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Date: December 11-31, 2014

Subject: GCC Energy – King II Mine
UNDERGROUND MINER GROUND MOTION STUDY
La Plata County, Colorado

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GCC ENERGY – KING II MINE

UNDERGROUND MINER GROUND MOTION STUDY REPORT

La Plata County, Colorado
December 11-31, 2014

SUMMARY

Matheson Mining Consultants, Inc. (MMC) was retained by GCC Energy to investigate potential ground motion at the surface directly above underground miner activities in response to continued perception of ground motion in the Vista de Oro subdivision. This study is in addition to studies performed on January 8, 2013, where potential ground motion was investigated between the Luz and Coyne residences, near the mine fan, screen, and conveyors (please see report: GCC Energy – King II Mine, Ground Motion Studies).

Permanent Monitor Station Location

A portable instrument was set out overnight for an 18 hour period on December 11, 2014 and was located on the surface approximately 300 feet above the underground miner in order to discern if additional local study was necessary. A permanent station was placed on the surface above the center of the underground mining area expected over the course of the next month.

Temporary Seismograph Monitor Station

MMC recommends adherence with the United States Bureau of Mines (USBM) and/or the Office of Surface Mining Reclamation and Enforcement (OSMRE) Variable Frequency versus Particle Velocity criteria (Figure 4). Above 4 Hz, 0.50 to 2.00 inches per second (ips) is allowed, depending on dominant frequency (the threshold level for possible damage to plaster-on-lath). Adherence to these criteria provides a maximum level of liability protection. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities greater than those recommended in the USBM and OSMRE standards.

The threshold of human perception is around 0.030 ips. Oil and gas wells, pipelines, water wells, and fiber optic cables can withstand significantly higher levels and a level of 2.00 ips on these engineered structures is conservative. Bell Labs states that a limit of 4.00 ips is safe for their fiber optic cable and U.S. Bureau of Mines states that a limit of 4.92 ips is safe for a pipeline of any age or construction material and that this level is also appropriate for oil, gas, and water wells. Ten inches per second is considered a safe level for concrete.

Any potential ground motion experienced by residents in the Vista de Oro subdivision must be caused by a source other than King II mine activities. No ground motion was detected on the surface directly above underground mining at levels from one fourth to one sixth of what a human can feel. All ground motion levels recorded in the January 8, 2013 studies recorded at the mine screen, fan, and conveyors were very low level and will not transmit beyond the immediate vicinity.

INTRODUCTION

The ground motion is measured in terms of peak particle velocity and is a combination of body and surface waves (Figure 1)[1]. The body waves attenuate more rapidly with distance from the vibration source than the surface waves. Body waves spread spherically, whereas the surface waves expand in two dimensions. The principal cause of ground motion attenuation with distance is due to simple geometric spreading. As the ground motion wave train spreads outwards from the energy source, the medium's individual particles are set in retrograde elliptical motion about their rest positions. The wave is generated as each particle transmits energy to the next particle. Some energy loss occurs with each transmission of energy from one particle to the next, which is also a cause of ground motion attenuation with distance. The ground motion is a complex wave train consisting of many different wave types (Figure 2)[1]. As the body waves impinge upon the surface, they are converted to surface waves. Body waves may also be reflected and refracted to the surface to become converted to surface waves. As the surface wave spreads out, the various components of the wave train have different particle motions, travel at different velocities, and have different geometric constraints.

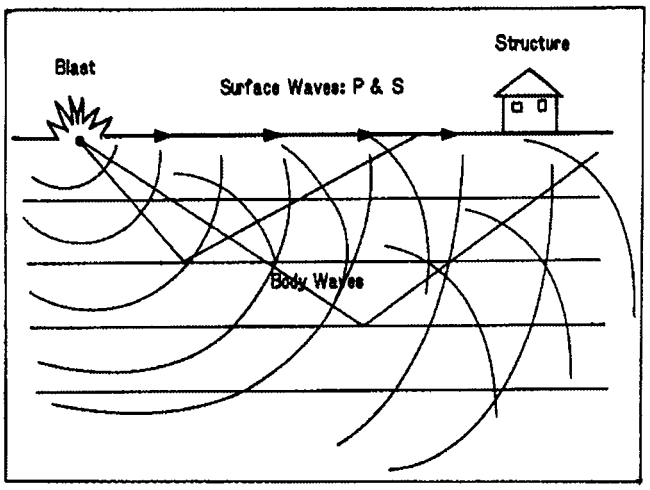

Figure 1 - Surface and Body Waves

Particle velocity has been determined to be the most significant single parameter, in terms of the potential for damage (as opposed to acceleration or displacement). Furthermore, the peak particle velocity found on any of the three geophone channels is the parameter used, rather than the resultant vector sum particle velocity. All research has been done and all regulations have been written in terms of peak particle velocity (PPV). Using the PPV instead of the vector sum allows for easier, more consistent comparison of values. A true resultant velocity could be calculated from the peak measurements for all three components if they occurred at the same instant of time. In addition, there is variability in how different seismograph manufacturers calculate the vector sum. Some actually calculate a pseudo resultant sum. These models take the peak levels on all three channels, regardless of where they individually occurred in time, to calculate the vector sum.

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[1] Rosenthal, M.F., and G.L. Morlock. Blasting Guidance Manual. U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, March, 1987, p.11.

[1] Ibid., p. 12.

