ROCK BLASTING and the COMMUNITY

The concern of damage from ground vibration, airblast, and flyrock from blasting are a major concern to both the nearby landowners and ODOT as the quarry owner. In most cases these concerns are based on misunderstandings and unsubstantiated fears resulting from a lack of information. The purpose of this handout is to help illustrate the concept of blasting, explain the science, and hopefully provide the information needed to explain what is being proposed, and what surrounding property owners can expect.

To set the stage for the remainder of this discussion, we want to first address some of the common terms and definitions related to blasting:

- Explosives – Any chemical mixture poured or placed in a borehole that reacts at a high speed to generate gas and heat, thus causing tremendous outward pressures. Some common types used are ANFO (ammonium nitrate and fuel oil), dynamite, TNT, and water gels and emulsions for boreholes filled with groundwater.
- Two basic forms of energy are released when explosives react – gas energy and shock energy. Shock energy is the pressure that is transmitted outward from the borehole into the rock, causing microfractures to form and propagate outward for a short distance. Gas energy is the pressure that is exerted on the borehole walls by the expanding gases after a chemical reaction has been completed. These gases follow the 'path of least resistance' along existing and newly-formed fractures in the rock and this causes the majority of rock breakage in quarry blasting.
- Energy from a blast which is not used for rock breakage is wasted in the form of ground vibration and airblast.
- Ground Vibration – Seismic waves that spread out from the blasthole(s) along and through the ground, much like ripples in a pond. Ground vibration is comprised of many different waves with different frequencies and travel paths. The components (frequency, displacement, peak particle velocity, and acceleration) are measured with a seismometer, and it has been found that PPV is the most predictable and indicative of damage. Vibration levels, typically far below the levels required to produce damage, can be felt by humans (Figure 2).
- Peak Particle Velocity (PPV) – A measurement of ground vibration. The maximum speed (measured in mm/sec or in/sec) at which a particle in the ground is moving relative to its inactive state.
- Airblast – An airborne wave emanating from the blast, which is observed by people and structures as sound and pressure. It is measured in decibels (dB), just like noise. The airblast from an improper blast is what can crack walls and break windows.
- Flyrock – Rock or debris that is propelled into the air by the blast. Flyrock usually originates from material on the surface or the upper free face.

- Scaled distance (on Figure 1) is a formula for reducing the combined effects of distance and weight of the explosives into a single value that can be related to PPV. Scaled distance is d / $\sqrt{w}$ where
  - d = distance from blast
  - w = weight of explosive per delay (if instantaneous this is the <u>total</u> weight of explosives; if delayed these are individual detonations).
- Delayed Blast – A blast in which boreholes or groups of boreholes are detonated separately, by a time interval of at least 15 milliseconds. This time has been shown to be generally sufficient to isolate the energy from individual detonations. Thus a blast can consist of a large number of holes that when fired produce vibrations approximately equivalent to firing holes one at a time.
- Free Face – The visible near-vertical wall(s) within the quarry (see Figure 3 for this and explanations for other blasthole terms)
- Burden – The distance from a blasthole or row to a free face (Figure 3)
- Stemming Height – The top portion of the blasthole normally filled with crushed rock to confine the explosion downward (Figure 3)

Ground vibrations, measured as Peak Particle Velocity (PPV), are commonly viewed as the major concern for off-site damage resulting from blasting.

Extensive research has been conducted throughout the last 40 years by the United States Bureau of Mines (USBM) and the Office of Surface Mining (OSM) [both bureaus of the U.S. Department of Interior], universities, and private groups. This research has led to the development of acceptable vibration standards, vibration damage criteria, seismographs, and techniques to predict and control blast vibrations that greatly reduce the risk of off-site impacts from blasting.

When the OSM developed regulations pertaining to ground vibration, they concluded that "if ground vibration (PPV) were limited to 1 inch per second then 95% of the damage to (surrounding) houses, etc. would be prevented." Initially the OSM made a policy decision that 95% was an acceptable level of public protection and made 1 inch per second the standard. After more recent research, both law and science have set the PPV limit at 0.5 inches per second to avoid off-site damage (which feels like, according to Figure 1, the same as a loaded truck or bus going by 50-100 feet away). As a real example, Las Vegas had used a maximum PPV of 0.25 inches per second since 1993, but as of 2000 the city has changed the criteria and raised the allowable vibration to a maximum PPV of 0.5 inches per second.

Principle factors that affect ground vibration levels at a given point of interest are:

- Weight of the explosive fired per delay period
- Distance from blast to point of concern (house, cistern, etc.)
- Blast configuration (existence of a free face, trench, confined area, etc.)
- Geology (sites with a thick layer of soil have been known to produce ground vibrations 10 times as great as locations with a thin layer of soil over rock)

The first two factors are the most influential to ground vibration, which is what most of the graphs are showing (see Figures 1, 2, 4). The distance from the blast to the point of concern cannot be controlled by the Blasting Contractor, but the weight of explosives fired per delay period can be. Some site conditions, such as removing a thick layer of soil, can also be manipulated to lessen the amount of ground vibration.

