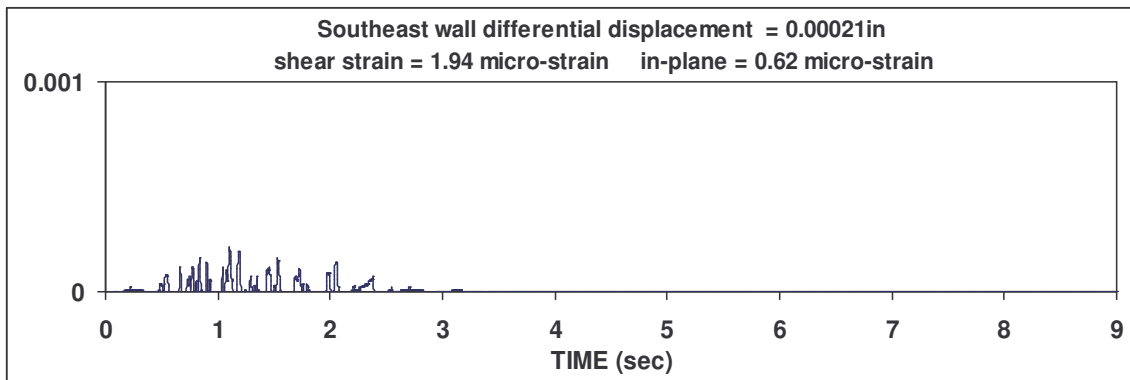
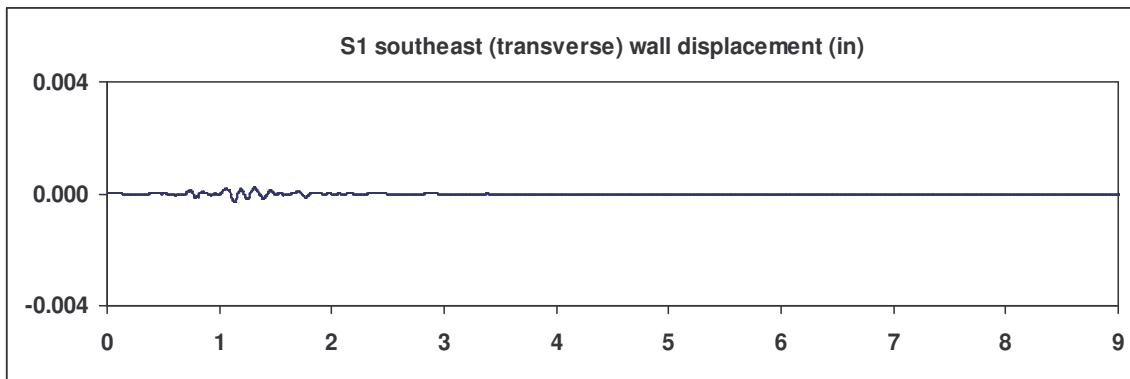
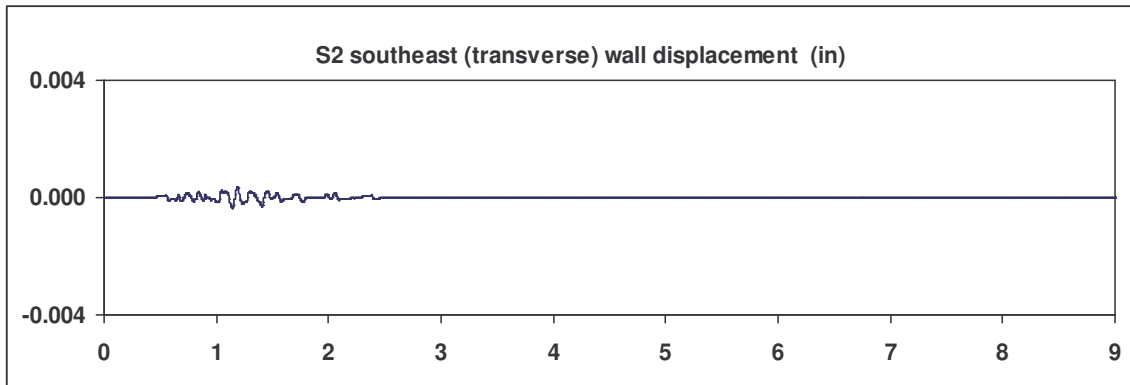
3/16/05b High Mesa



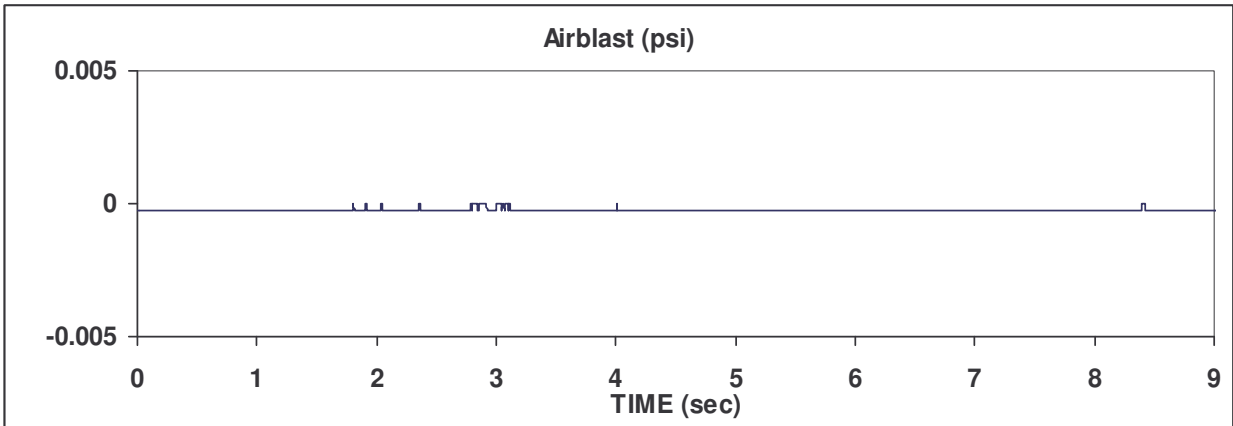
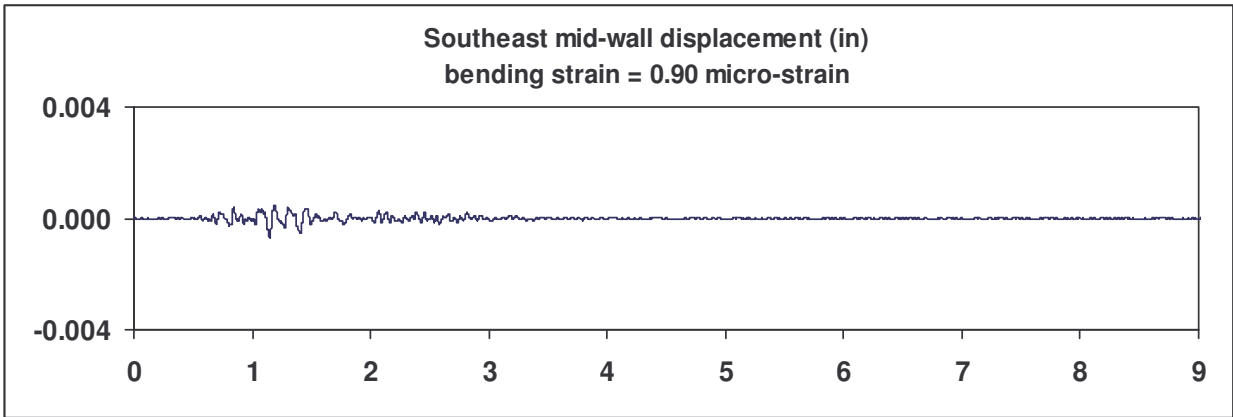
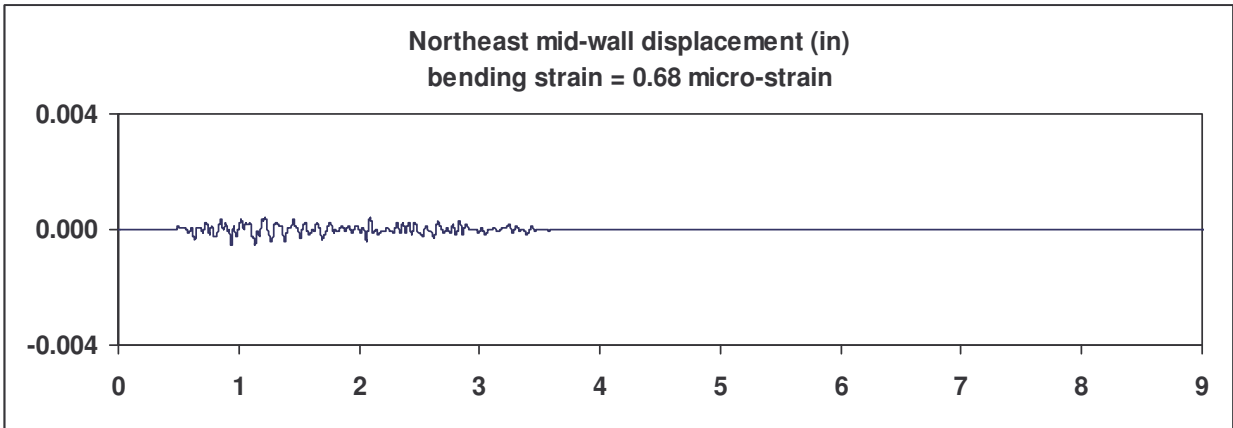
3/16/05b High Mesa



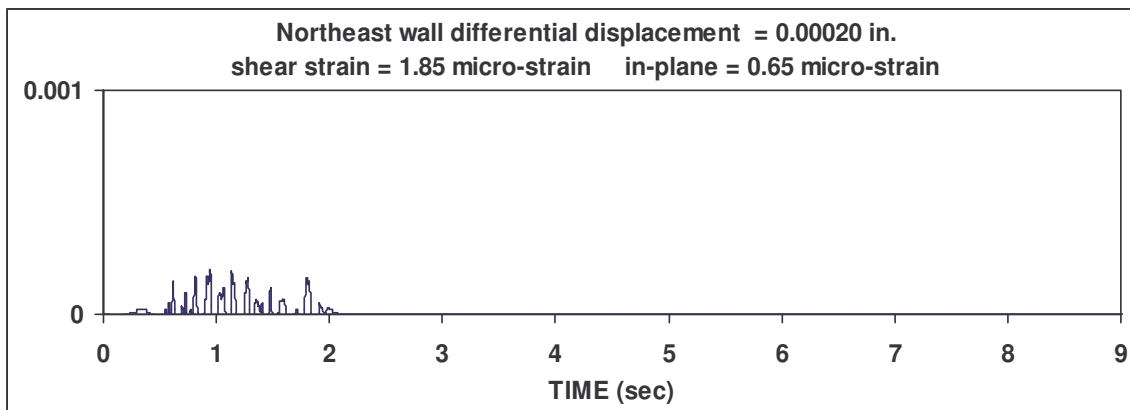
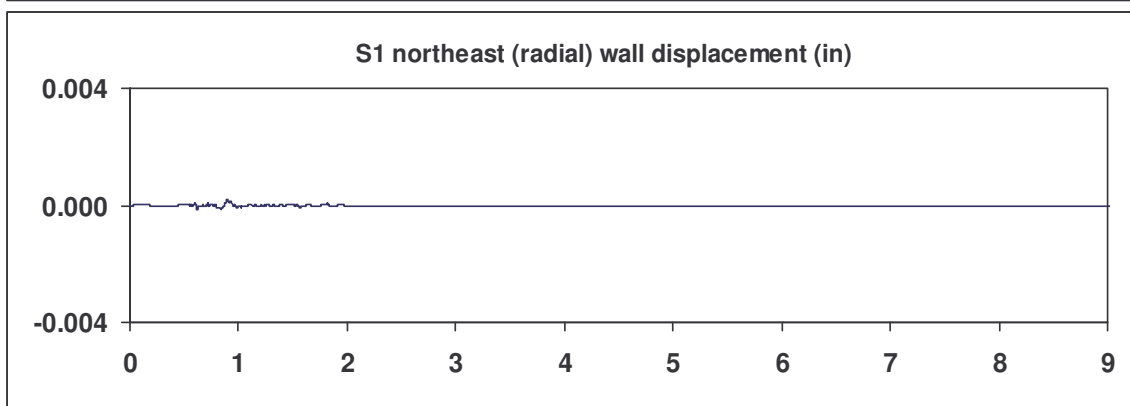
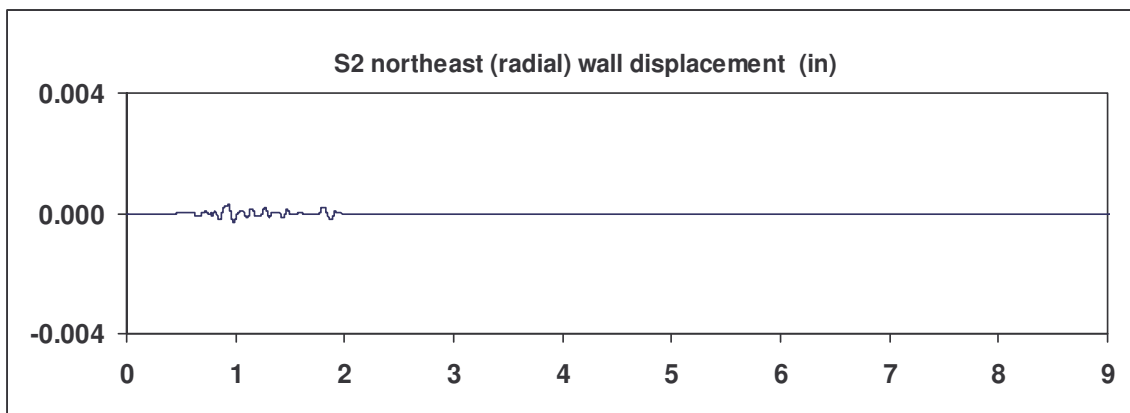
3/17/05 High Mesa



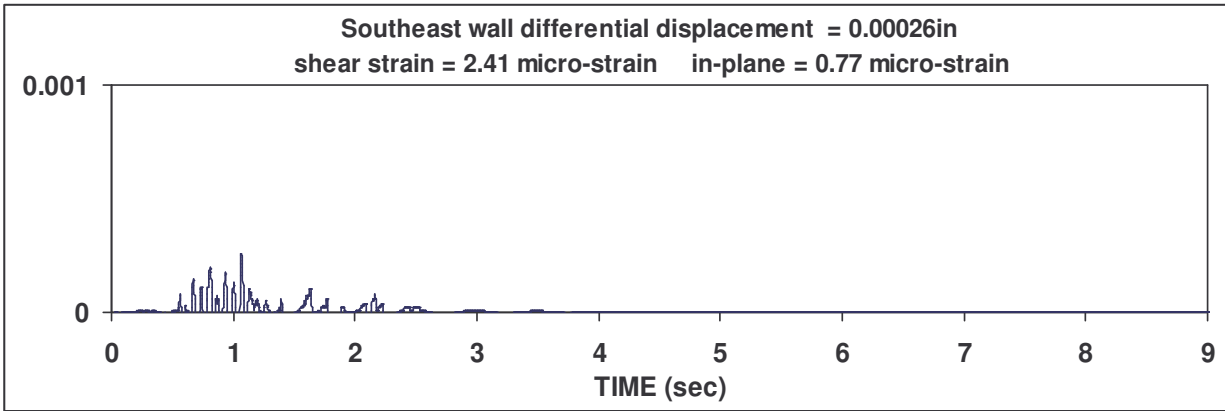
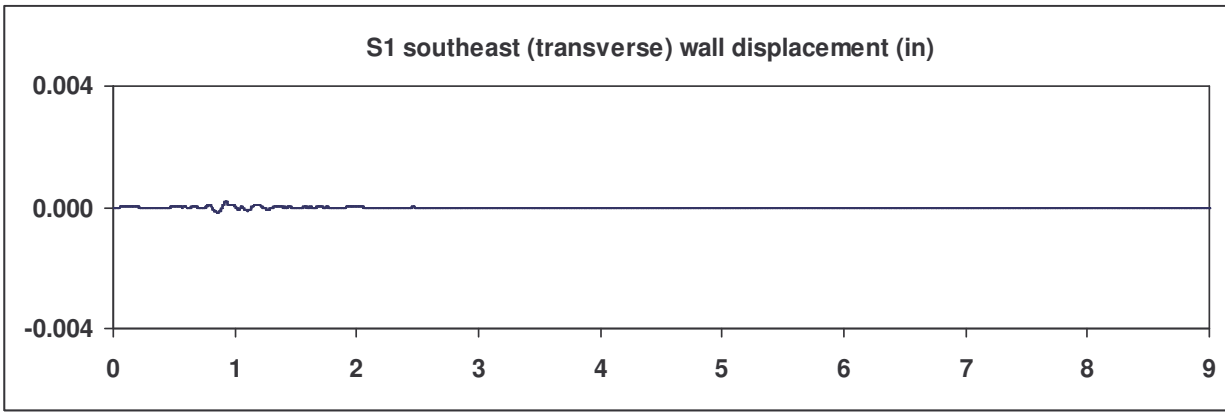
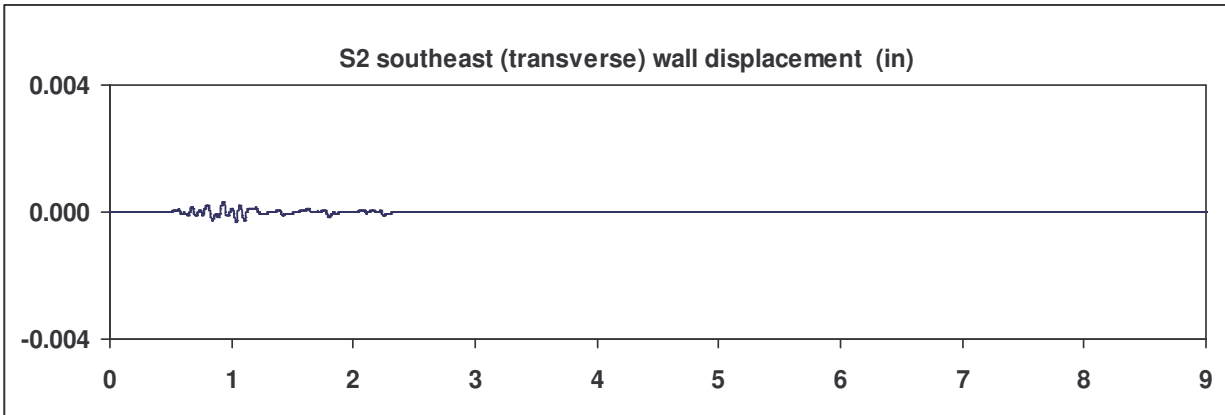
3/17/05 High Mesa