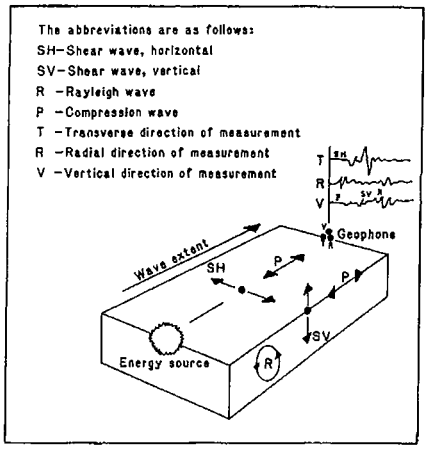


Figure 2 - Types of Ground Motion Waves

Since the 1920's or earlier, ground vibrations have been studied extensively to determine their potential for damage to various structures and construction materials. Blasting activities are among the most common sources of ground motion, have therefore been studied the most, and have thus prompted the ordinances and regulations that are in place. At the present time, the only federal regulation that pertains to ground motion is from the OSMRE. This regulation was written to protect residential structures. Complaints of damage to residences were, and are, the most common form of complaint resulting from the perception of ground motion.

INSTRUMENTATION

Vibration records were collected using an Instantel Minimate Plus and a Blastmate III seismograph. Each seismograph records particle velocity digitally in the frequency range of 1.5 to 250 Hertz. Each event is measured in three orthogonal channels of ground motion: vertical, longitudinal, and transverse. Zero-crossings of each of the three waveform components are calculated to determine frequency response.

An excerpt from the Blastmate III User's Manual is attached as part of Appendix I and describes the specifications and function of the instrumentation, and record processing.

An independent party using shake table and electronics traceable to the National Institute of Science and Technology has calibrated the instruments within the past year. Copies of the Calibration Certificates for the instrument and geophone are also included in Appendix I.

The microphone measures air overpressure in dBL. Air overpressures are typically produced from blasting activities and much of the energy is beneath the range of human hearing. This channel was turned off for the purpose of the study.

It is not possible to alter the vibration recordings or file names in any way, other than the ability to add post event notes. For security reasons, the instrument and software manufacturer (Instantel) will not release any of the programming code to any outside interests for any reason.

A self-test (on board calibration) was performed at each monitor location after setting up the instrument.

METHOD

A portable instrument was set out overnight for an 18 hour period from December 11, 2014 at 17:25 until December 12, 2014 at 12:02 and was located on the surface approximately 300 feet above the underground miner. This instrument was set with the minimum trigger level of 0.005 ips in full waveform mode. If ground motion was detected from the underground miner, additional portable monitoring at various distances would be performed. No ground motion was detected, so additional study with the portable seismograph was not performed. The temporary monitor station was located at a coordinate of N37 16.256 W108 07.370 and was 14,339 feet away from the Luz/Coyne residence monitor location.

A permanent station was placed on the surface above the center of the underground mining area expected over the course of the next month at a coordinate of N37 16.174 W108 07.401. This station was 13,854 feet away from the Luz/Coyne residence monitor location. Cellular service was not available at this location, so remote access was not possible. To conserve memory, the seismograph was set in histogram mode. In histogram mode, the instrument continuously monitors and registers the peak particle velocity for each five minute time period. A test was performed from December 12, 2014 at 9:40 until 11:17. The instrument was then placed back in monitor mode from 11:22 on December 12, 2014 until 6:27 on December 31, 2014, when the unit lost power and exited monitor mode.