How Peak Particle Velocity (PPV) is calculated and used to design a blast:
To determine the weight of explosives that can be detonated without off-site damage, the Blasting Contractor uses the following formula that relates peak particle velocity to distance and the weight of explosives fired in a single delay period:

$$\mathbf{PPV = k * (d \ / \sqrt{w})^a}$$

where **k** and **a** are constants that vary depending on site conditions. Ideally, values for **k** and **a** are generally derived from blast vibration monitoring at a site and define a line that represents a relationship between PPV and the weight of explosives for those conditions. In the absence of vibration monitoring from previous shots in the quarry and to take into account variations in geologic conditions and blast patterns, the values for **k** and **a** are set to represent an upper limit to peak particle velocities relative to scaled distance (shown as Upper Limit on Figure 4, which is based on over 10,000 measurements recorded worldwide). ODOT uses the following values for **k** and **a**, which were developed by Federal Highway Administration (FHWA):

k = 100
a = -1.6

Thus, if a structure is 530 feet away from a blast (1/10 of a mile) and the peak particle velocity at that point is limited to 0.5 inches per second, then according to the formula above, the maximum weight of explosives that can be detonated during a single delay period, and still be under the limit to avoid off-site damage, is approximately 370 pounds. If a structure is 1,320 feet away (1/4 of a mile) and the peak particle velocity at that point is limited to 0.5 inches per second, then the maximum weight of explosives that can be detonated is approximately 2,300 pounds per delay period.

To illustrate the example in reverse, consider that typical blasts at quarries use a 3½ inch diameter hole approximately 40 feet deep. The explosive most commonly used is ANFO and the top part is stemmed with sand/gravel or drilling cuttings poured on top of the ANFO to help force the blast energy into the rock. The amounts of ANFO and stemming vary depending on the location of the hole in the blast pattern, site conditions, the hardness of the rock to be blasted, and of course, on PPV limitations for surrounding structures. Generally, a minimum amount of stemming for a 3½ inch diameter, 40 foot hole would be approximately 7 feet, which would leave 33 feet of hole for ANFO. The weight of explosives in the hole would be approximately 115 pounds. If a single hole is fired per delay period, at a distance of 530 feet, the PPV should be approximately 0.2 inches per second. If three holes are fired simultaneously (within the same 15 millisecond window), then the PPV at a distance of 530 feet should be approximately 0.47 inches per second. Note that the relationship between PPV and the weight of explosives is not linear – three times the explosives do not produce three times the PPV. The PPV calculated with this formula represents a likely maximum value (the Upper Limit line); the actual PPV would generally be less than these values and be located below the Upper Limit line.

Effects of Blasting on Groundwater:

- Studies have shown that significant fracturing in the rock around a blast hole is generally limited to a distance of 20-40 blasthole diameters. Thus, for the typical 3½ inch drill hole, the zone of damage would generally be 6-12 feet.
- Studies have concluded that there are little to no significant long-term mechanical changes in an aquifer that could be attributed to blasts detonated at distances greater than 500 feet from the observation wells.
- Blast vibrations are not believed to permanently degrade groundwater quality, but can sometimes cause local and temporary turbidity that can extend for hundreds of feet beyond the blast zone. These sediments can remain in suspension for days or weeks; however, this is only temporary and aesthetic, and not suggestive of physical damage to the aquifer or well.
- In tests directly on wells, steel well casings remained intact even after 25 pound charges were detonated as close as 10 feet from the well screen (a PPV=33 inches per second derived from the equation).
- Blast vibrations have been shown in a number of cases to improve the long-term water yield in aquifers due to the "flushing out" of fine sediments from between joints, allowing more permeability and overall storage.

Principle factors that affect airblast levels at a given point of interest are:

- Distance from blast to point of concern
- Orientation of the free face
- Presence or absence of temperature inversions (commonly exist in the morning and evening)
- Burden distance
- Stemming height and/or material used
- Weight of explosive detonated per delay period

All but the first two or three factors can be adjusted by a Blasting Contractor to reduce airblast.

Principle factors that affect the amount of flyrock landing near point of concern:

- Distance from blast to point of concern
- Orientation of free face
- Zones of adverse geology (voids, decomposed seams, large joints)
- Weight of explosive detonated per delay period
- Burden distance

- Stemming height and/or material used
- Bench height
- Delay Configuration (when individual holes are detonated in relation to each other, which controls the direction and degree of rock displacement)

Again, all but the first two factors can be adjusted or designed for by a Blasting Contractor to reduce the amount of flyrock.