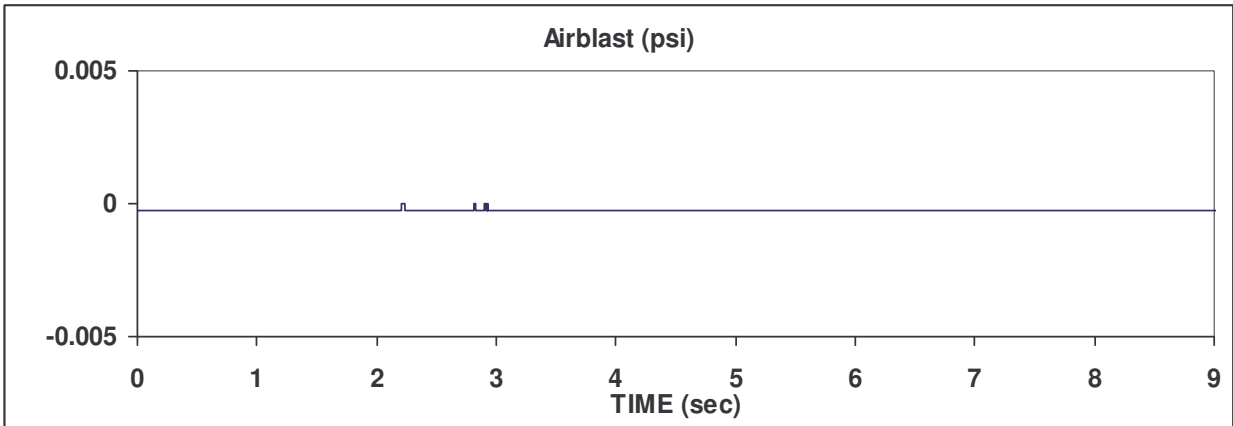
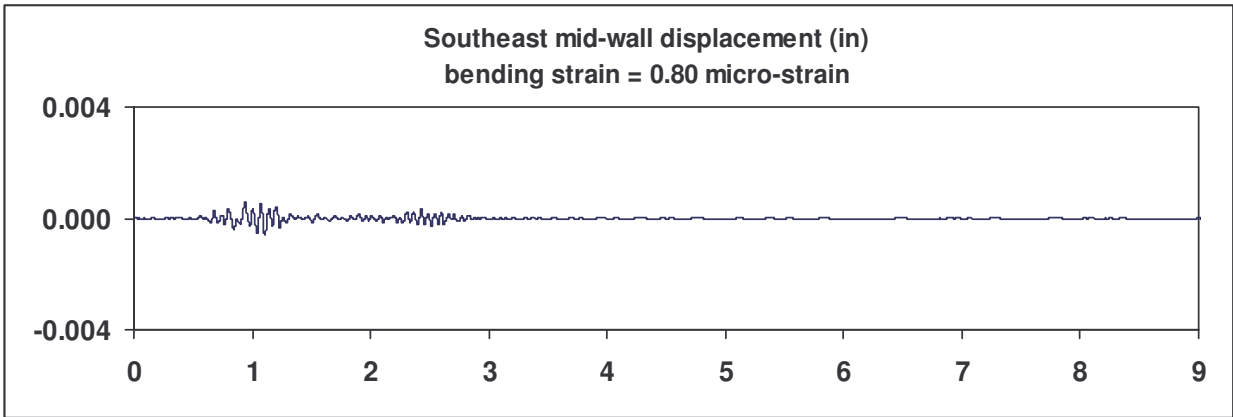
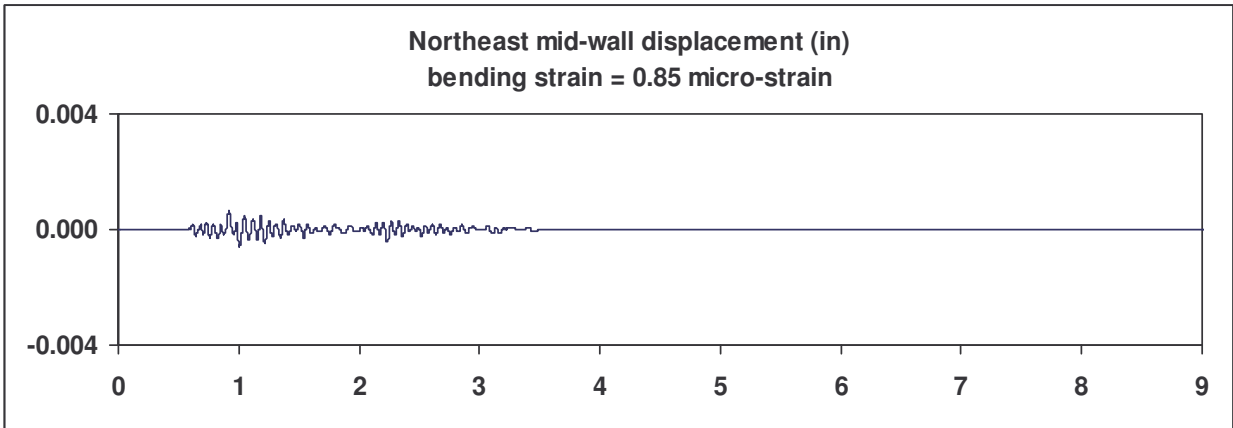
3/17/05 High Mesa



3/18/05a High Mesa

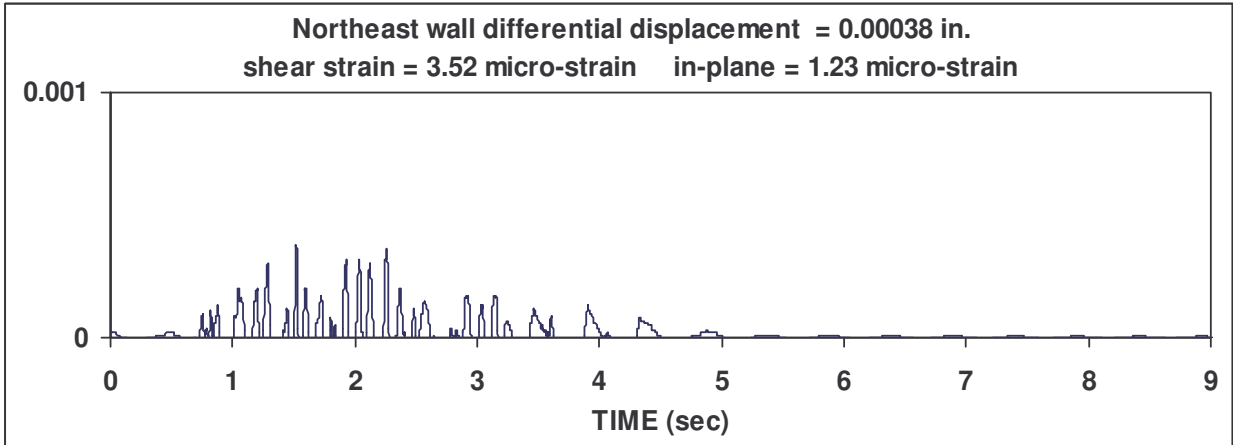
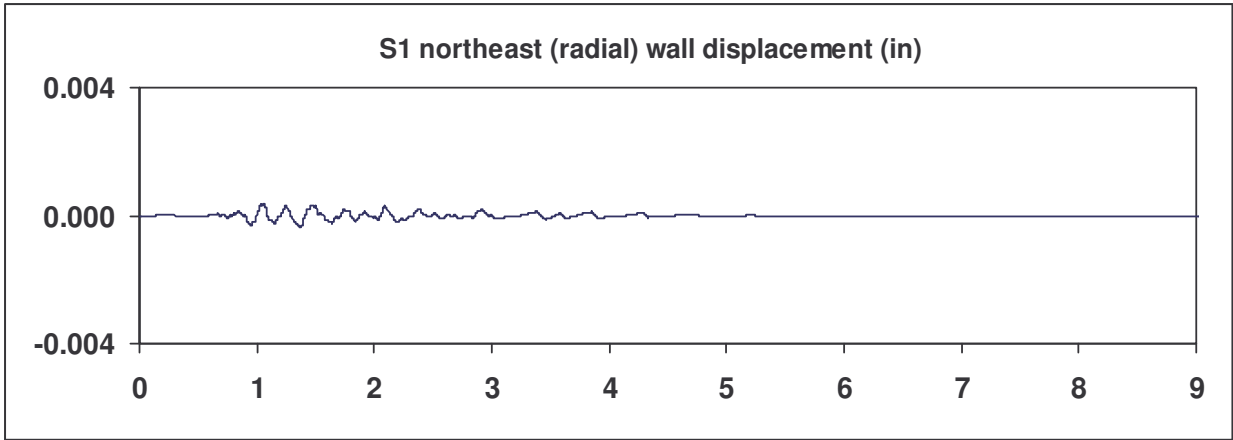
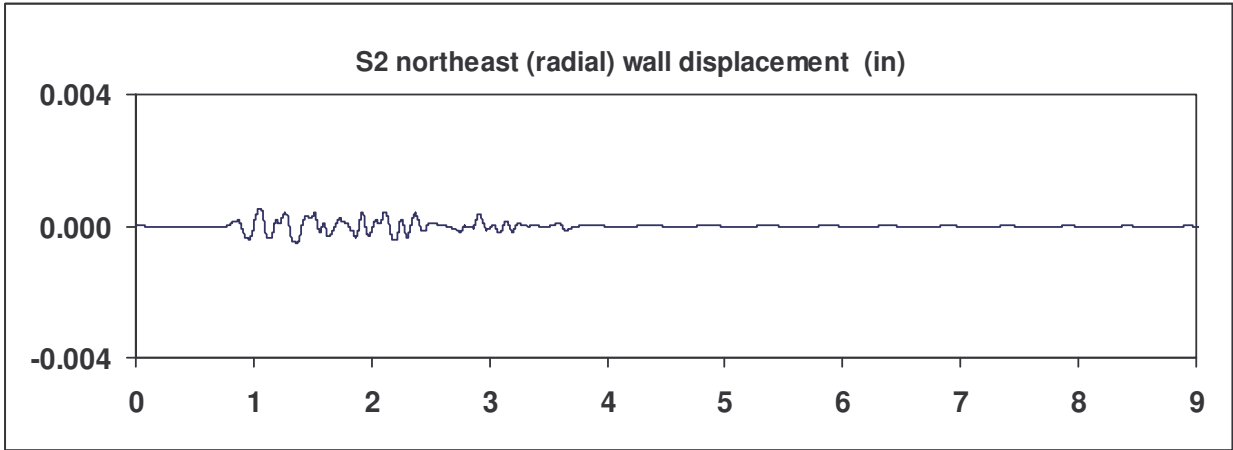


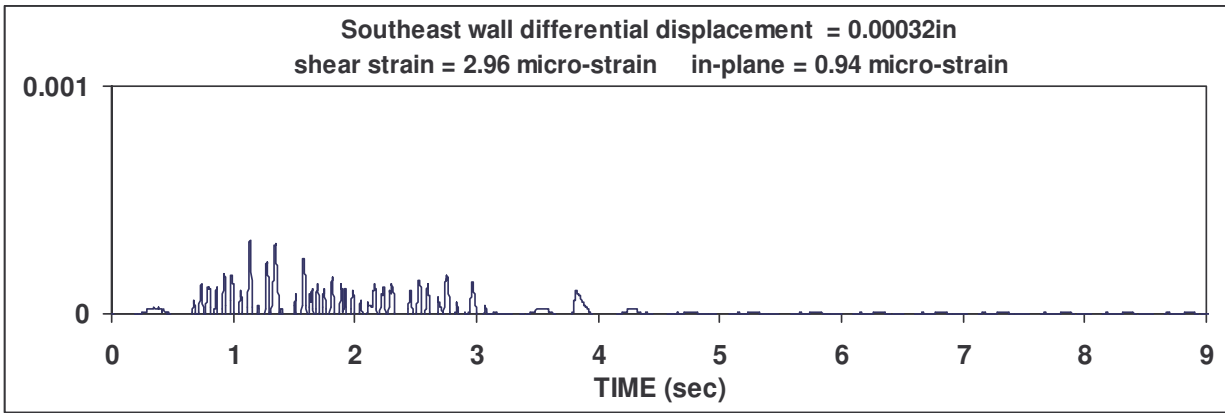
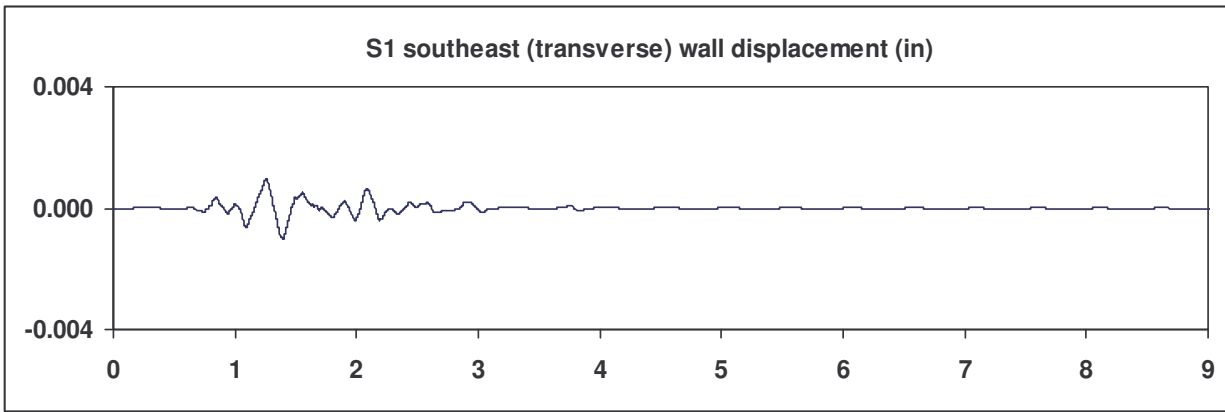
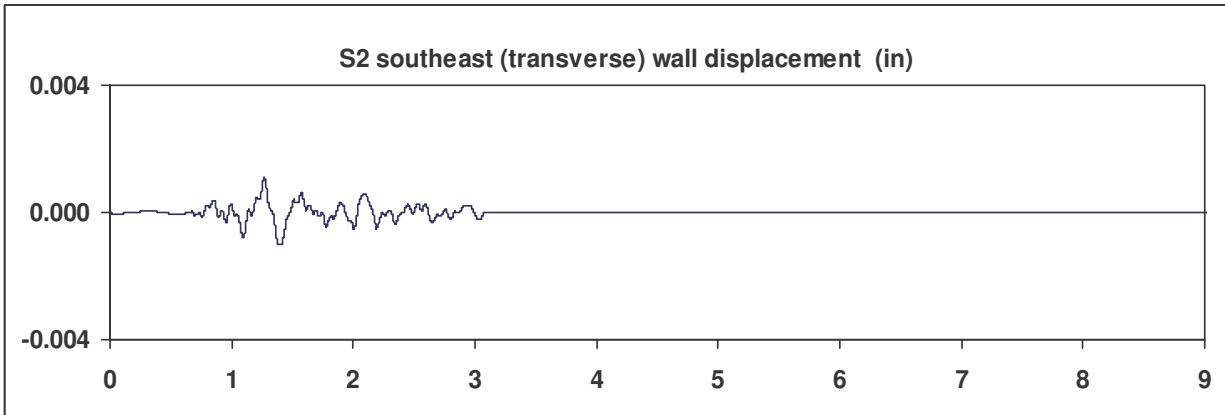
3/18/05a High Mesa



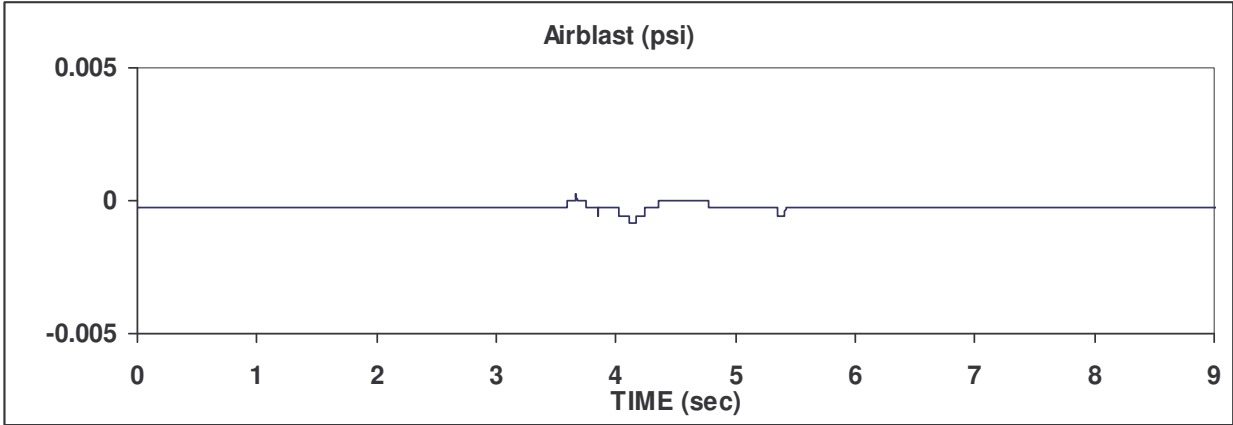
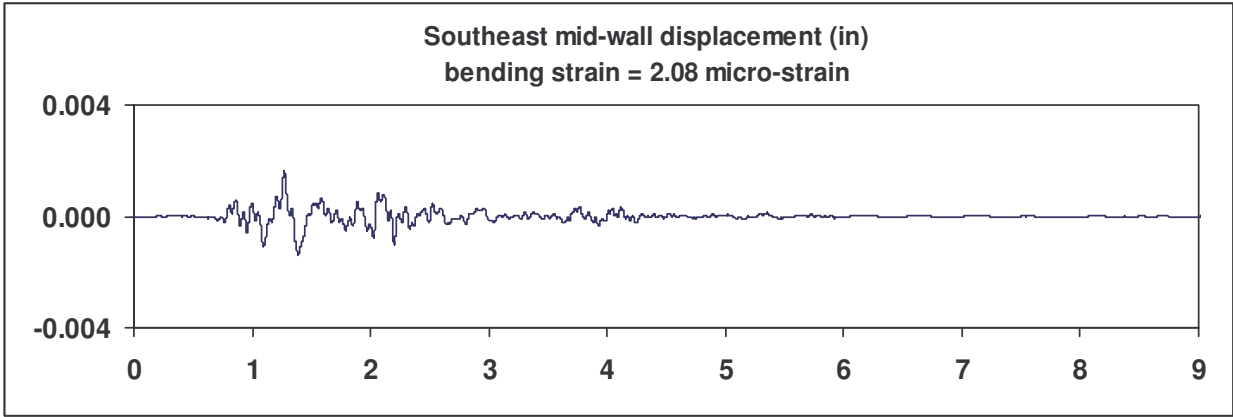
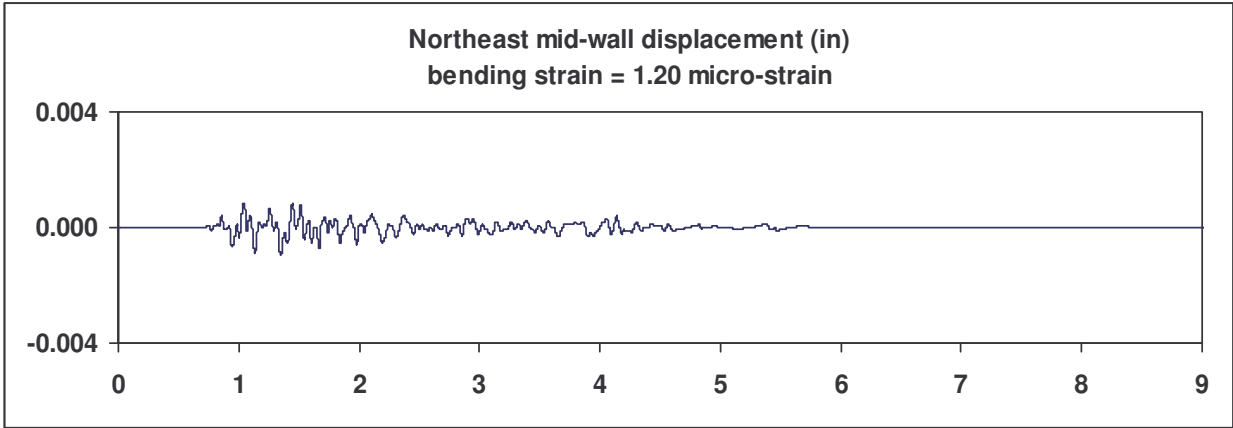
3/18/05a High Mesa