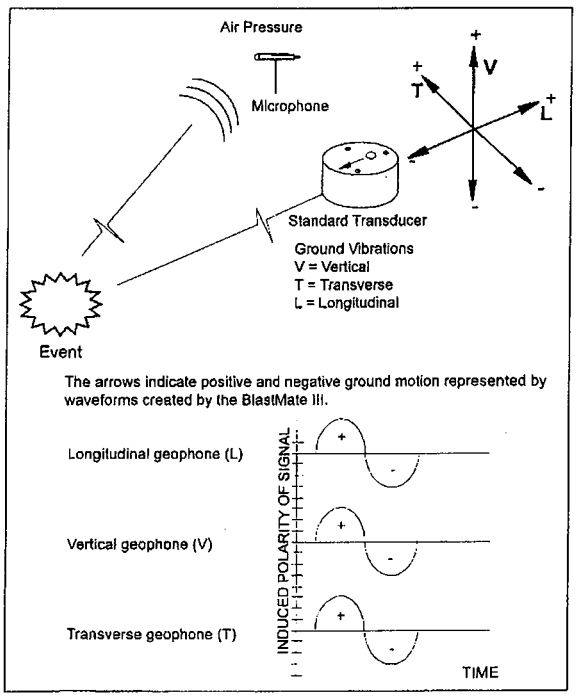


Figure 3 - Event Monitoring

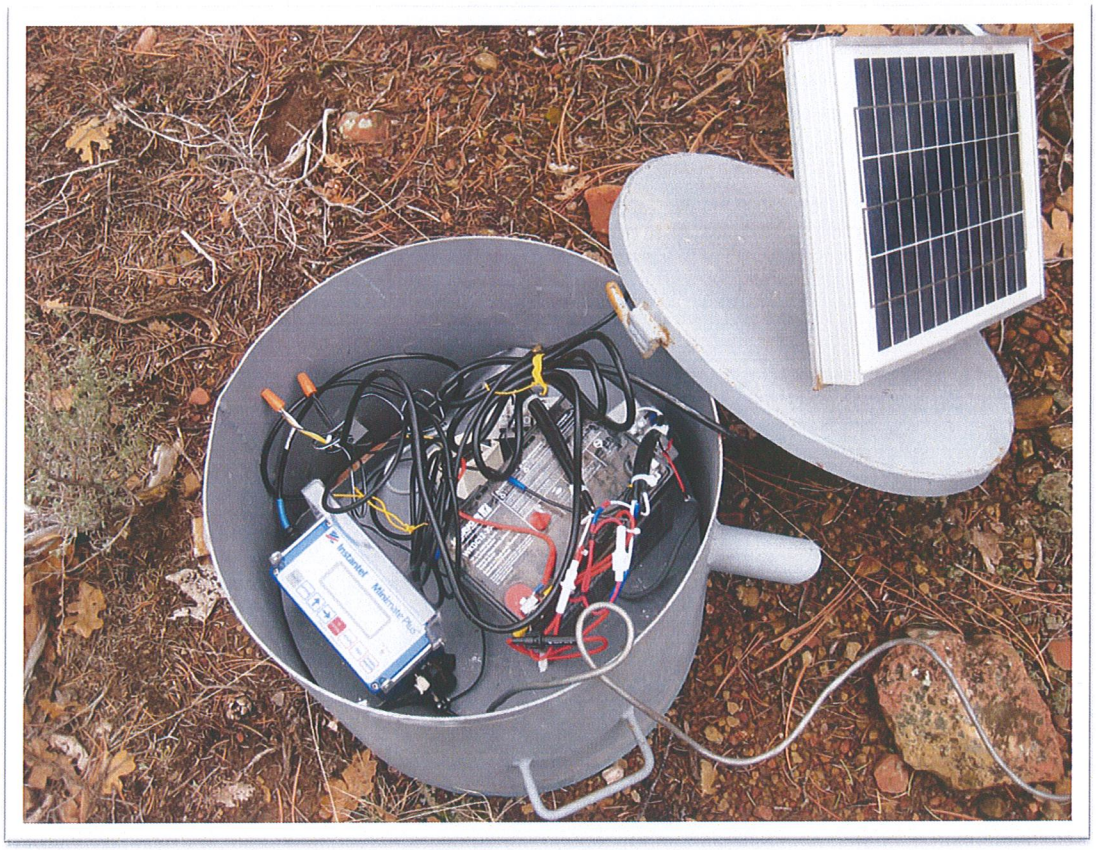
An Instantel Blastmate III seismograph was used for portable monitoring and a Minimate Plus seismograph was used in the permanent monitor station

A hand held GPS unit was used to record the monitor locations.

A map showing the locations of underground mining, the monitor location between the Luz and Coyne residences, and the study locations at the mine is found in Appendix II.

Figure 3 shows an excerpt from the Blastmate III user's manual and illustrates how the geophone was oriented relative to the energy source. Surface material was removed as necessary to get a good solid geophone plant at both recording locations.

Both instruments were set in sensitive mode with trigger levels set at the minimum of 0.005 ips.



Inside the Permanent Monitor Station

RESULTS

A monitor log showing when the instrument was armed and disarmed, as well as the trigger level and a summary of vibration recordings and vibration recordings for the portable instrument are found in Appendix III. The USBM and OSM variable particle velocity vs. frequency criteria is plotted on each vibration event report. The upper line represents the threshold level for possible sheetrock damage, while the lower, dashed line represents the threshold level for possible plaster-on-lath damage. All recommendations in this report are based on these criteria. Four operator induced vibrations were recorded at the startup on December 11, 2014 and one operator induced event was recorded when the instrument was shut down on December 12, 2014. No other ground motion in excess of 0.005 ips was detected.

A monitor log showing when the permanent station instrument was armed and disarmed and two histogram event reports (one for the test period and one for the December 12 – 31, 2014 time period) are found in Appendix IV. Both histogram records show operator induced (placing the lid back on the housing) ground motion at the beginning of the monitor period. Otherwise all histogram periods show ground motion less than 0.005 ips (background noise level).

CONCLUSIONS

No ground motion was detected on the surface directly above underground mining at levels from one fourth to one sixth of what a human can feel. All ground motion levels recorded in the January 8, 2013 studies recorded at the mine screen, fan, and conveyors were very low level and will not transmit beyond the immediate vicinity. Based on these studies, any perceived ground motion in the Vista de Oro subdivision must be caused by a source other than the King II mine screen, shaker, conveyor belts, or underground miner activity. Any potential ground motion produced by these sources would have to be very large to transmit over the relatively great distances to the subdivision.

RECOMMENDED VIBRATION LIMITS

The following is a discussion of recommended vibration limits including sections on residential, human, pipeline, and water well and aquifer response to ground motion.

The USBM in Report of Investigations 8507 (November 1980) recommends a Variable Particle Velocity versus Frequency standard for assuring non-damage to all structures (see Figure 5). The OSMRE regulations, as outlined in their Blasting Guidance Manual, employ a similar variable particle velocity versus frequency limit. These two standards are the most often quoted limits for ground vibration from blasting operations and are very conservative. Under typical circumstances ground vibrations need to exceed the USBM recommendations or the OSMRE regulations by a considerable amount in order to observe threshold damage such as plaster or drywall cracking or paint flaking. Engineered structures such as pipelines and wells are able to withstand significantly greater peak vibration levels. Human response is often the limiting factor in determining a reasonable ground vibration limit.

MMC recommends adherence with USBM and/or OSMRE Variable Frequency versus Particle Velocity criteria. Adherence to these criteria provides a maximum level of liability protection and is the least restrictive in allowing the highest particle velocities at close distance. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities less than those recommended in the USBM and OSMRE standards.

More restrictive ground vibration standards exist internationally, notably the German vibration standards (DIN 4150), Australian standard (CA 23-1967). These restrictive standards are based on prevention of annoyance, not for any technical or damage related justification.

RESIDENTIAL STRUCTURES

Seismological research by the USBM, foreign investigative groups, and individual seismologists has established criteria relating the occurrence of structural damage to certain frequencies and levels of ground motion.

USBM Report of Investigations 8507, "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,"[3] states that residential structures are most prone to damage as a result of vibration energy within the frequency range of 4-12 hertz. Within this range, a 0.5-inch per second maximum particle velocity is recommended to preclude 'threshold' damage to the plaster-on-wood lathe interior portions of older structures. The line that separates real from alleged or imagined damage is ill defined. Therefore, it is common to talk in terms of probability or possibility of damage.