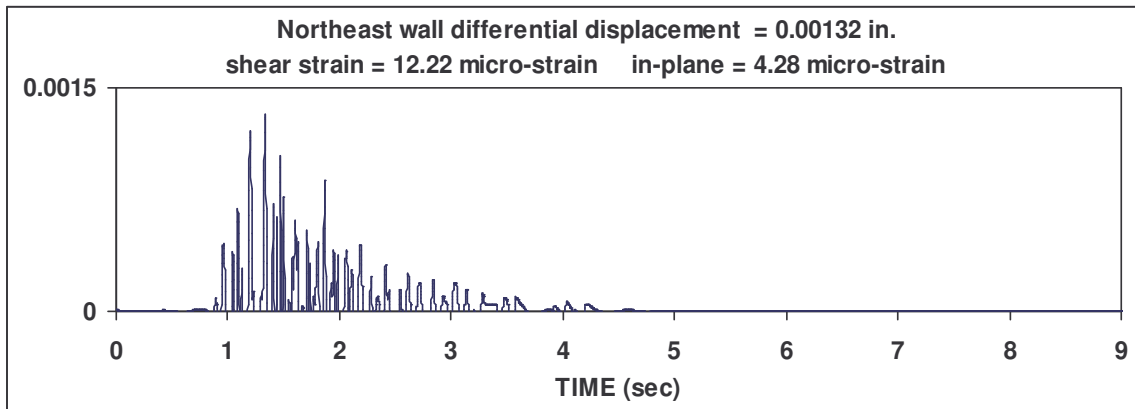
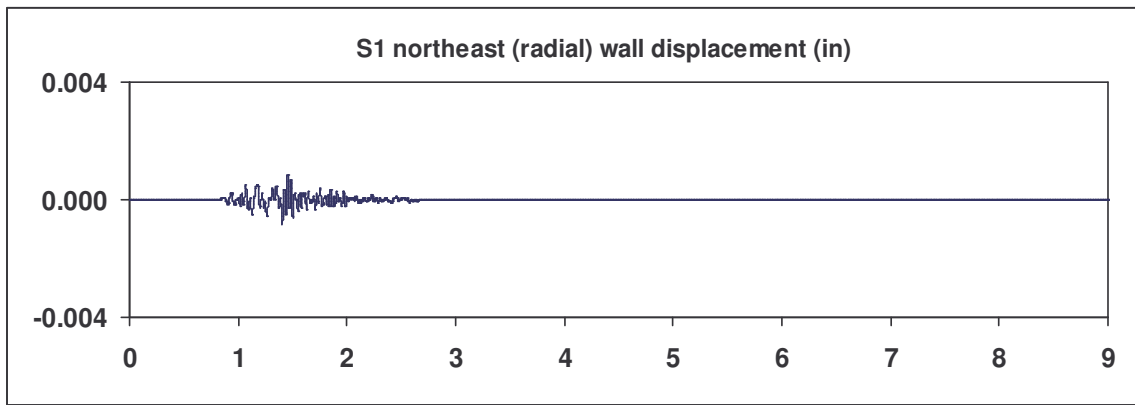
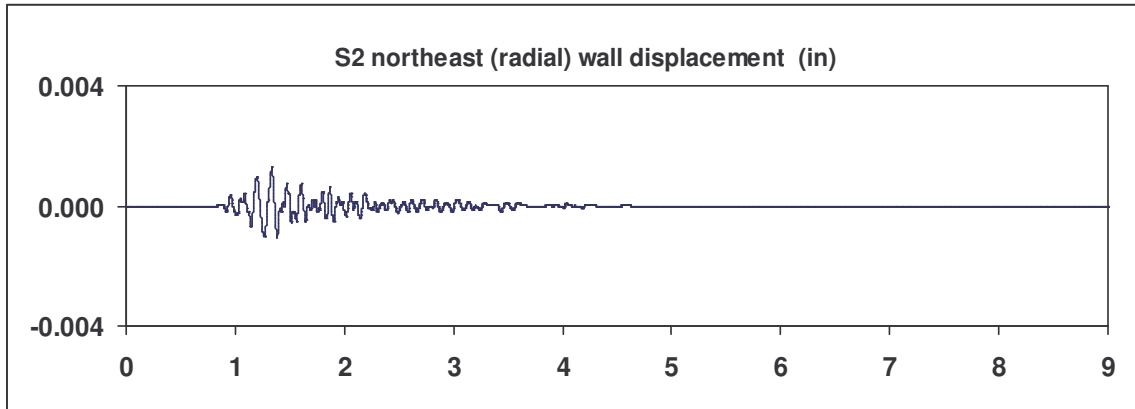




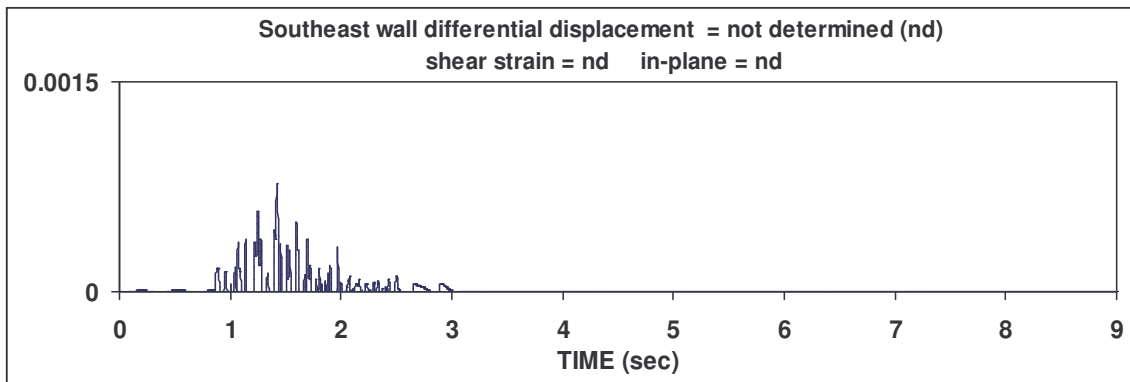
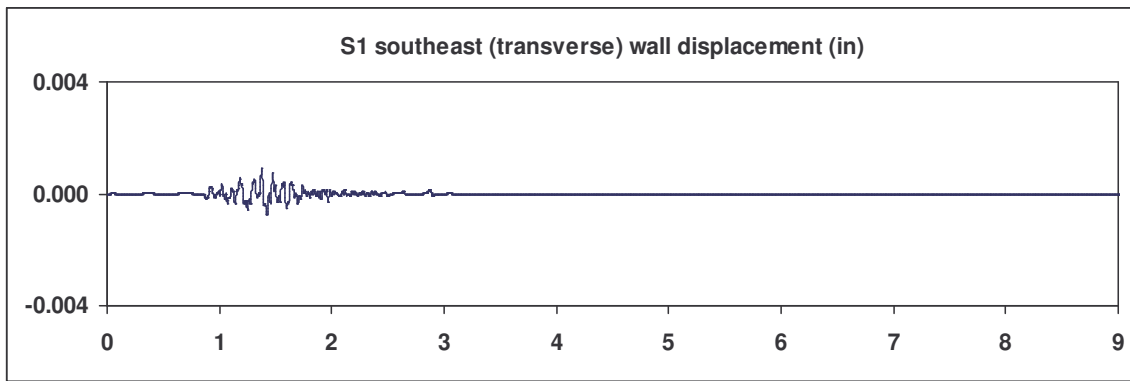
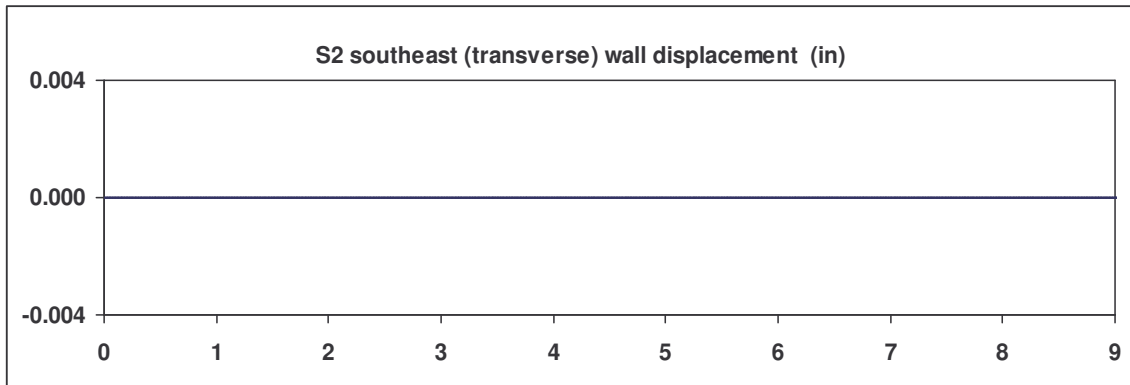
3/18/05b High Mesa



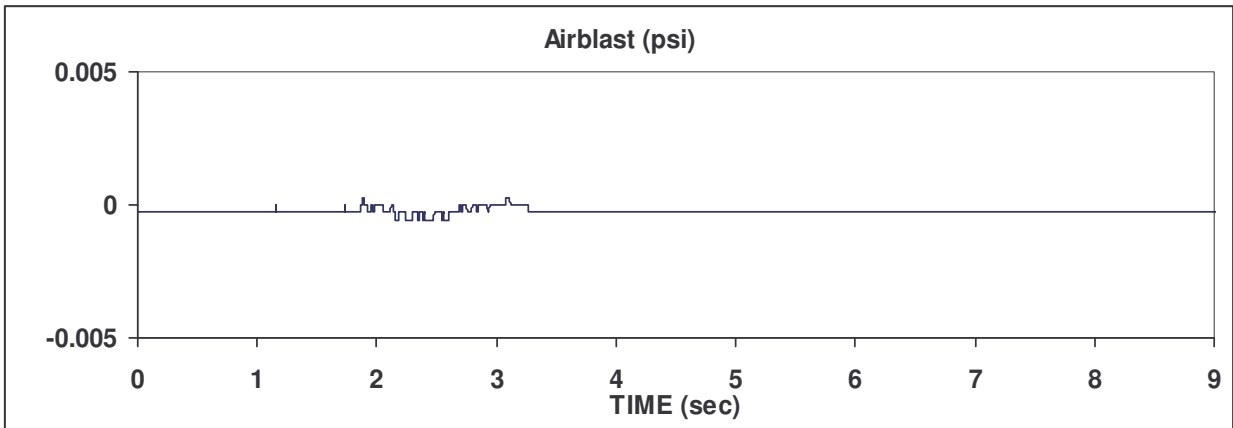
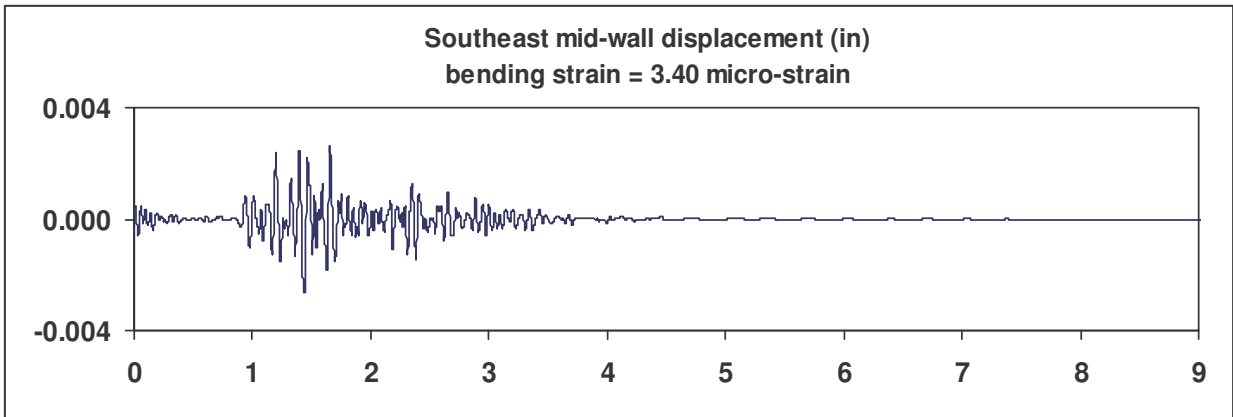
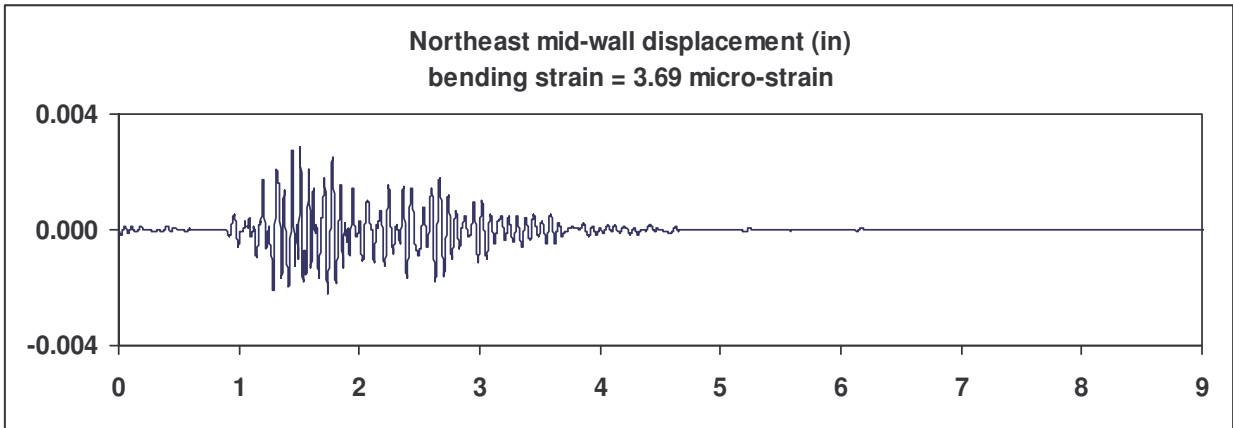
3/18/05b High Mesa



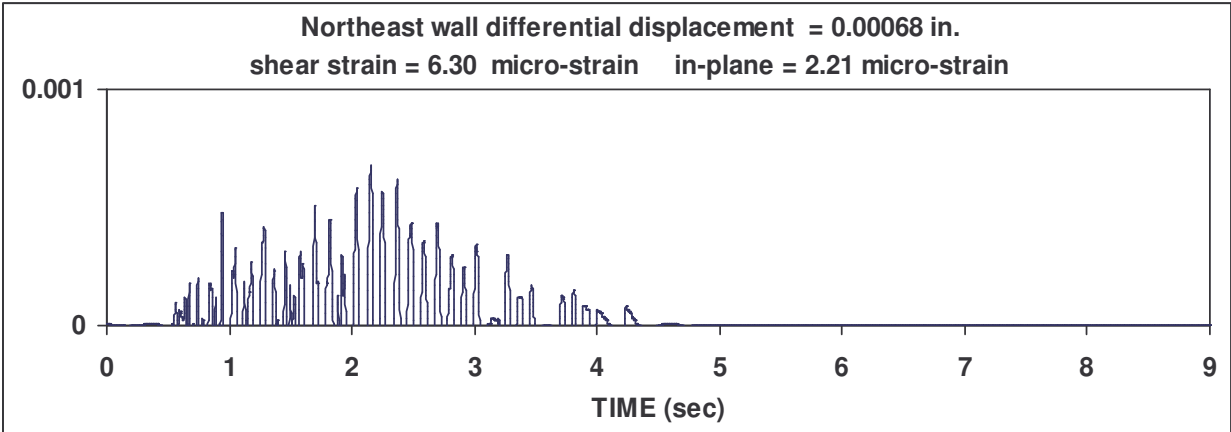
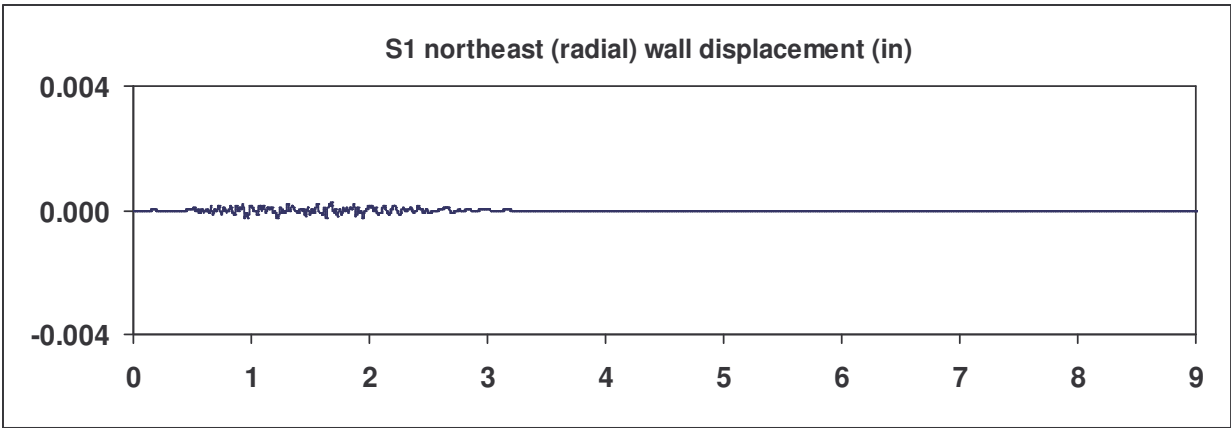
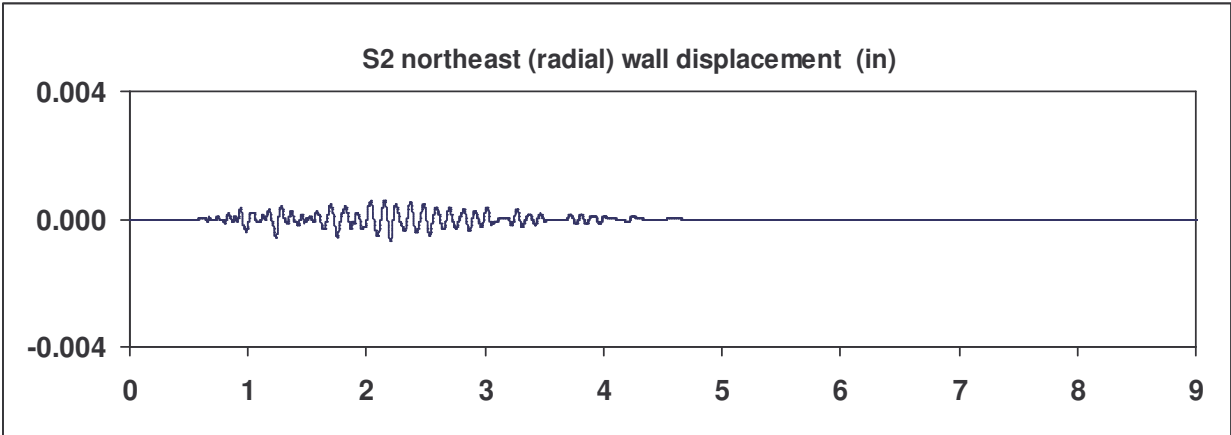
4/8/05 High Mesa

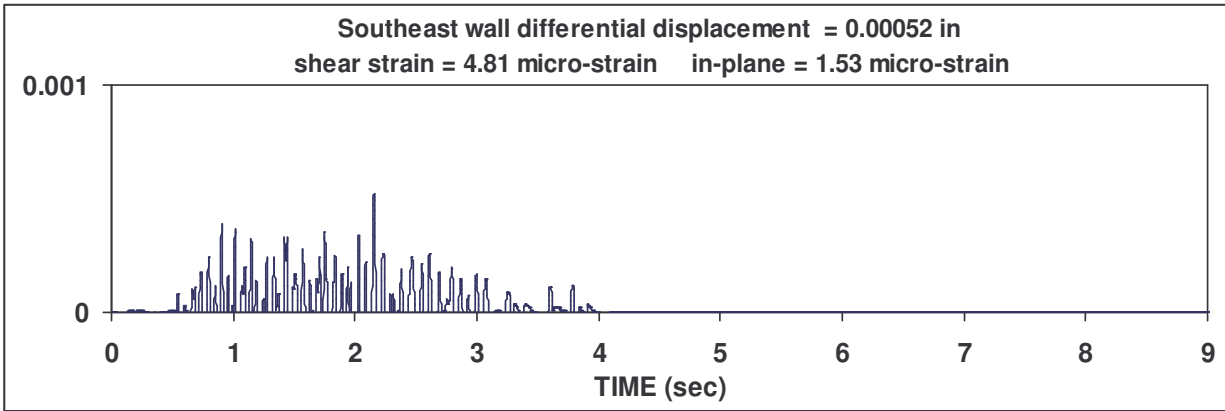
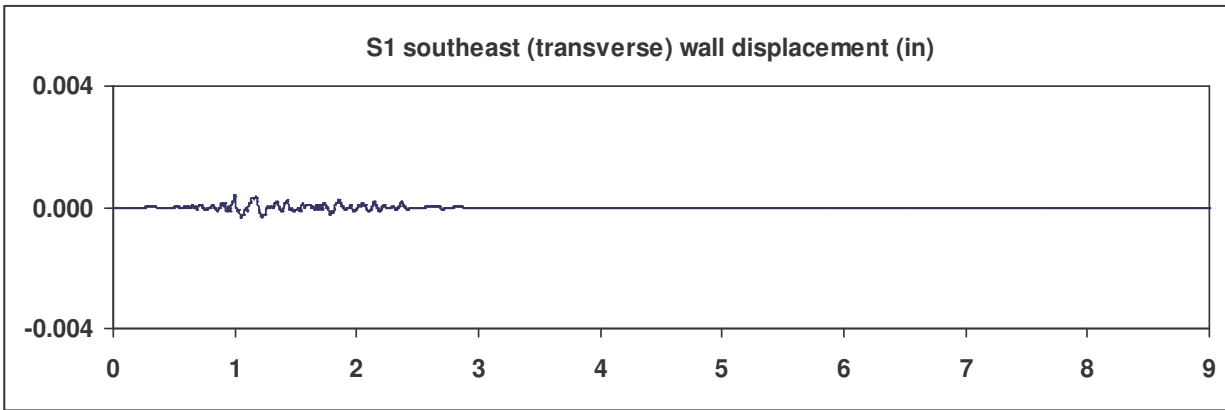
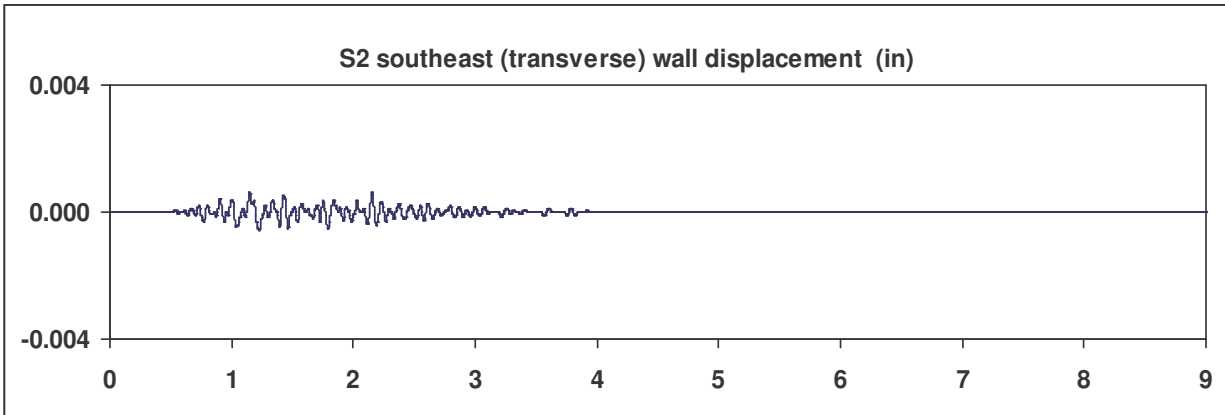


4/8/05 High Mesa



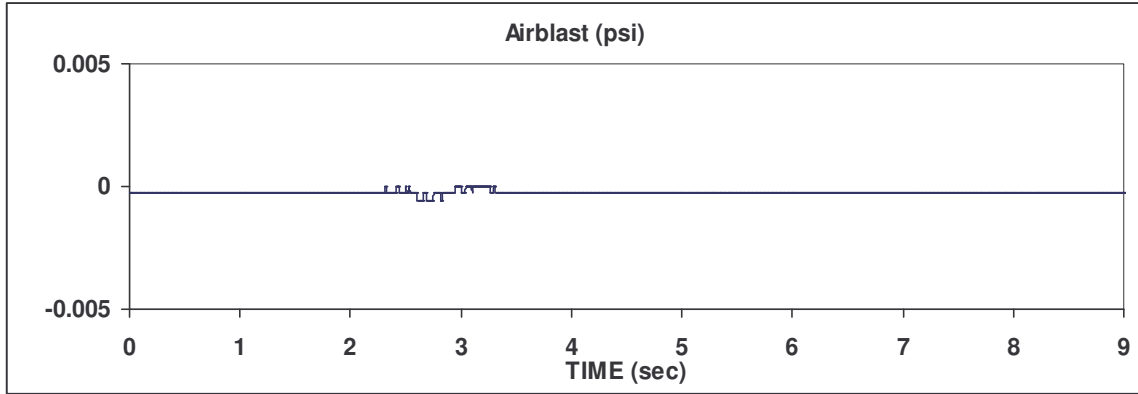
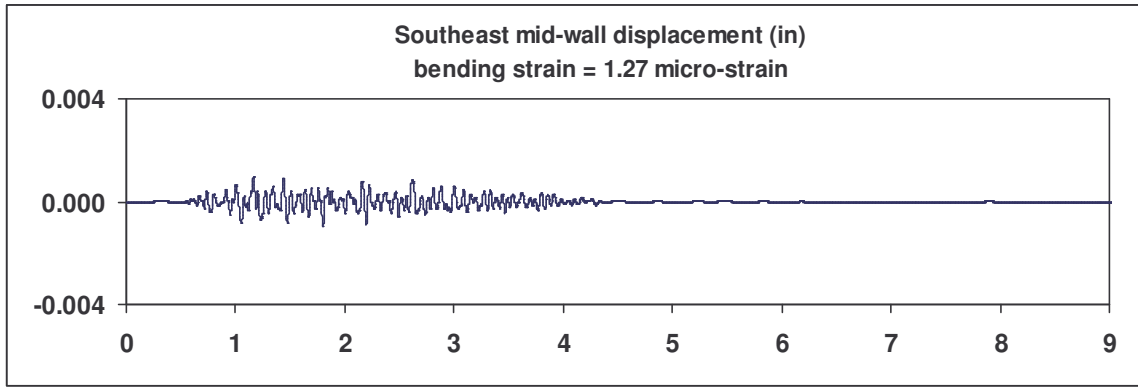
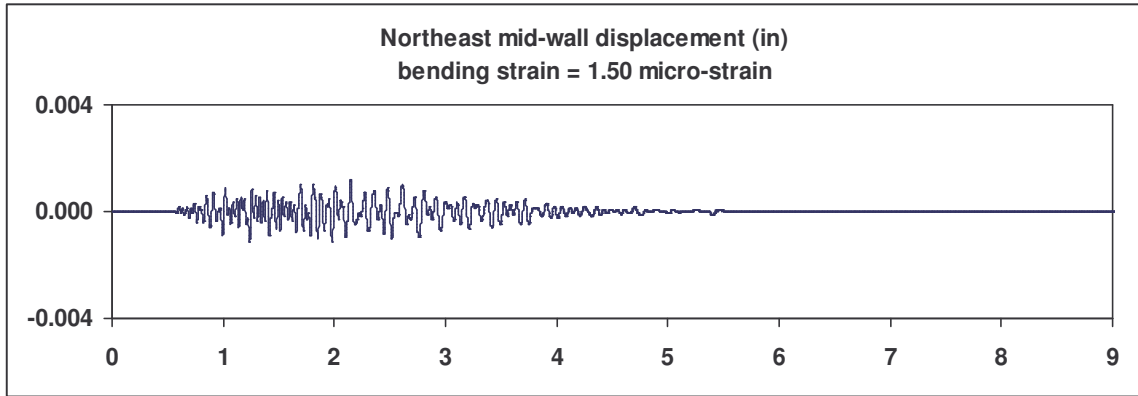
4/8/05 High Mesa



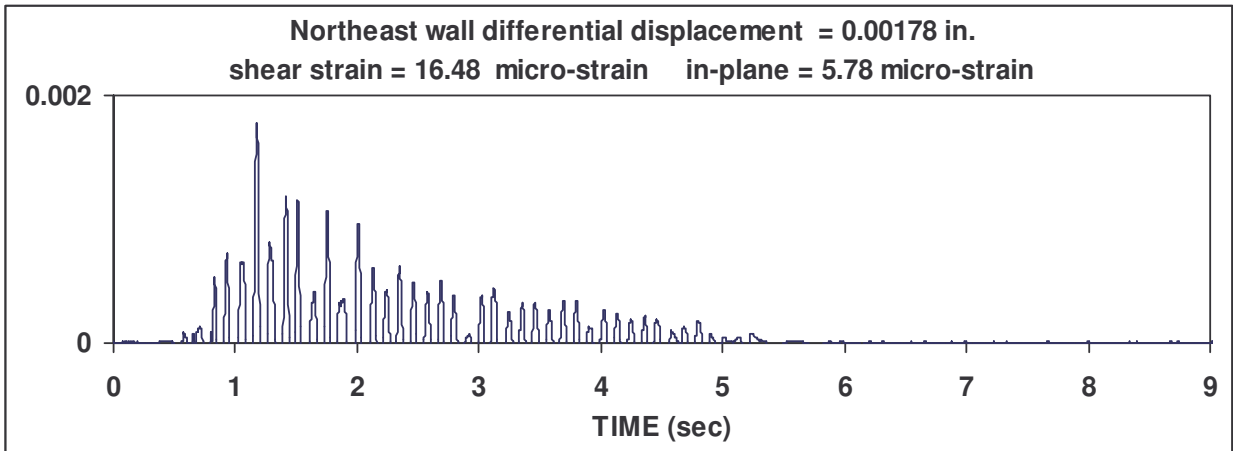
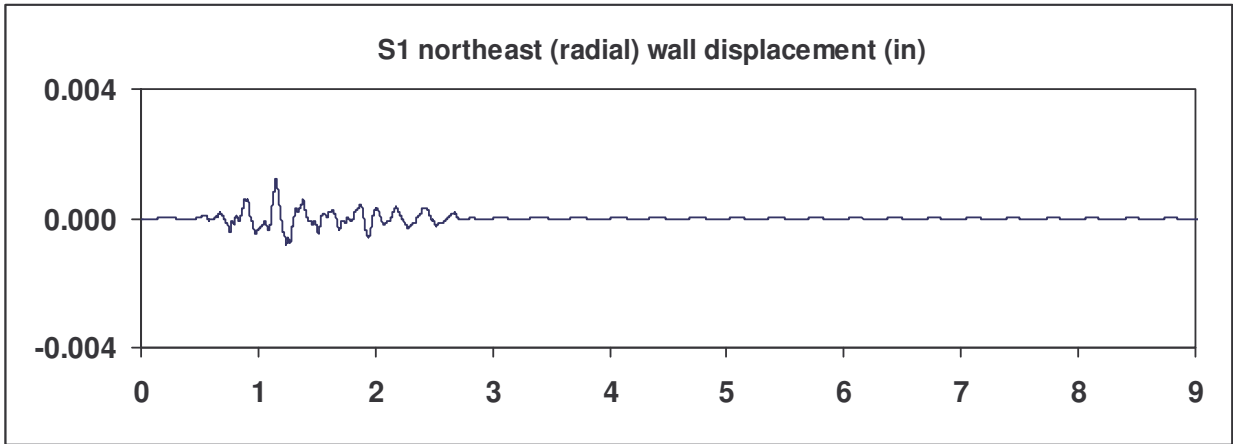
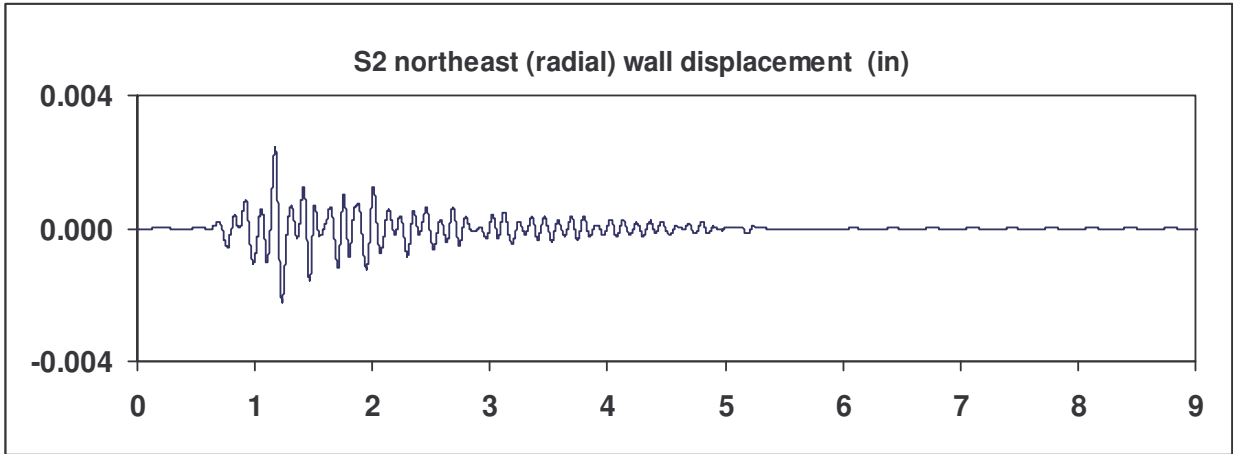