In general, very high particle velocities are necessary to cause any damage. Ground motion blast vibration damage is well documented, and the points at which threshold damage can occur are well defined. "Failure can occur to brittle materials such as plaster at particle velocities less than one inch per second at very low frequencies (1.5 to 10 Hz). The majority of failures will not begin to occur, however, until vibration levels exceed 3 to 4 inches per second."[1]

In addition to the threshold level of damage being dependent on peak particle velocity and frequency, it is also dependent on other factors such as: the geography and type of terrain the structure sits on, the type of structure, the height of the structure, the natural frequency of the structure, and the state of repair, or disrepair, of the structure. "...Some of these conditions may combine so that even if actual damage is unlikely below 2 or 3 inches per second, it is nevertheless possible that threshold damage might occur under some conditions at velocities as low as 0.50 to 0.70 inches per second...the (government) regulations are designed to provide positive protection against damage to private and public property."[1] Therefore, these regulations are as conservative as possible.

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[3] Siskind, D.E., M.S. Stagg, J.W. Kopp, and C.H. Dowding. Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, U.S. Bureau of Mines Report of Investigations 8507, p. 1.

[1] Ibid., pp. 31-32.

[1] Ibid., pp. 31-32.

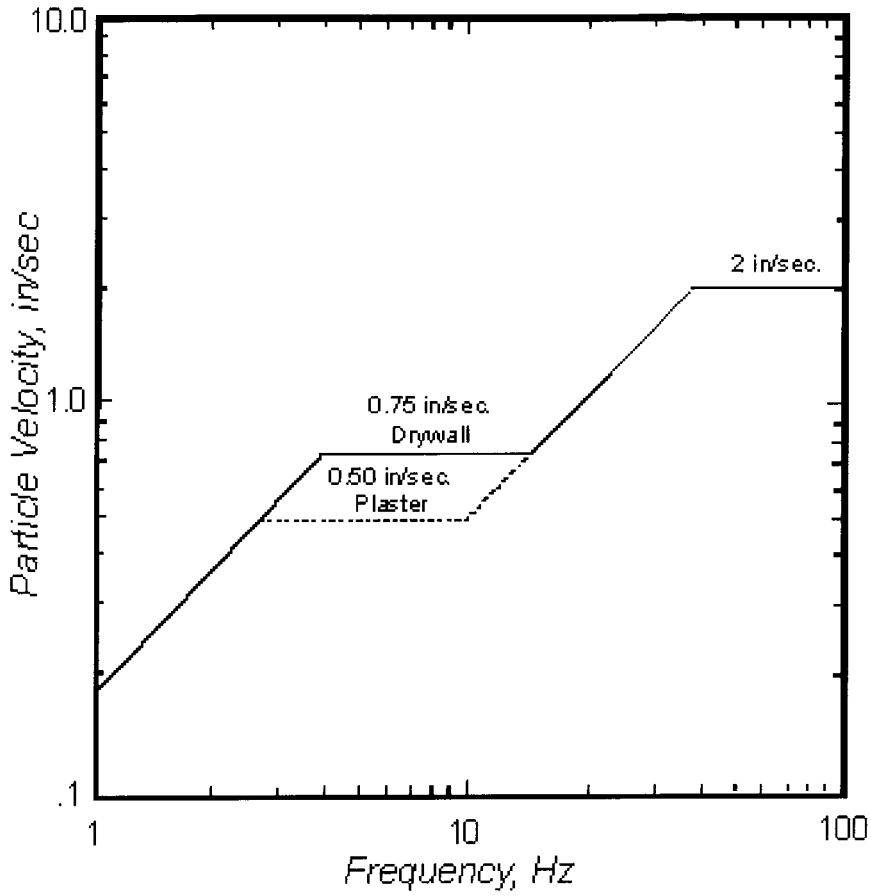

Figure 4: USBM Criteria from RI-8507, November 1980

Threshold damage is defined by the USBM as the loosening of paint; small plaster cracks at joints between construction elements or the lengthening of old plaster cracks. A maximum of 0.75 inch per second is recommended for the protection of modern drywall interior construction. The damage threshold is normally considerably higher for load bearing or other structural portions of a house.

Above 12 hertz, the allowable vibration increases as the frequency increases, up to 40 hertz. Above 40 hertz, a constant 2.0 inches per second level is recommended to protect the interior walls and ceilings of structures, regardless of construction material. A graphic representation of the USBM recommended criteria is shown in Figure 4.[3]

All buildings are characterized by a single natural fundamental frequency. This means that, as with a pendulum or a tuning fork, there is one dominant frequency to which a particular building will respond. The structures fundamental frequency depends primarily upon its height. Tall buildings are more flexible and respond to low frequencies. Low-rise structures, being stiffer, respond to higher frequencies.

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[3] Ibid., p. 7.

CONCRETE DAMAGE

In order for damage to occur to a concrete pad, the supporting soil must fail. It is therefore nearly impossible to damage concrete with elastic ground vibrations. Nearly all concrete has suffered some form of environmental damage. This is due primarily to initial curing shrinkage and thermal expansion and contraction. Expansive soils (such as clays), erosion, and settlement are also common causes of concrete damage. The peak displacement associated with most surface vibrations is of no consequence to concrete. For example, a shot recently measured by MMC at 1.20 inches per second had a peak displacement of only 0.0146 inches. "Typical deflections in bridge deck, building floors, and highway slabs are often greater by up to a factor of ten...The only known cause of damage to concrete slabs from typical external industrial and construction sources of vibrations comes from very close or intense sources that can directly rupture the concrete, as in the crater zone of a blast."[2]

ENVIRONMENTAL FORCES

Environmental forces that act on structures include both internal and external stresses. Internal stresses include: changes in moisture, changes in temperature, curing of lumber, drying and curing of plaster, stucco, concrete, or adobe; changes in application of internal heat, aging, the loss of coulomb friction, and gravity. External sources include: poorly compacted or expansive soils, poor drainage, water damage, wind, freeze/thaw cycle, and vegetation. Environmental forces are generally static (non-vibratory).