4/12/05 High Mesa

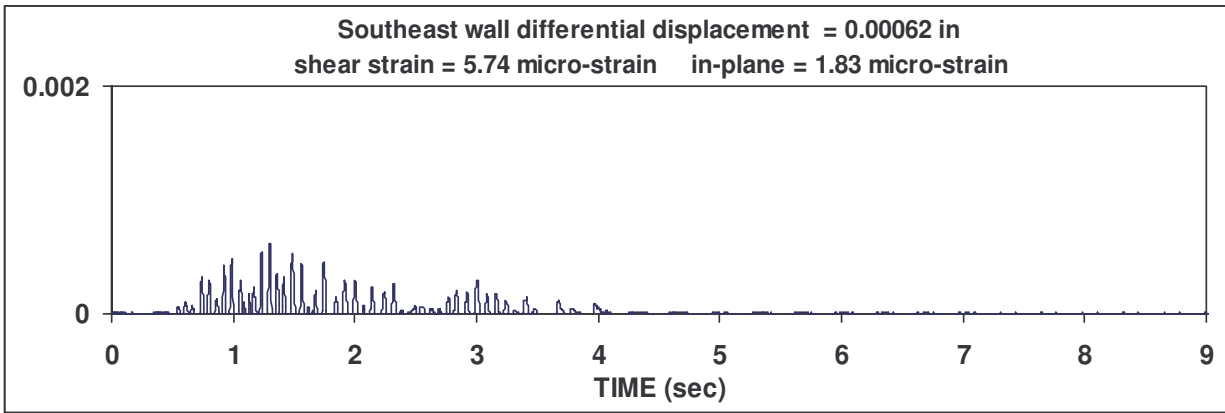
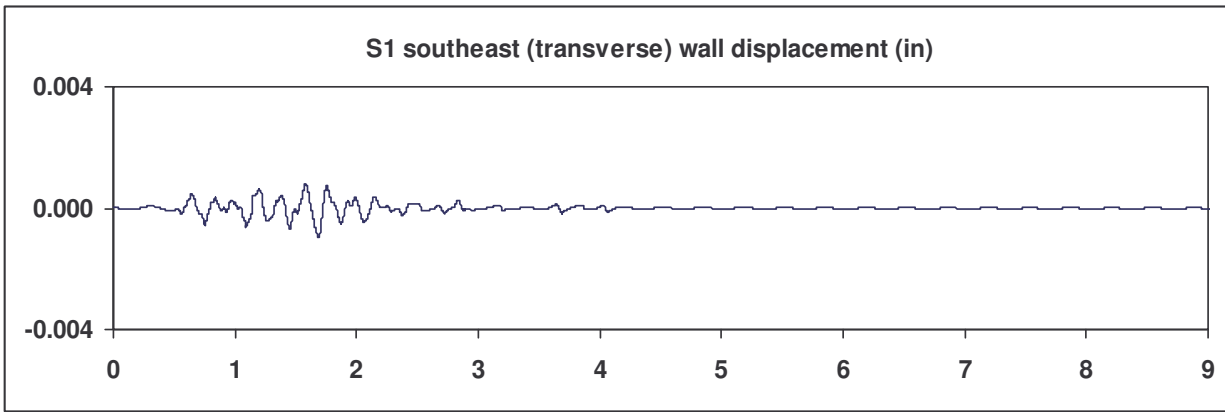
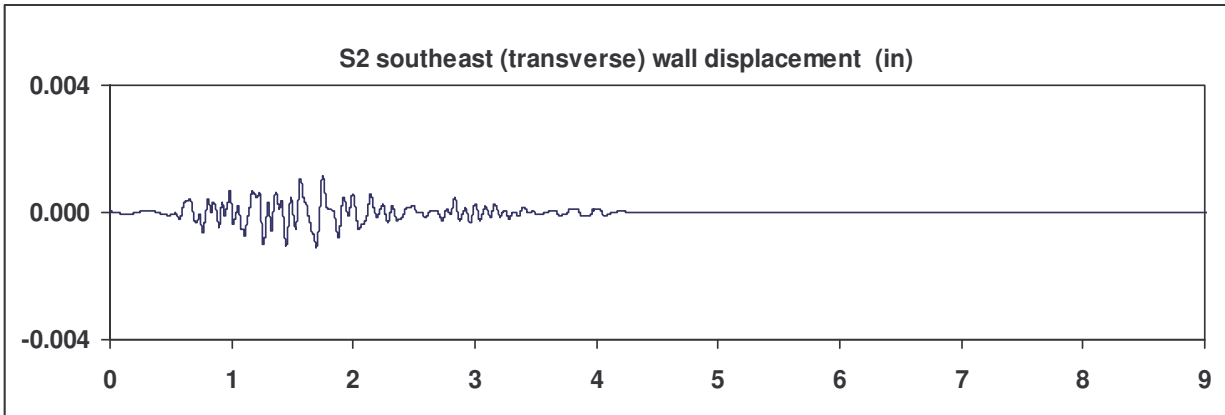




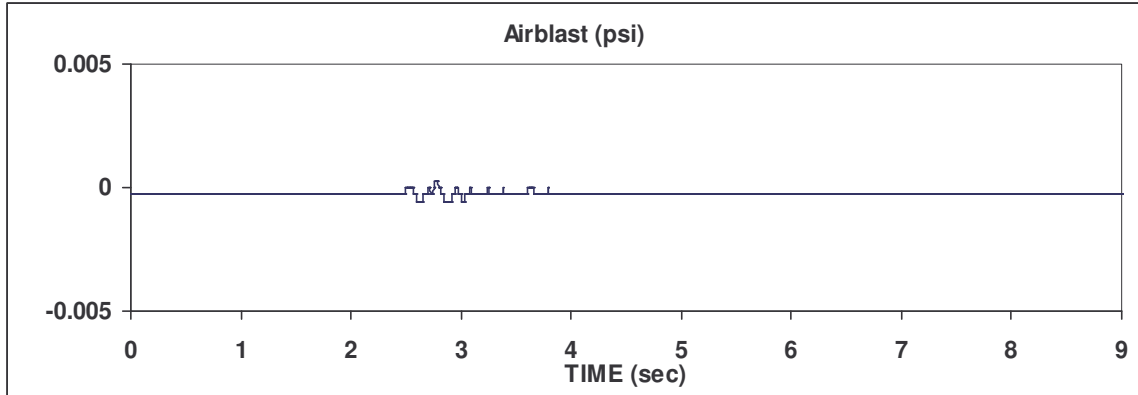
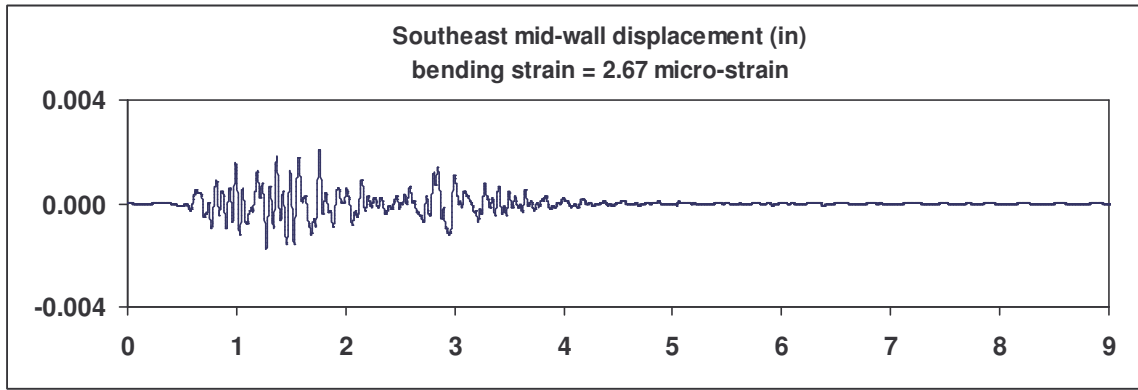
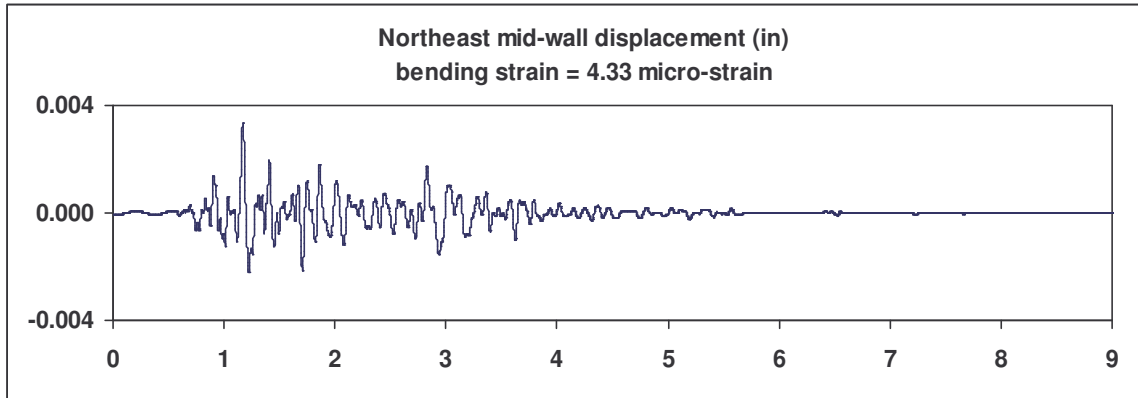
4/12/05 High Mesa



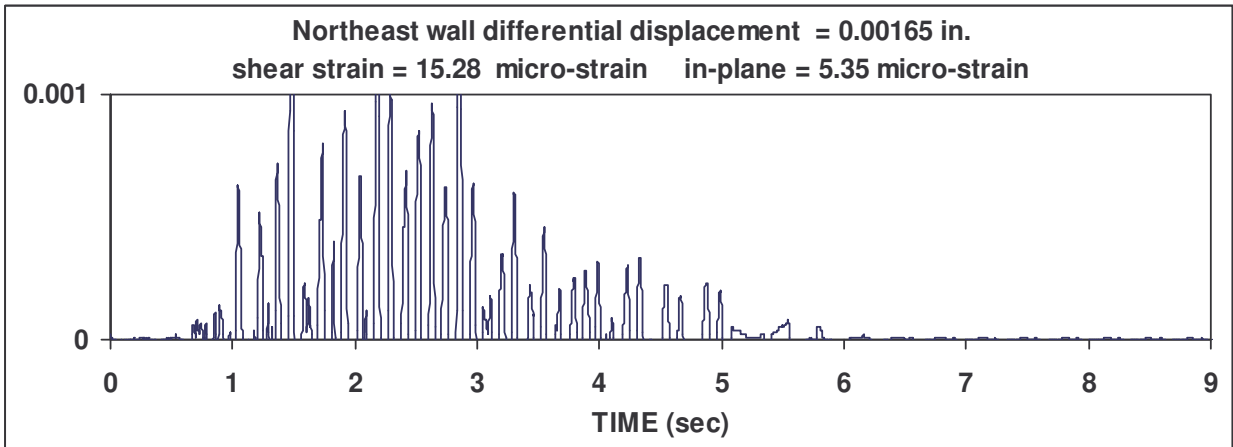
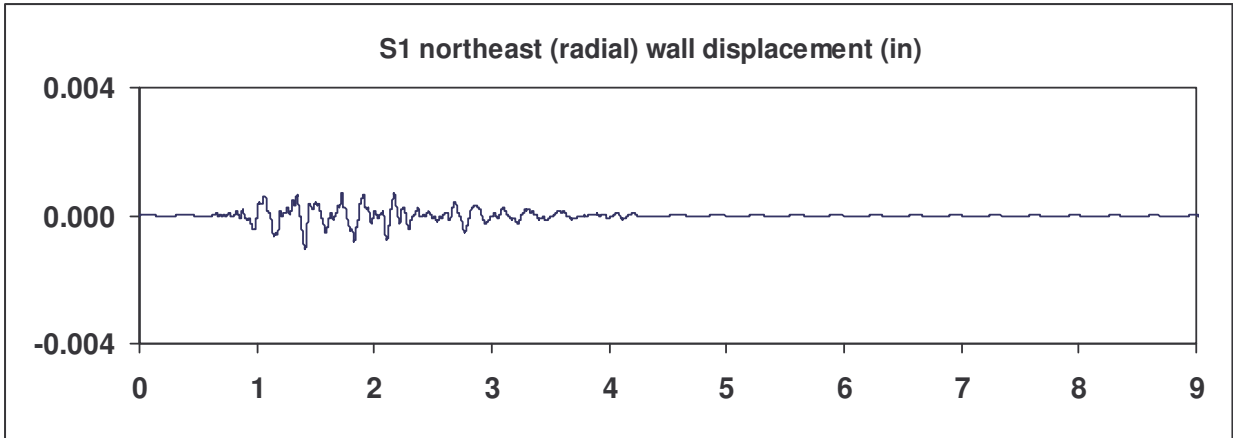
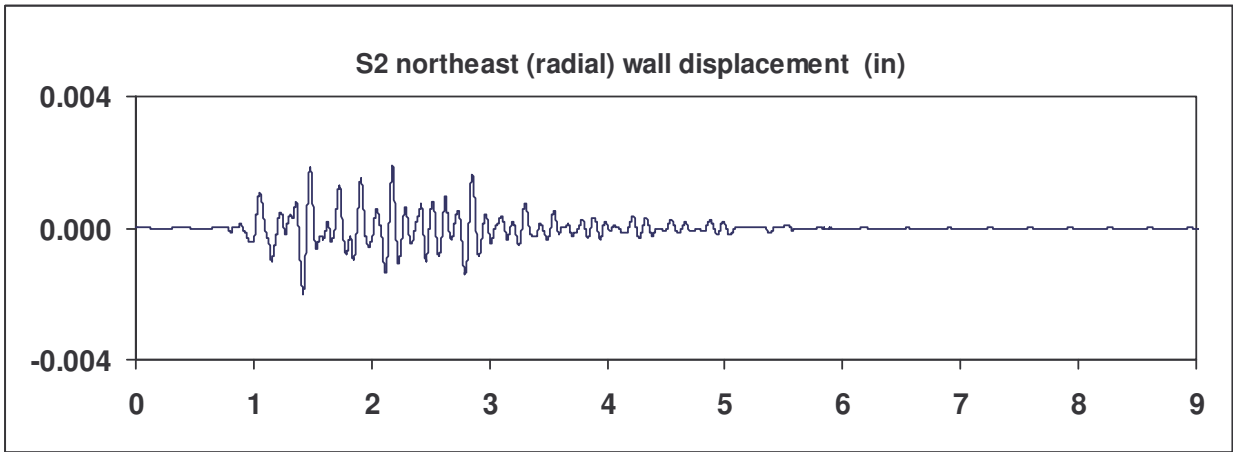
4/13/05 High Mesa



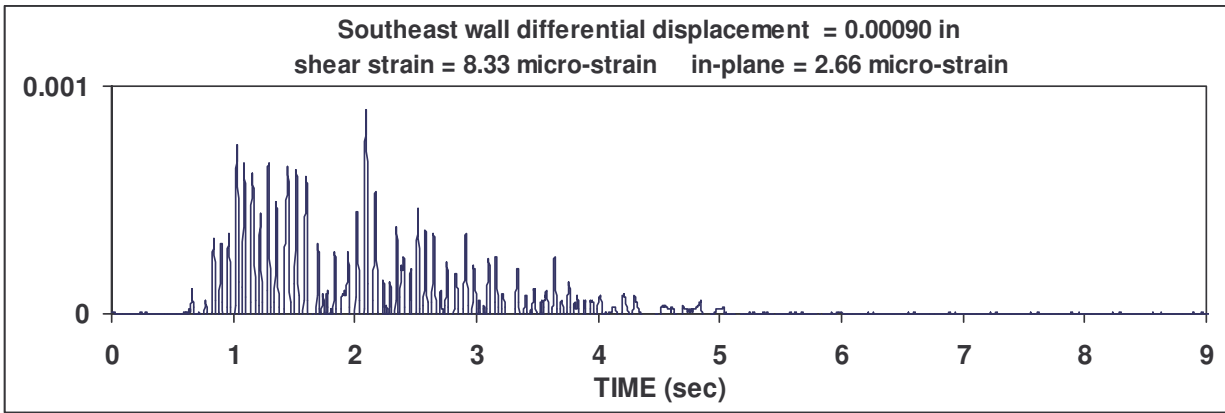
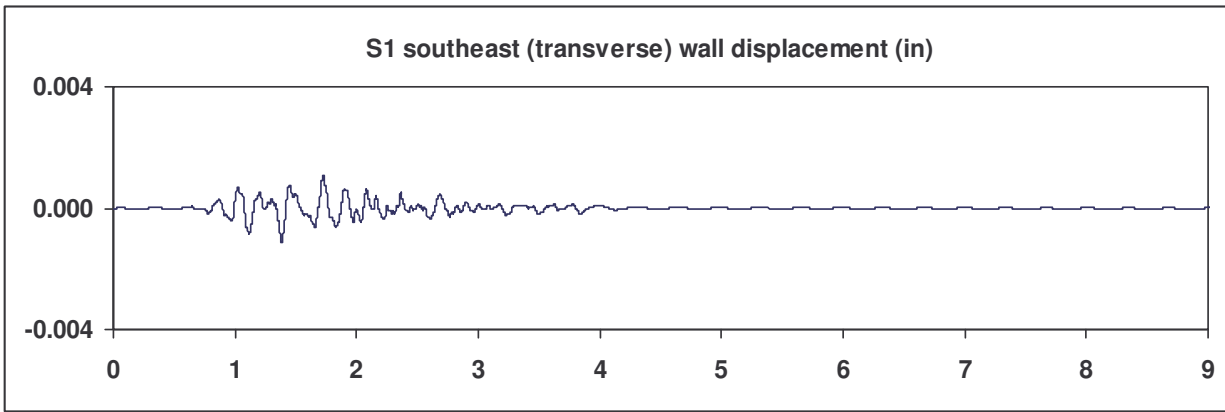
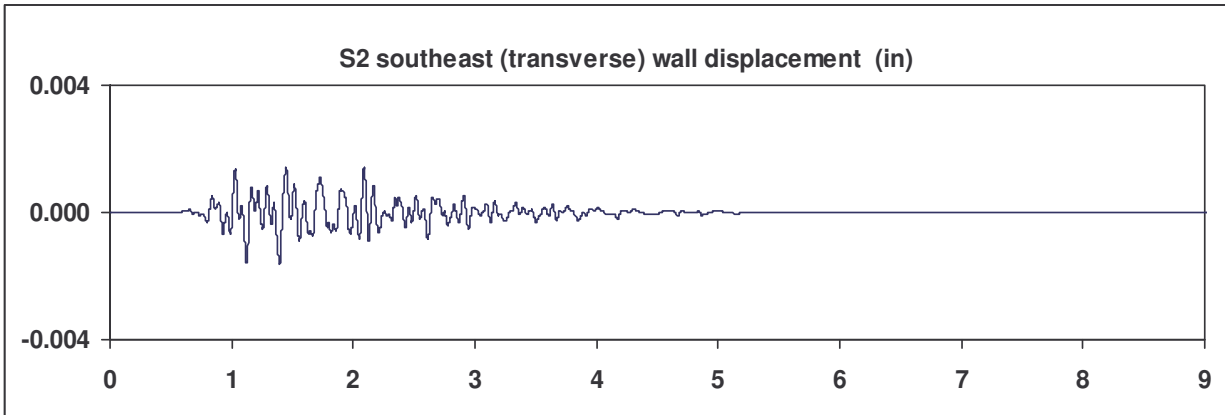
4/13/05 High Mesa



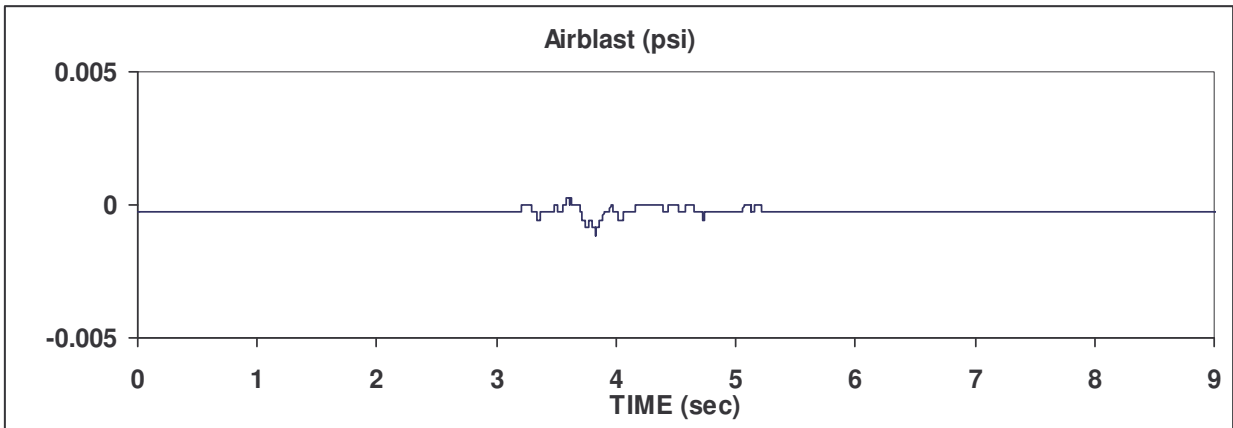
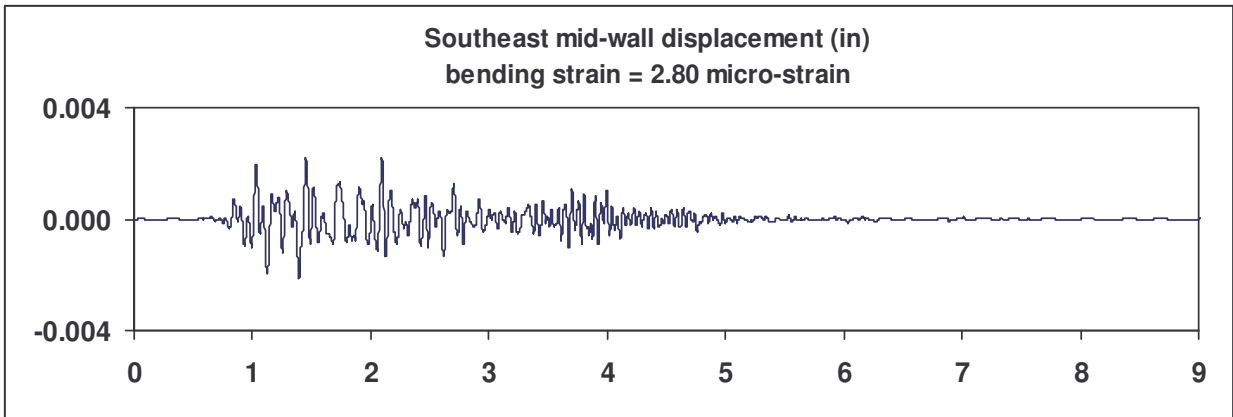
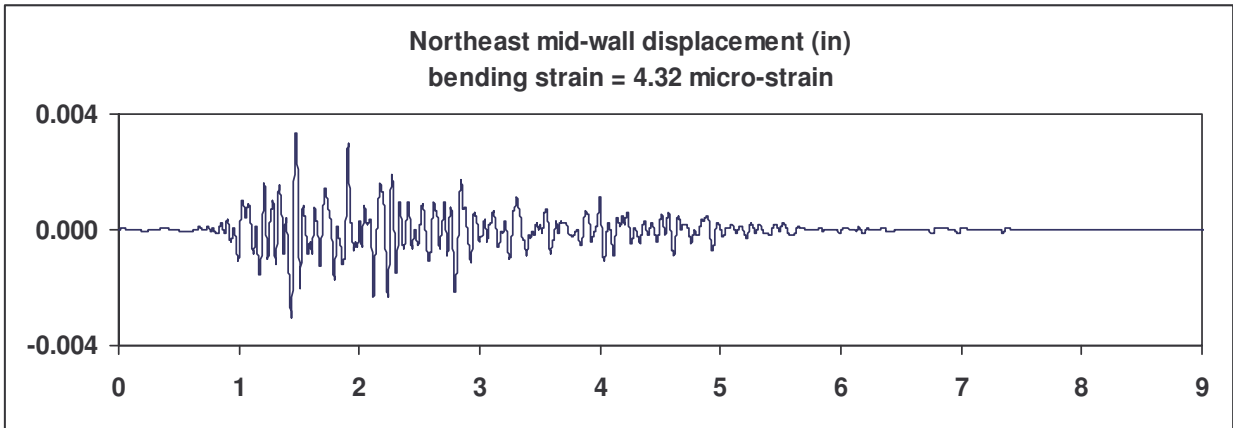
4/13/05 High Mesa