Most environment forces act silently. Therefore, most people are unaware of the large stresses and large strains induced in structures and materials. Many people who feel they have incurred damage from a ground vibration find it difficult to believe the silent environmental forces cause more stress than the vibration they felt and heard. Environmental forces are responsible for on going, time-dependent damage and deterioration to all structures and materials. "A careful study of buildings shows that cracks continue to increase in size and number as the building ages."[2]

Figure 5 shows typical environmental stresses and equivalent ground vibrations. This table is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard. This was derived from information in USBM R.I. 8896, Effects of Repeated Blasting on a Wood-Frame House (Stagg, 1984)[2]. Environmental forces may induce equivalent ground vibrations as high as eight inches per second in a structure.

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[2] Ibid., pp. 353-354.

[2] Ibid., p. 356.

[2] Ibid., p. 358.

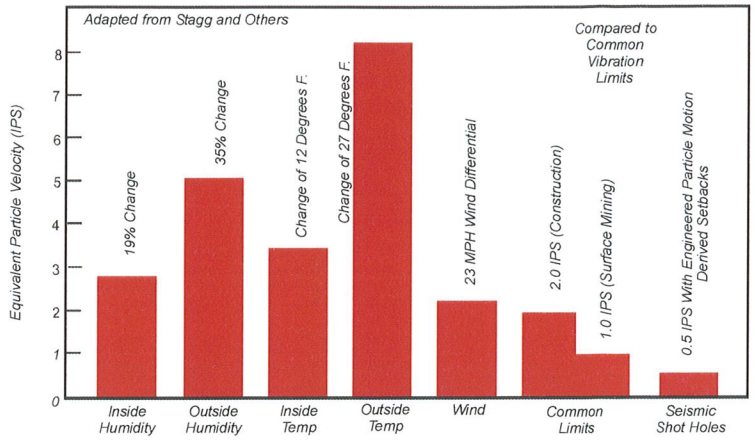

Figure 5: Typical Environmental Stresses & Equivalent Ground Vibrations

EVERYDAY ACTIVITIES

Stresses are also induced in structures as a result of human activities, traffic, and industrial activities. Human activities include door slams, walking, jumping, pounding nails into a wall, etc… These stresses are not as intense as environmentally induced stresses but nevertheless may produce equivalent ground vibrations as high as 2 inches per second. These stresses often account for hairline cracks in plaster and sheetrock around doorways and window frames. Figure 6 shows vibrations from everyday activities and equivalent ground motions and is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard and was also adapted from USBM R.I. 8896, Nicholls, 1971, and others.[3]

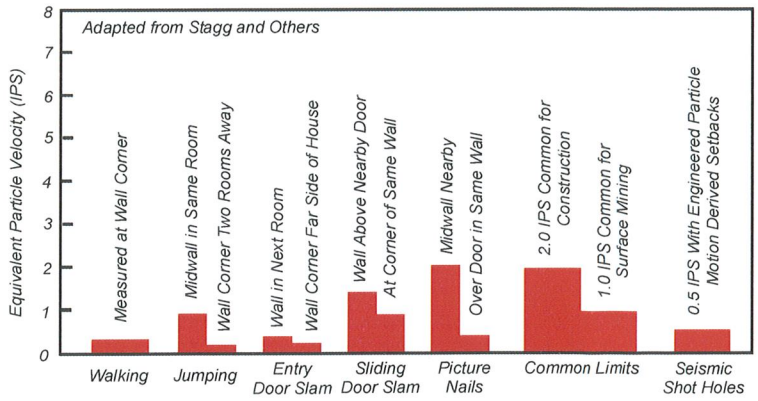

Figure 6: Vibrations for Everyday Activities

[3] Ibid, p. 359.

CYCLE FATIGUE

There is often a misapprehension by property owners that repeated blasting has a cumulative effect on the structure. USBM study R.I. 8896, Effects of Repeated Blasting on a Wood-frame House is an investigation of this concept. In this study, the USBM built a wood-frame test house in the path of advancing surface coal mining. Structural fatigue and damage were assessed over a two-year period.

The house was subjected to vibrations from 587 production blasts with particle velocities that varied from 0.10 to 6.94 inches per second. Later, the entire house was shaken mechanically to produce fatigue cracking. Failure strain characteristics of construction materials were evaluated as a basis for comparing strains induced by blasting and shaker loading to those induced by weather and household activities.

Cosmetic or hairline cracks 0.01 to 0.10 mm wide occurred during construction of the house and also during periods when no blasts were detonated. The formation of cosmetic cracks increased from 0.3 to 1.0 cracks per week when ground motions exceeded 1.0 in/s. Human activity and changes in temperature and humidity cause strains in walls that were equivalent to those produced by ground motions up to 1.2 in/s. When the entire structure was mechanically shaken, the first crack appeared after 56,000 cycles, the equivalent of 28 years of shaking by blast-generated ground motions of 0.5 in/s twice a day.[4]

HUMAN RESPONSE TO GROUND MOTION

"Vibration levels that are completely safe for structures are annoying and even uncomfortable when viewed subjectively by people."[5] Figure 7 was taken from Bulletin 656 and shows subjective response of the human body to vibratory motion. These limits were based on empirical results for sinusoidal vibration.