4/14/05 High Mesa



4/14/05 High Mesa

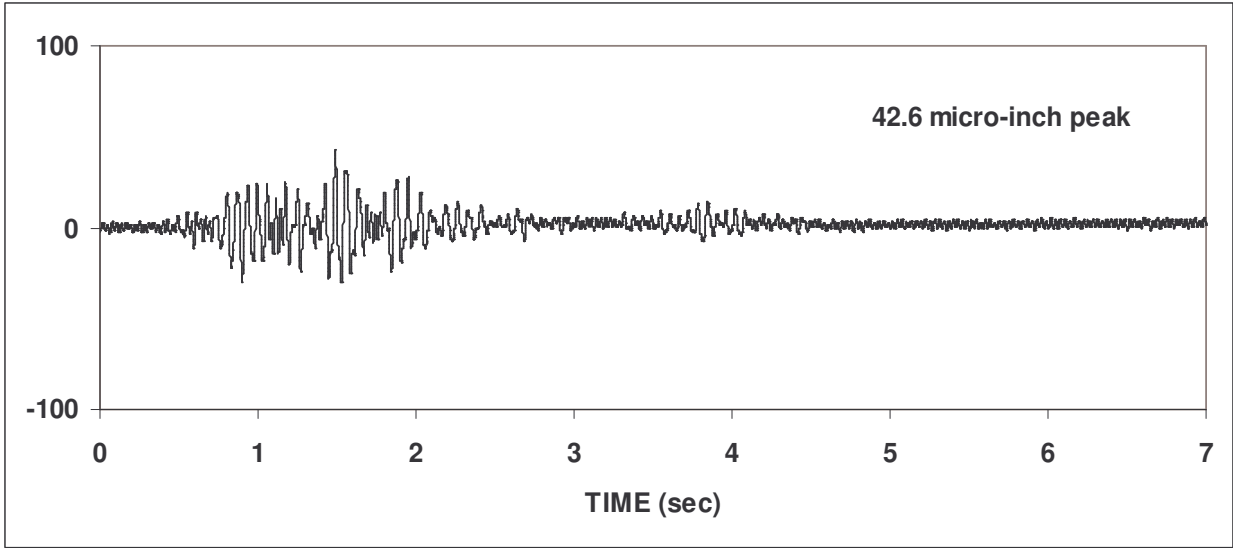


4/14/05 High Mesa

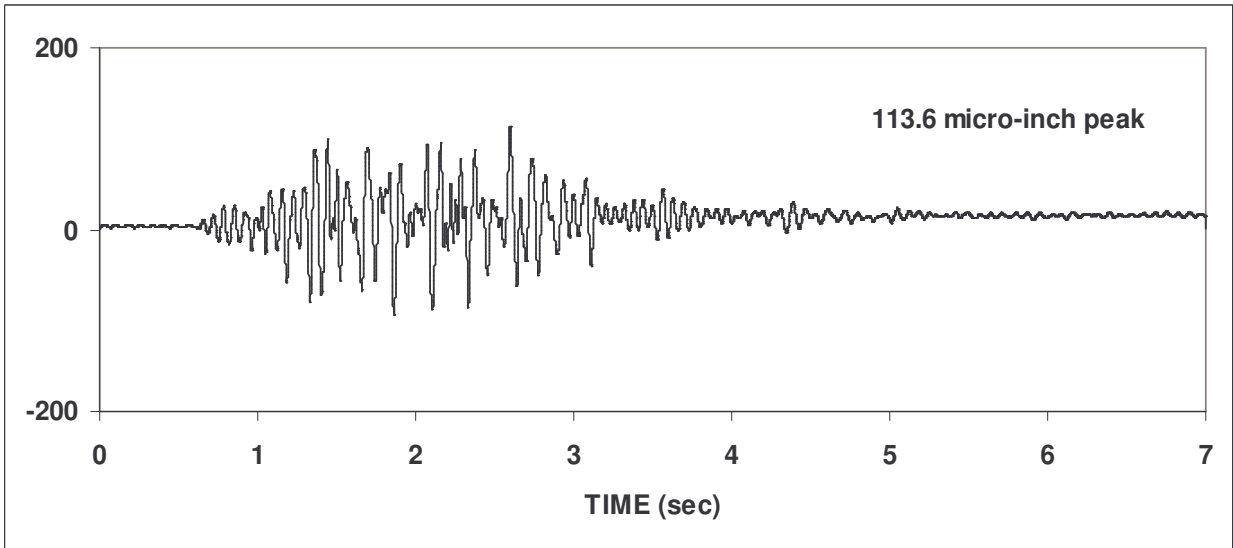
## Appendix F

Crack displacement time histories  
for High Mesa structure

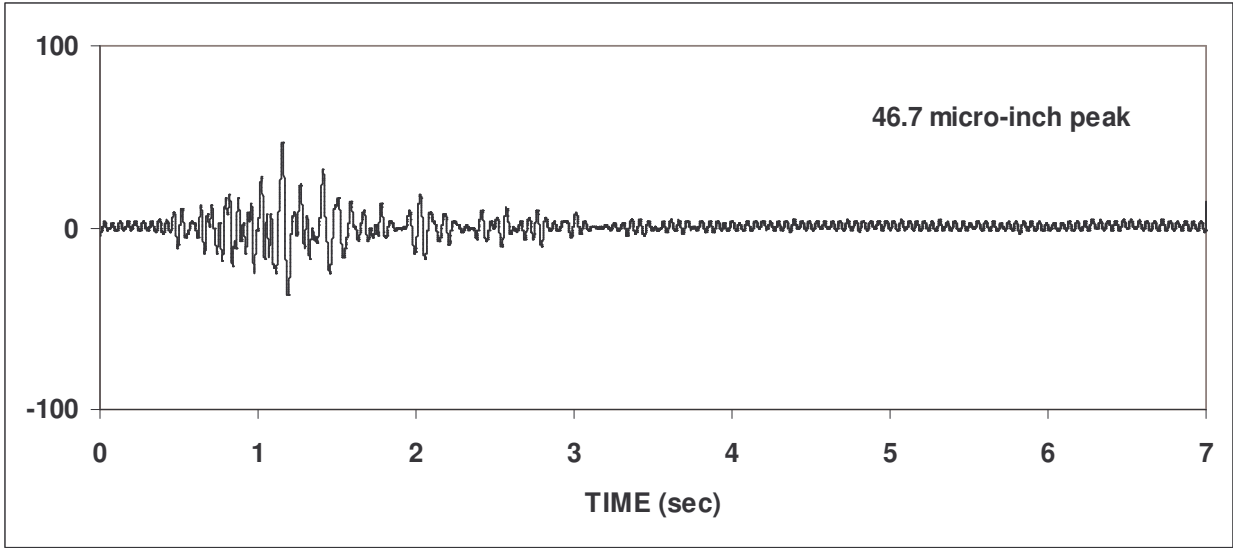




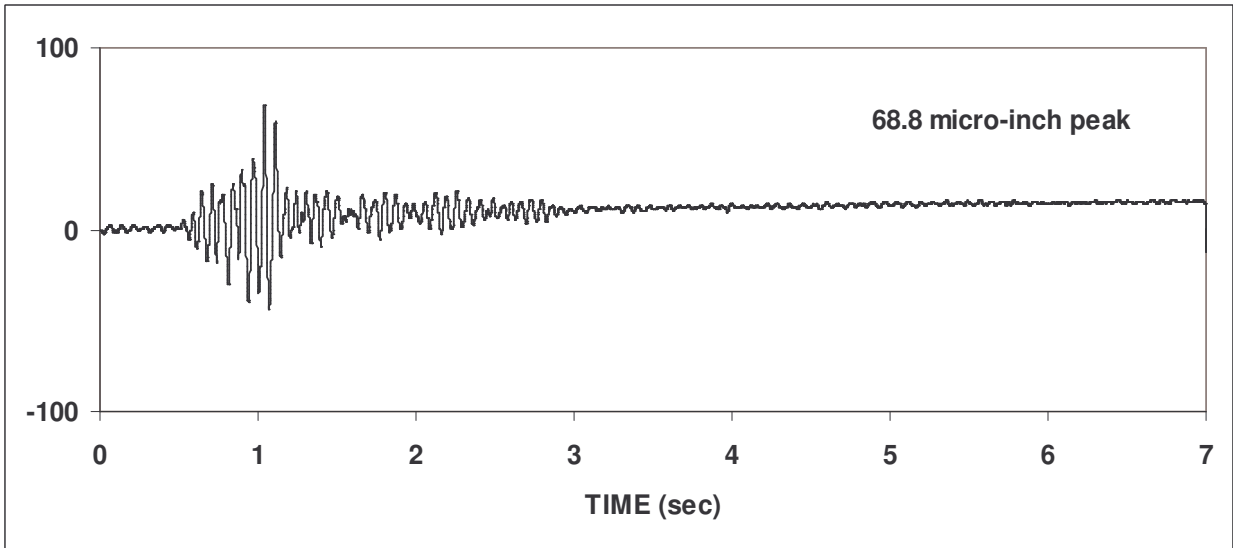
3/16/05a



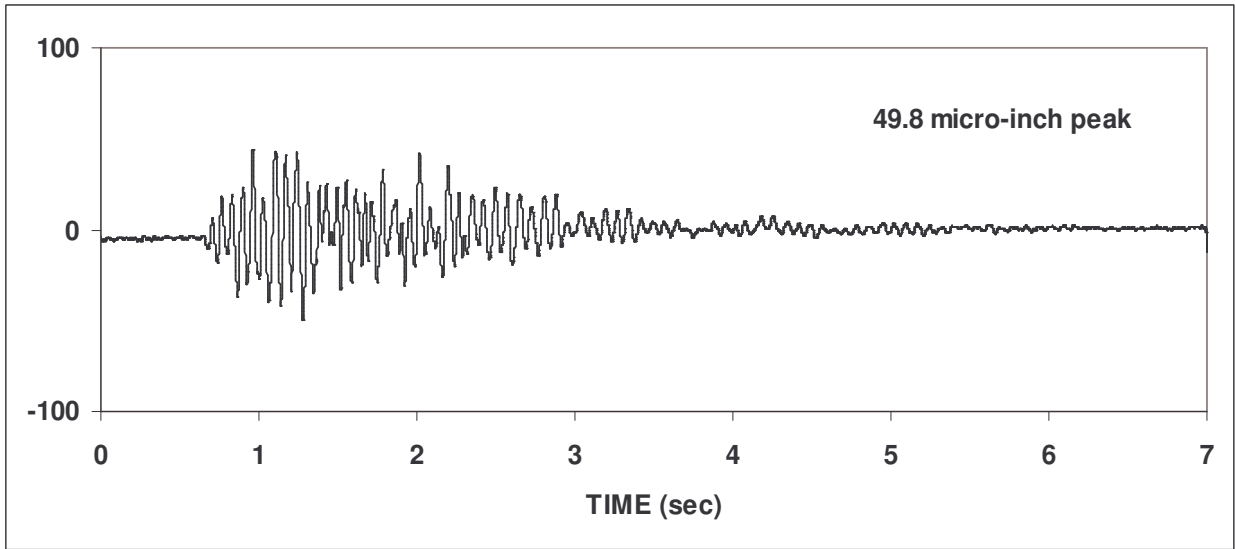
3/16/05b



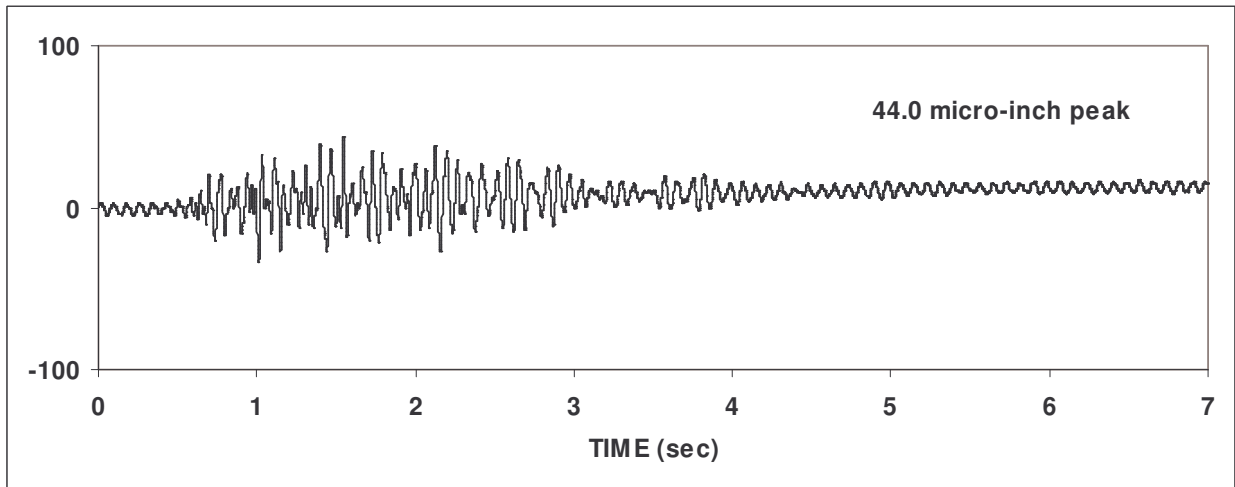
3/17/05



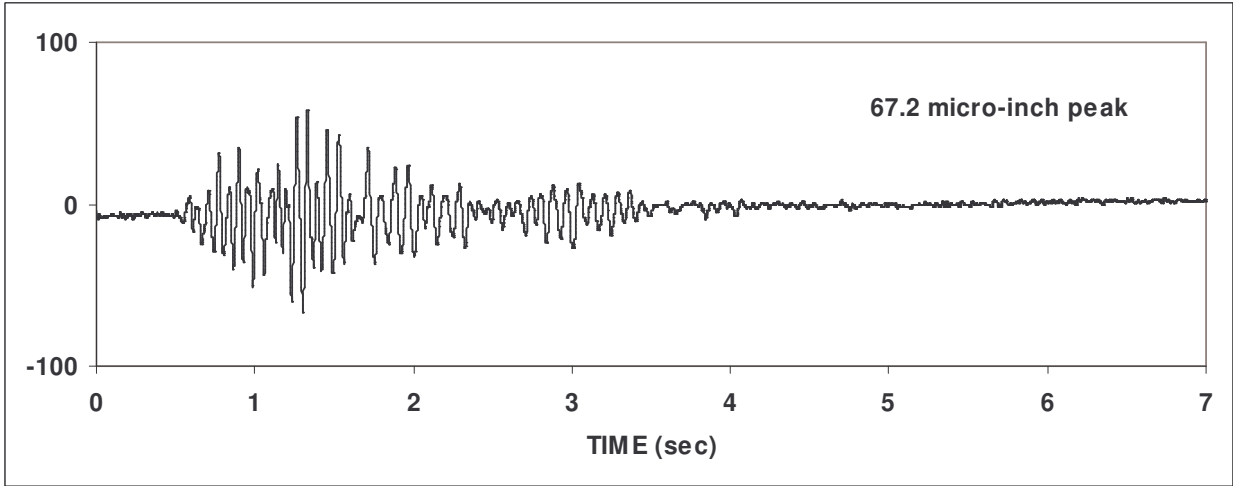
3/18/05a



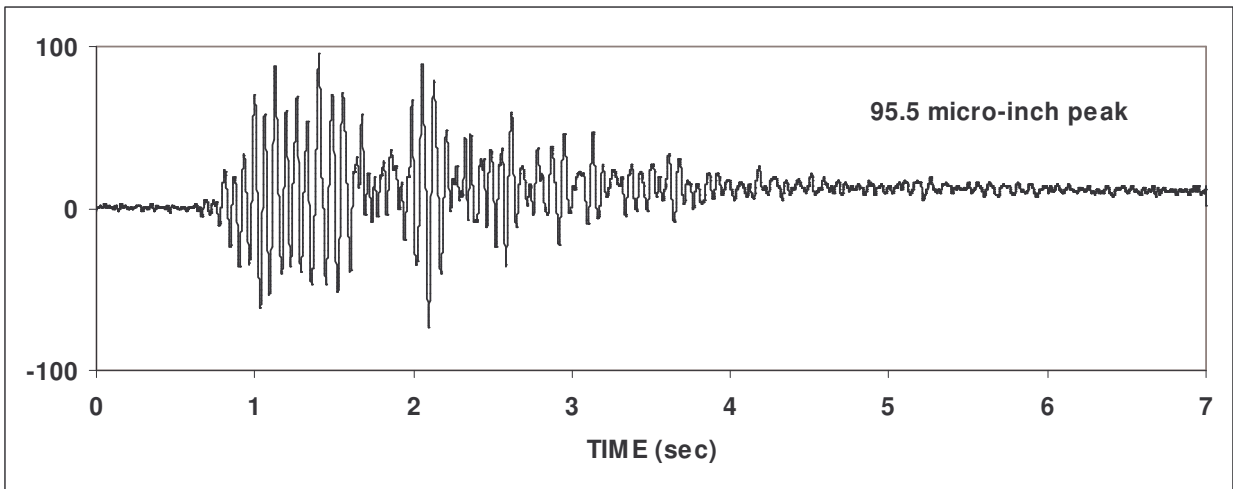
3/18/05b



4/12/05



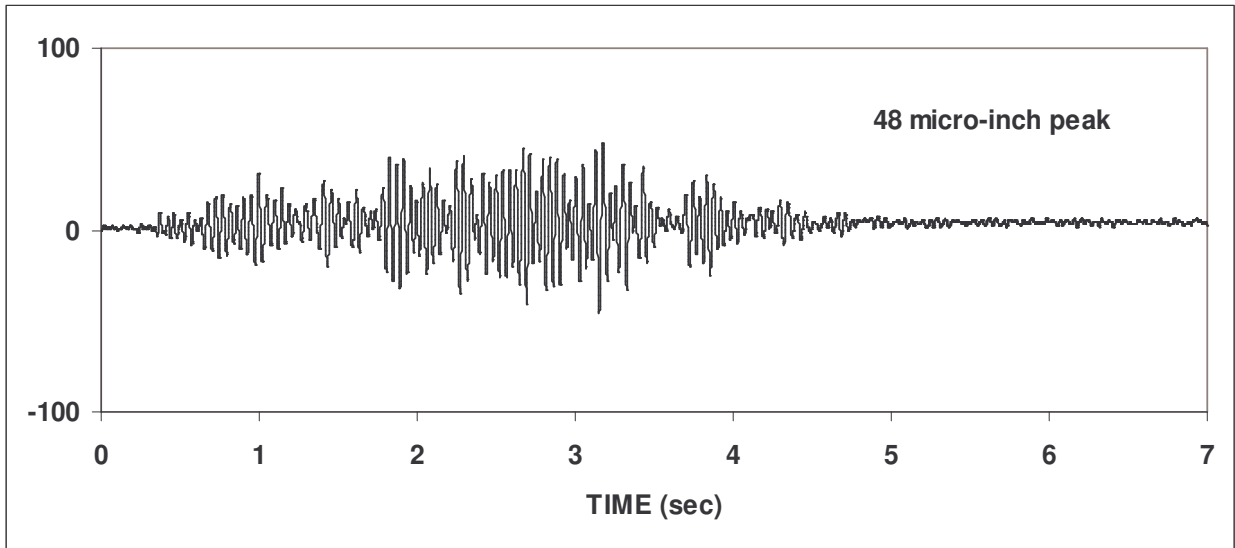
4/13/05



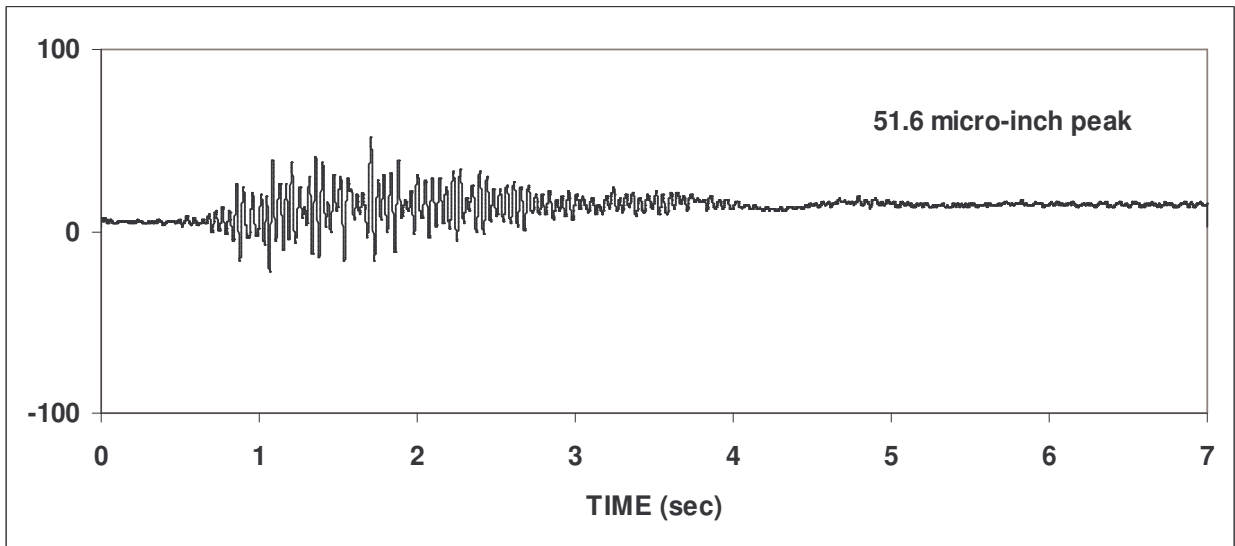
4/14/05

## Appendix G

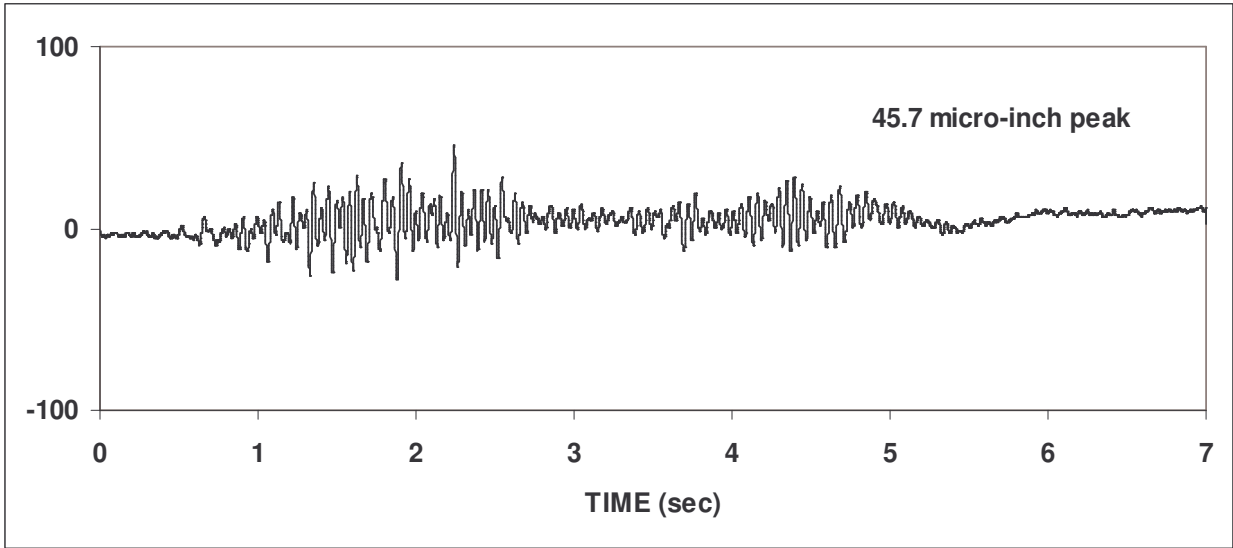
Crack displacement time histories  
for Bighorn structure