According to the OSMRE Blasting Guidance Manual, "Most researchers agree that the threshold of human perception of ground motion is around 0.03 inches per second. Depending on activity, sensitivity, and whether or not the subject knows when the event is to occur, a few humans can sense ground motion…to about 0.01 inches per second.

Although complaints can occur at any level perceptible to humans, they are unusual below 0.08 inches per second or so…At, say, 0.25 inches per second, a level that is eminently safe, and well within OSMRE limits, except below 2 Hz, complaints can be expected."[1] Human reactions to ground motion from blasting can be the limiting factor. Vibration levels can be felt that are considerably lower than those required to produce damage. "Particle velocities of 0.5 in/sec…should be tolerable to about 95% of the people perceiving it as 'distinctly perceptible.'"[1]

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[4] Stagg, M.S., D.E. Siskind, M.G. Stevens, and C.H. Dowding. Effects of Repeated Blasting on a Wood Frame House. U.S. Bureau of Mines, Report of Investigations 8896, 1984, p. 1.

[5] Nichols, H.R., C.F. Johnson, and W.I. Duvall. Blasting Vibrations and Their Effects on Structures. U.S. Bureau of Mines Bulletin 656, 1971, p. 27.

[1] Ibid, p. 34.

[1] Ibid, p. 37.

What is annoying to one person may not be annoying to another. Each person perceives movement differently. Factors that can influence how human beings perceive blasting are:

- The frequency content of the blast events.
- The number of events per day or week.
- The time of day. The structure response.
- The condition of the property.
- The degree of activity of the person.
- The state of health of the person.
- The state of mind of the individual.
- The position and attitude of the person, i.e., in bed, working, sitting, inside or outside, etc…
- The local perception of the operation.
- The history of local damage claim payments (including "good neighbor" payments related to claims where liability was denied).

In some cases, regardless of the levels of ground motion experienced, complaints may still arise. "No amount of objective data will convince a person who "feels" strong vibrations that the vibration level as measured was barely perceptible-similarly with noises and air blasts. Personal contact and strong efforts in public relations help alleviate the problem but convince few."[5] In this event, pre-survey inspections, a monitoring program, and good record keeping can be invaluable should matters proceed to the legal arena. In extreme cases, dishonest individuals may see this as an opportunity for repairs or new water well.

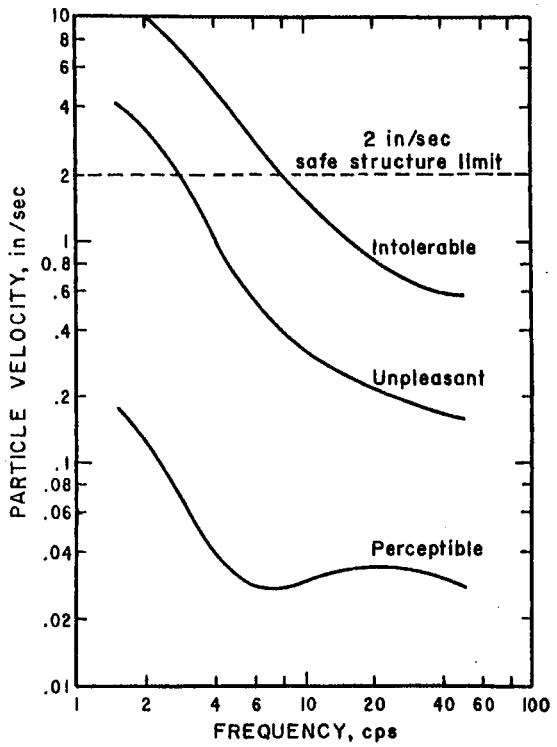

Figure 7: Subjective Response of the Human Body to Vibratory Motion (From USBM Bulletin 656, 1971)

[5] Ibid, p. 27.

WATER WELLS AND AQUIFERS

Water wells and aquifers exhibit a constrained response when subject to ground vibration. That is to say, they move in concert with the geologic material that surrounds them. In general, this geologic material surrounding the well must be disrupted to cause damage to a water well. In the case of the aquifer, a change in its structure (permeability) would be the necessary affect for it to have undergone changes as a result of blast vibration. Furthermore, the amplitude of the ground motion greatly decreases with depth. Following is general information on hydrology as well as information from studies on shot hole geophysical exploration and surface mine blasting effects on water wells and aquifers.

Hydrology

A groundwater system is a dynamic system where water moves down gradient from a recharge area to a discharge area (i.e., a spring). Normally, ground water moves slowly, the rate ranging from a fraction of an inch per year to a few feet per day. The geology determines the rate of ground-water recharge and movement. Most sedimentary aquifers consist of sandstone, limestone, Tertiary sediments, recent alluvium, or coal seams. Aquifers can also exist in fractured metamorphic rocks and igneous rocks. Hydraulic characteristics of aquifers include porosity, permeability, transmissivity, and the coefficient of storage. These characteristics differ greatly among different rock types.

Porosity is the volume of void space in a unit volume of material (this space can be occupied by water). Permeability is a measure of the capability of a geologic material to transmit water through a unit area. Transmissivity is defined as the permeability times the vertical thickness of the material, usually an aquifer. Coefficient of storage is defined as the volume of water that an aquifer can release from or take into storage per unit surface area, per unit change in head in a line normal to that surface.

Shot-Hole Geophysical Exploration

In "A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana,"[6] five widely distributed sites in eastern Montana were chosen and monitored: (1) a 25 pound charge at a 197 foot depth, 150 feet away from the 150 foot deep test well, (2) a 25 pound charge at a 197 foot depth, a 165 foot distance away from the 90 foot deep test well, (3) a 80 pound charge at a 200 foot depth, 400 feet away from an 80 foot deep test well and a 25 pound charge at a depth of 150 feet, 150 feet away from the same test well, (4) a 25 pound charge at a 200 foot depth, 150 feet away from a test well with a 22 foot depth and a test well with a 96 foot depth, and (5) a 25 pound charge at a 200 foot depth, 150 feet away from a 135 foot deep test well and a 207 foot deep test well.

> Pumping tests of existing water wells and specially drilled observation wells, before and at several times after the firing of a seismic shot, revealed no detectable change in the physical properties of the aquifers. Analyses of water samples collected from water wells, observation wells, and test holes, at frequent intervals throughout the study period, showed only the random minor variations expectable in water from shallow aquifers. A few water

[6] Bond, E.W., A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana, State of Montana – Montana Bureau of Mines and Geology, Special Publication 67, 1975.

> samples from shotholes showed minor temporary increases in some chemical constituents, but these were not enough to affect the use of the water. Water-level measurements during the pumping tests showed that most of the shotholes were virtually sealed through the aquifer within a few months, at most, but tests could not be repeated over a long enough period to determine the final sealing date of all shotholes.
>
> Any mechanical change in aquifer structure as a result of seismic shooting should be indicated by change in permeability of the aquifer material. None of the aquifer tests conducted at the five test sites showed any change in aquifer structure, although poor efficiency of common well construction was evident...A change in aquifer permeability would require either a change in the packing arrangement of the aquifer material or an alteration of the cement holding the aquifer material together.
>
> Because drill holes for seismic programs average only about 200 feet in depth, multiple aquifers would have relatively small differences in hydrostatic head, and the quality of the waters would probably be similar.[6]

This indicates minimal interflow between aquifers.

In "The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota,"[7] the results of a literature search, a preliminary investigation, a field investigation, and an experimental investigation are presented. The preliminary investigation involved sending questionnaires to federal, state, county, and city agencies, certified water well contractors, as well as, grazing and environmental groups.

The questionnaires along with a news release resulted in numerous personal letters alleging effects during and after seismic testing. A third of these wells were field investigated. Both old and new wells were investigated. Eighteen wells were less than twenty years old and twenty-five wells were more than twenty years old. This indicates the problem is not restricted to older wells. Effects that were described by owners include long term decline in water quality (over a several year period), an abrupt (over several hours) decline in water quality, and 53 of 76 questionnaires cited decreased yield. In some instances these wells were not pumped wells, but rather were flowing wells. A gradual decline in a flowing well (or spring) is a naturally occurring result of usage.

Few instances of legal action were found during the study's preliminary search. Few people have good or complete records of their wells with respect to production and water quality. This causes difficulties when defending their position. A few respondents claimed to have replaced wells and equipment at their own expense. Also, because of the lack of background information on the wells, it is difficult to draw definitive conclusions regarding changes in water quality and production.

> Pumping tests conducted in a sand and coal aquifer system showed no apparent physical effects when shots were detonated one-quarter mile away from the pumping wells. Shots 500 feet distant resulted in no permanent effects. Shots 100 feet or closer increased the yield from wells finished in the sand aquifer and decreased the yield from the coal aquifer. Fracturing of the poorly indurated sandstone aquifer is suggested as the mechanism for the

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[6] Ibid.

[7] Beaver, F.W. The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota, Master's Thesis Submittal, University of North Dakota, 1984.

increase. Collapse of the fractures is suggested as the failure mechanism in the coal aquifer. Well casings remained intact after 25-pound charges were detonated as close as 10 feet from a well screen...

During the pumping tests, no significant long-term chemical or mineralogical equilibrium changes were observed which could be attributed to the blasting.[7]

Surface Mining

The source of these comments is the U.S. Bureau of Mines (USBM) study "Survey of Blasting Effects on Ground Water Supplies in Appalachia."[8] This study relates to coalmine blasting where large per delay explosive weights exceeding 5000 pounds are common. The USBM study included four test sites chosen for geographic and geologic diversity. Maximum resultant particle velocities of up to 5.44 inches per second were recorded at the surface next to the wells.

No direct evidence of change in water quality or well performance was produced by blast vibrations, but removal of down slope support by excavation does cause lateral stress relief which permits the water-bearing fractures to become more open. This additional storage capacity causes the static water level to drop and for well-bore permeability to improve. Static water level recovers if sufficient recharge is available and well performance is improved.

The well continues to perform in the same manner although blast induced round vibrations at the surface may approximate 2.0 inches per second maximum resultant particle velocity, until surface mining approaches to within about 300 feet of the water well.

State agencies and coal companies in Appalachia were contacted to develop a list of reportedly blast damaged wells. Of 36 wells so reported, 24 were investigated in the field but there was no clear evidence that the problem was blast related. In most cases, it was evident that other factors were responsible for changes in well behavior.

Maximum ground vibration levels at the four test wells, measured as close as practical to the well heads, were 2.2, 5.44, 2.14, and .84 inches per second resultant particle velocity. Based on observable change in well conditions immediately after a blast, there was no direct evidence of any significant change as a result of blasting. At three sites, when mining approached within a distance of approximately 300 feet, a fairly abrupt drop in static water level occurred followed by a significant improvement in well performance as indicated by specific capacity. At the fourth site, there was no change.

Measurements made at the bottoms of wells indicated that vibrations were considerably attenuated at depths of 140 to 160 feet.[8]

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[7] Ibid.

[8] Robertson, D.A., Gould, J.A., Straw, J.A., and M.A. Dayton. Survey of Blasting Effects on Ground Water Supplies in Appalachia, U.S. Bureau of Mines Contract J-0285029, prepared by Philip R. Berger & Associates, 1980.

[8] Ibid.

This study found the vibrations at the bottom of an observation well to be between 14 to 68 % as strong as those at the surface (approximately 150 feet deep). The largest effects on vibration attenuation with depth are the geometric relationship between the charge location and the well and the degree of confinement of the shot.