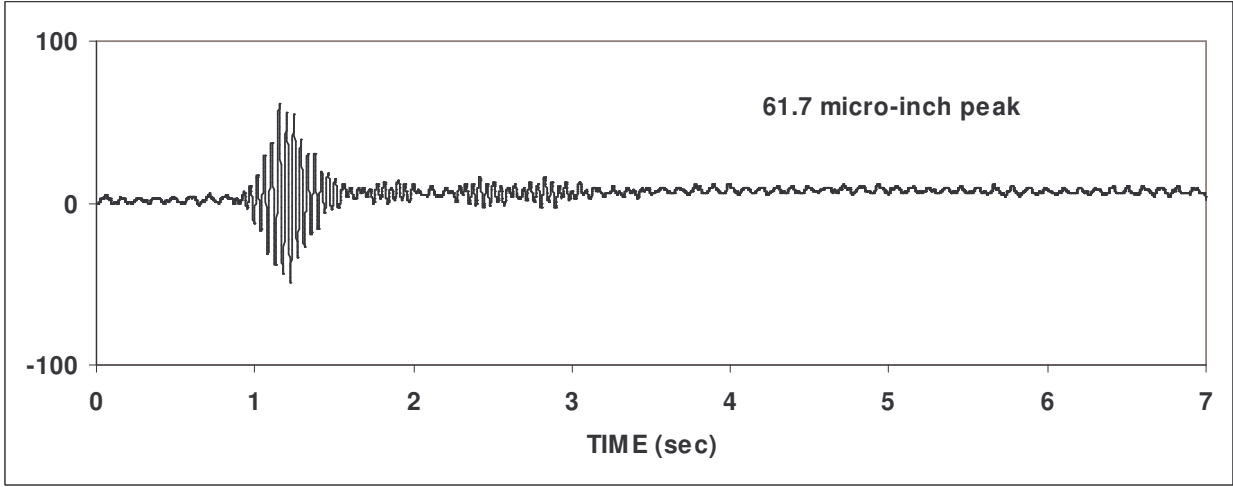
3/15/05a



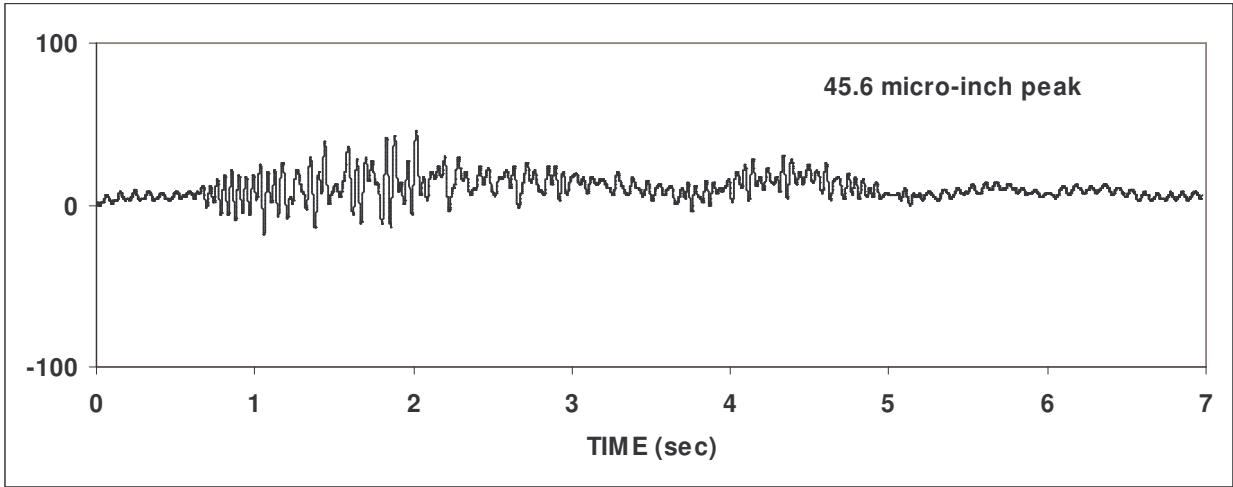
3/16/05a



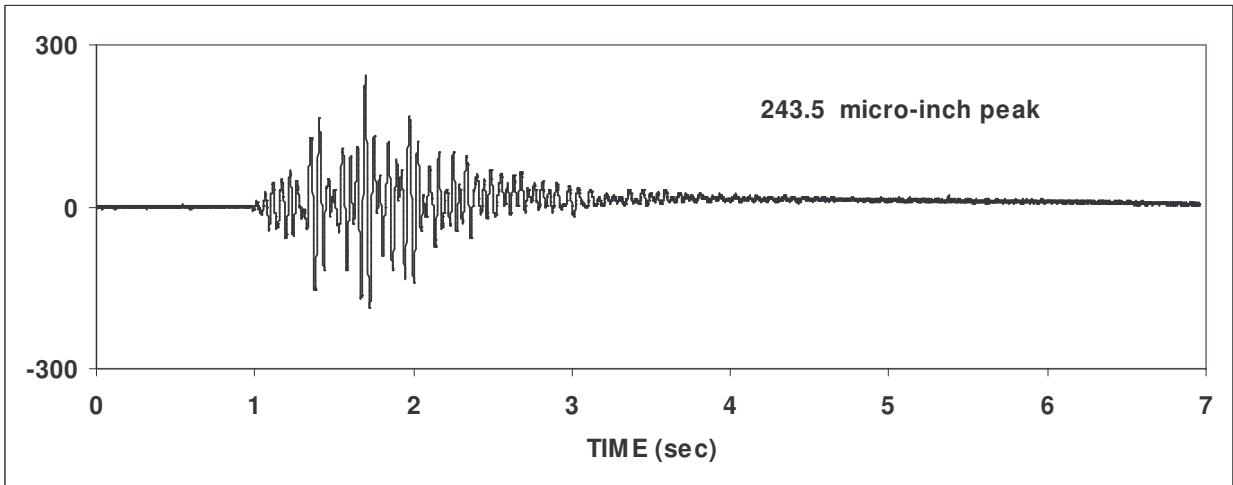
3/16/05b



3/21/05

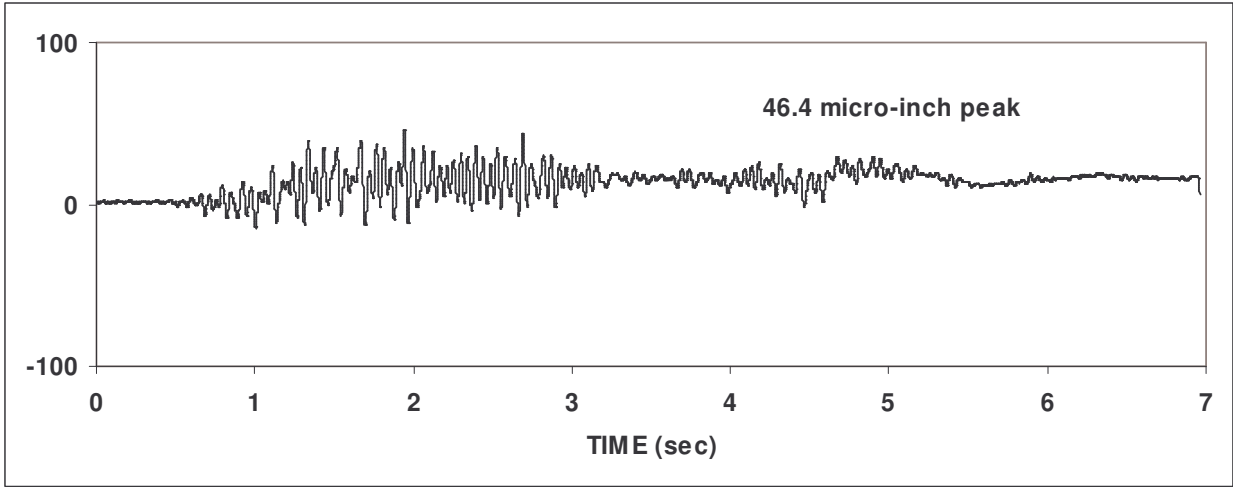


3/22/05

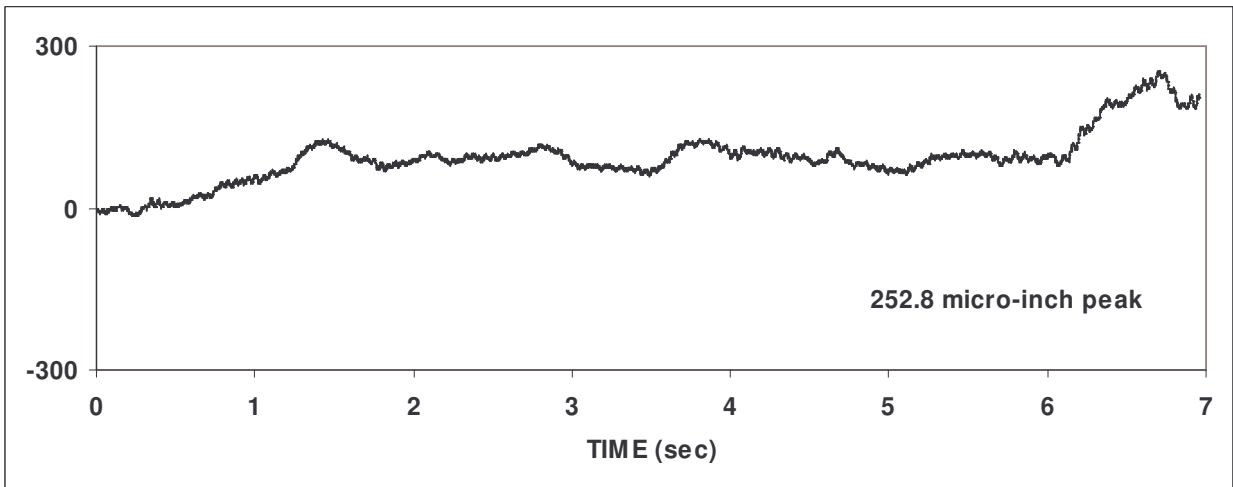


3/23/05b

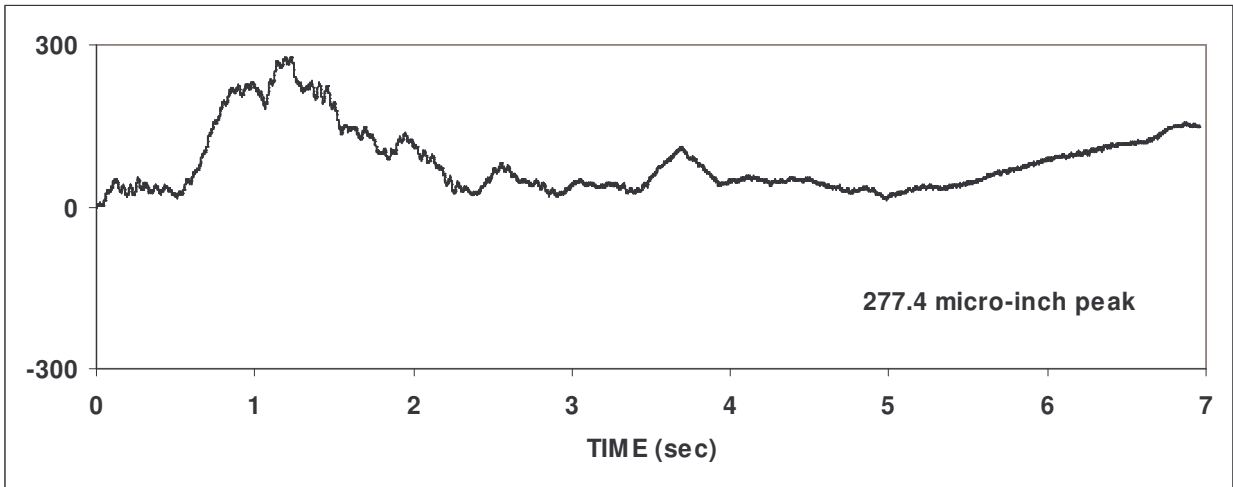




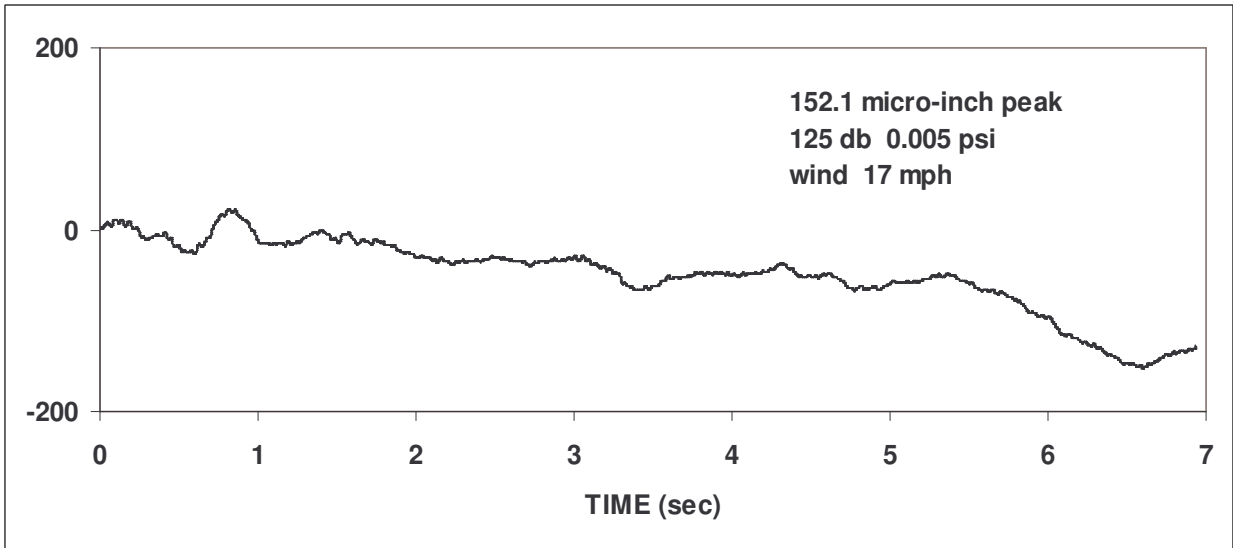
4/14/05



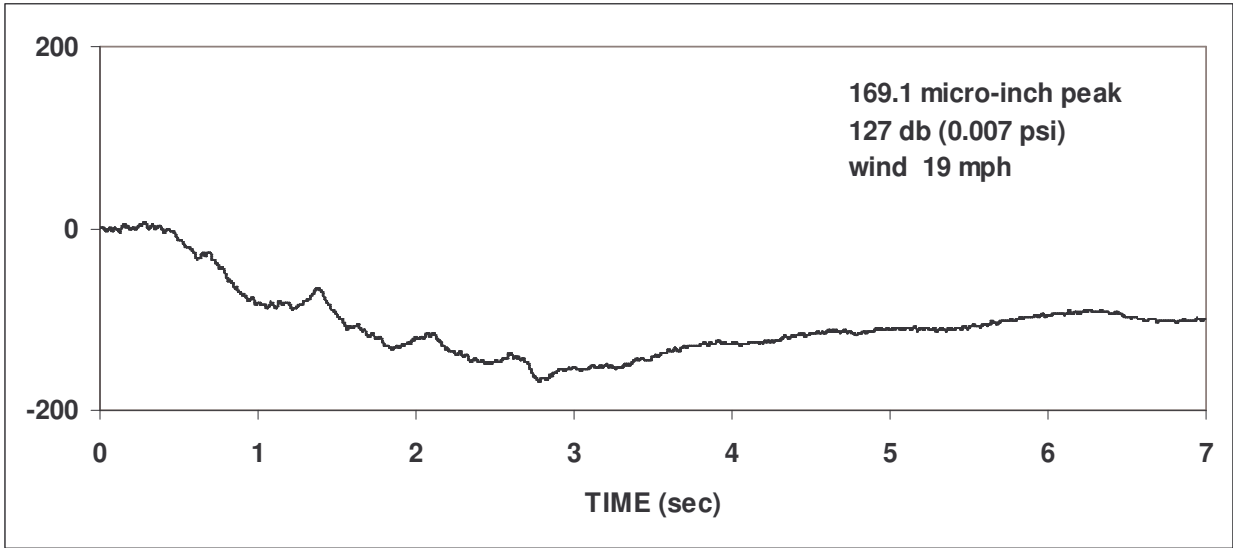
Wind gusting on 3/22/05 at 11:54 pm



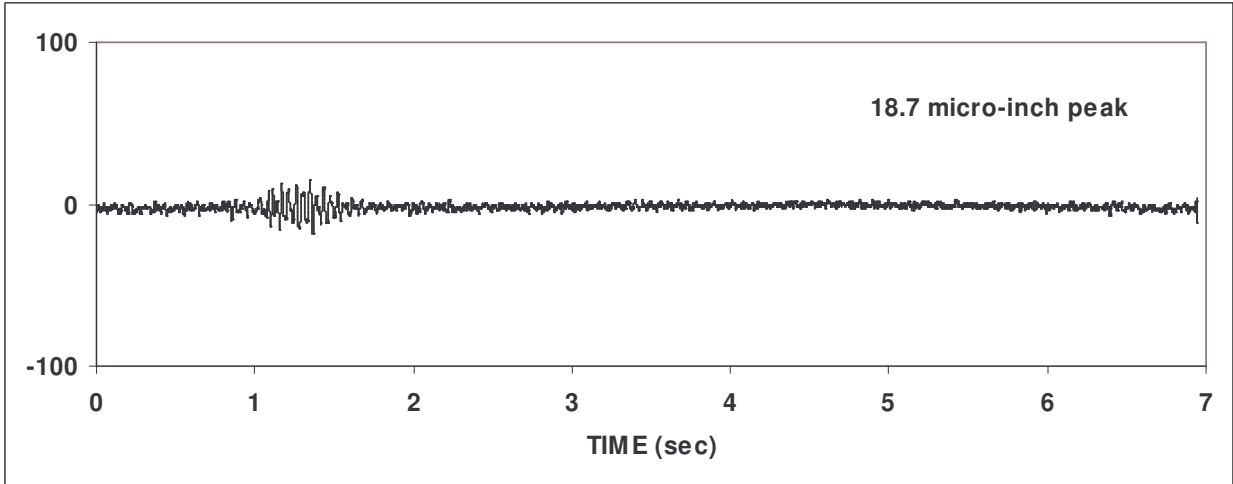
Wind gusting on 3/23/05 at 2:15 am



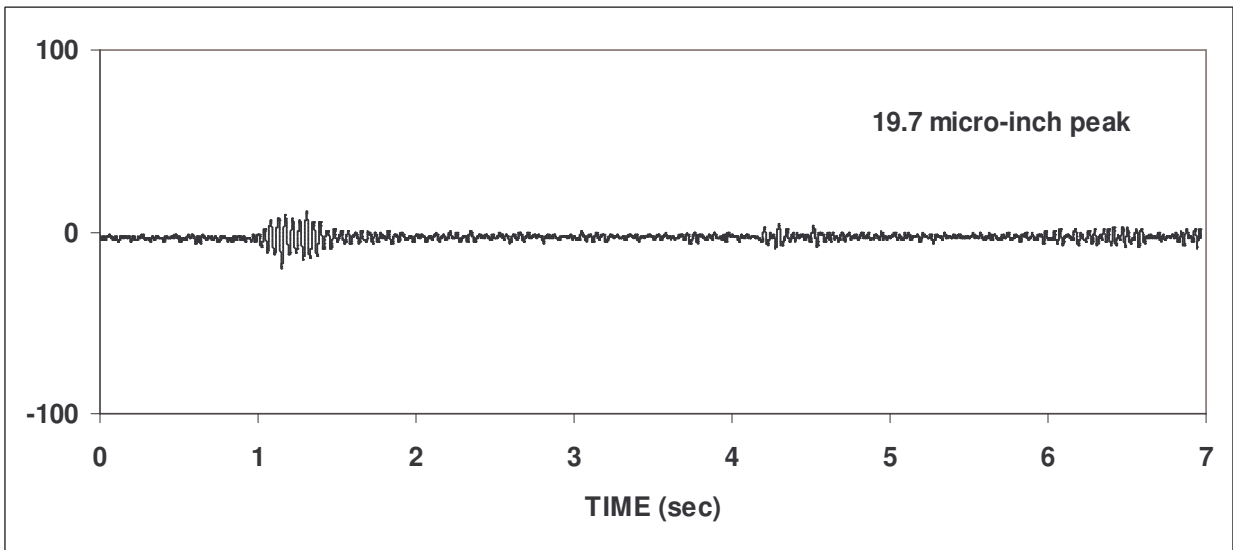
Wind on 3/17/05 at 9:08 pm



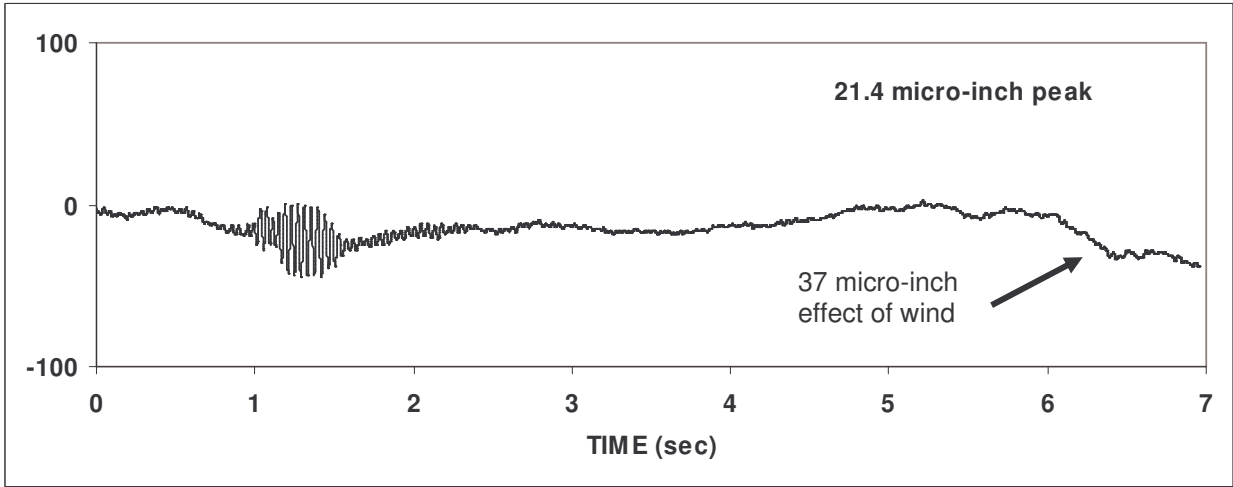
Wind on 3/17/05 at 10:02 pm



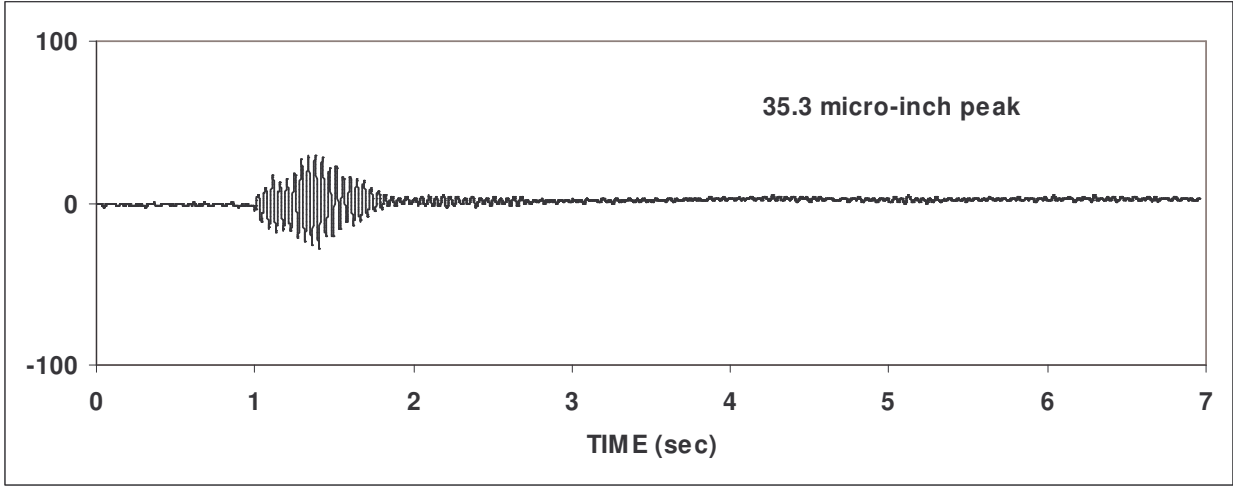
Excavating equipment on 3/17/05 at 12:19 pm



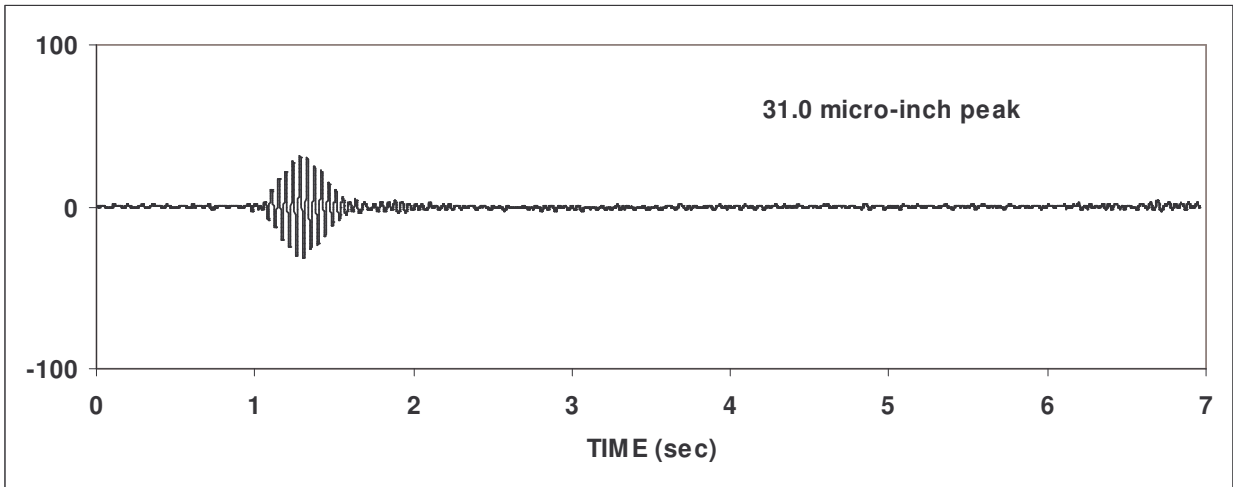
Excavating equipment on 3/18/05 at 7:01 am



Excavating equipment and wind on 3/23/05 at 6:40 am



Excavating equipment on 4/12/05 at 12:15 pm



Excavating equipment on 4/13/05 at 10:46 am