This study quotes another study, "Water Well Design for Earthquake Induced Motions,"[9] a survey of published reports describing the conditions of numerous water wells during and after three major earthquakes. This study involved 350 wells in areas where severe damage to structures occurred. Almost all wells reported to be permanently damaged were in regions of permanent displacement of the surrounding earth, primarily land sliding. Eight wells were destroyed, four were inoperable but reparable, and forty-five wells were damaged but operable. The intensity of the earthquakes in the study were modified Mercalli scale magnitudes VIII, IX, and X.

PIPELINE RESPONSE

Five pipeline sections were studied by the USBM in conjunction with the State of Indiana and AMAX Coal and its consultants in the advance of coal mine overburden blasting (USBM R.I. 9523).[10] These tests were conducted on the highwall of the Minnehaha Mine near Sullivan, Indiana and were designed for testing to failure.

All five pipeline sections were 76 m (249 ft) long. Four sections were welded steel pipe and one section was PVC. The pipeline sections were laid parallel to one another, 3 m (9.8 ft) apart, with 1 m (3.3 ft) depths of burial. They were buried in a clay soil. Each pipeline had three uprights for pressurization and gage access. Following is a summary of the pipeline attributes:

Outside Diameter, cm, (in)	Wall Thickness, mm, (in)	Fill Material	Age	Material Type
Steel:				
16.8, (6.6)	4.78, (.188)	Gas	Used	X-42
32.4, (12.8)	6.35, (.250)	Gas	Used	Grade B
32.4, (12.8)	6.35, (.250)	Gas	New	X-42
50.8, (20.0)	6.63, (.261)	Water	Used	X-56
PVC:				
21.9, (8.6)	8.43, (.332)	Water	Used	SDR26

Steel Pipelines: Initial pressurization 6.2 MPa (900 psi).
PVC Pipeline: Initial pressurization 0.62 MPa (90 psi).

The pipelines were monitored for vibration, strain, and pressure for a period of 6 months while production advanced up to a point 15 m (49 ft) away. 29 productions blasts were measured. The blasts used maximum charge weights per delay of up to 950 kg (2090 pounds) in 31 cm (12.25 inch) diameter holes.

Following the production blasts, a single row of four blast holes was drilled between the pipelines to complete the destructive test. The explosive charge was below the pipes at 5 to 6 m

[9] Nazarian, H.N. Water Well Design for Earthquake Induced Motions. ASCE J. Power Div., V. 99, No. P02, Paper 10176, November 1973, pp. 377-394.

[10] Siskind, D.E., M.S. Stagg, J.E. Wiegand, and D.L. Schulz. Surface Mine Blasting Near Pressurized Transmission Pipelines. U.S. Bureau of Mines, Report of Investigations 9523, 1994, 51 pp.

(16.4 to 19.7 ft) distances. The vibration level measured was greater than 900 mm/s (35.43 in/s), however, this was non-elastic response. The result of the destructive test on each pipeline is as follows: 1) 16.8 cm (6.6 in) diameter steel pipe - severely bent but unbroken, 2) new 32.4 cm (12.8 in) diameter steel pipe - bowed, but unbroken, 3) used 32.4 cm (12.8 in) diameter steel pipe - cleanly broken at the risers, 4) water filled 50.8 cm (20.0 in) diameter steel pipe - uplifted, parted, fell back down, and 5) 22 cm (8.6 in) diameter PVC pipe - came apart at O-rings, but unbroken.

The results of the closest production blast (15 m (49.2 ft) distant from the closest pipeline) resulted in a 635 mm/s (25.00 in/s) measurement at the surface and 234 to 274 mm/s (9.21 to 9.84 in/s) on two instrumented pipelines.

> Analysis found low pipe responses, strains, and calculated stresses from even large blasts. Ground vibration of 120 to 250 mm/s (4.72 to 9.84 in/s) produced worst-case strains that were about 25% of the strains resulting from normal pipeline operations and calculated stresses of only about 10% to 18% of the ultimate tensile strength. No pressurization failures or permanent strains occurred even at vibration amplitudes of 600 mm/s (23.62 in/s)...
>
> ...Although particle velocities of over 600 mm/s (23.62 in/s) were sustained without loss of pipe integrity, it is recommended that 125 mm/s (4.92 in/s) measured at the surface is a safe-level criterion for large surface mine blasts for Grade B or better steel pipelines. The same criterion is recommended for SDR 26 or better PVC pipe...Also, no adjustment is believed needed for pipeline age, assuming the protective coating is intact, unless the pipeline is known to be at higher risk from previous damage or other causes. The same safe-level criterion also appears applicable, at a minimum, to vertical wells and telephone lines.[10]

The primary blasting risk to pipelines appears to be from block motion or from having the pipeline in the actual crater zone. In both cases, permanent strain has occurred in the surrounding geologic material, which is weaker than the pipe.

In the early 1960's work was undertaken by the American Gas Association Pipeline Research Committee to establish limits for charge size (pounds per delay) and distance from a blast to high-pressure gas transmission pipelines. The primary research found that there had been no reported case of pipeline failure due to normal blasting activities. Failures were recorded only when explosives were detonated directly adjacent to a pipeline.

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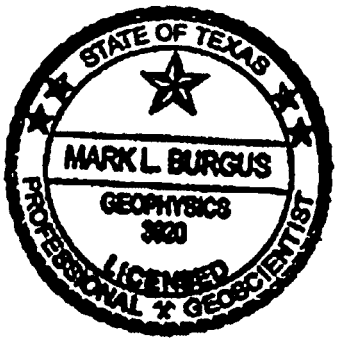
[10] Ibid., pp. 1, 36.

Sincerely,

Mark L. Burgus

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