What ODOT and the Blasting Contractor can do to keep ground vibration, airblast, and flyrock at acceptable and safe levels:

- Require an approved Blasting Consultant to design/approve the blasting plans
- Perform pre-blast surveys. These are done either by or through the Blasting Contractor prior to the blast to document the condition of structures, foundations, windows, etc. prior to exposure to vibration from blasting.
- ODOT review the submitted blasting plan(s) prior to allowing the blast(s) to proceed
- Require ground vibration monitoring during the blasts(s)
- Require that blast mats be laid upon the blast area(s) to help contain flyrock
- Blasting contractors are licensed and bonded
- Place safeguards in the Special Provisions of the contract

  Example: Contractor Responsibility and Liability: Oregon Standard Specifications for Construction

  00170.94 Use of Explosives – The Contractor shall comply with all Laws pertaining to the use of explosives. The Contractors shall notify anyone having facilities near the Contractor's operations of Contractor's intended use or storage of explosives. The Contractor shall be responsible for all damage resulting from its own, its agents' and employees', and its Subcontractors' use of explosives. (See 00330.41 (e) and Section 00335.)

CONCLUSION:

Blasting is an inherently dangerous activity which can result in serious injury, death, and/or damage if not designed and performed professionally. With the safeguards and technology employed in this industry today, many of the concerns of the past are exactly that – concerns of the *past*.

Today's Blasting Contractors are professional. They have the knowledge and technology to make this dangerous task safe, for themselves and the surrounding property. The key to making sure blasts are carried out successfully and safely is knowing what the issues and concerns are up front. For example, a blast design cannot take into account potential impacts to wells and springs if their existence is not known.

When ODOT or a Contractor working for ODOT is preparing for the blasting phase of a project, they try to be thorough in identifying all elements of concern; but sometimes things are not obvious. This is why ODOT and the Contractor need to rely on local knowledge of the surroundings.

It is in the best interest of ODOT and the Contractor to complete this work in a timely, efficient, and safe manner. This can and will be the end result as long as all factors of concern are known and taken into account.

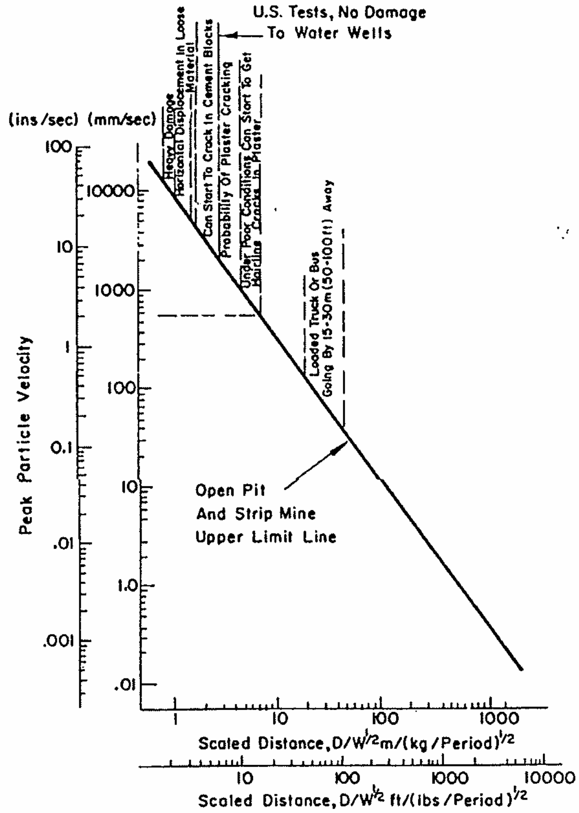

Fig. 1. Structural response at different scaled distances from pit blasts.

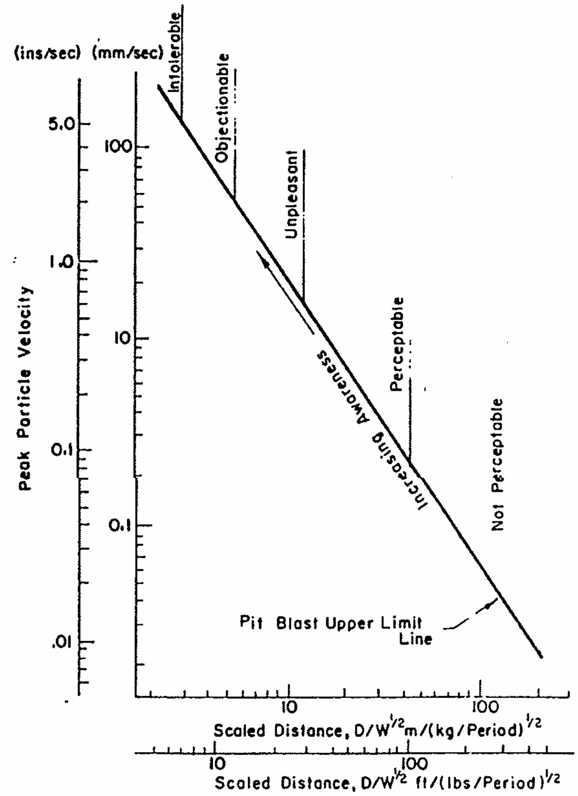

Fig. 2. Anticipated human response to blast vibrations at different scaled distances from pit blasts.

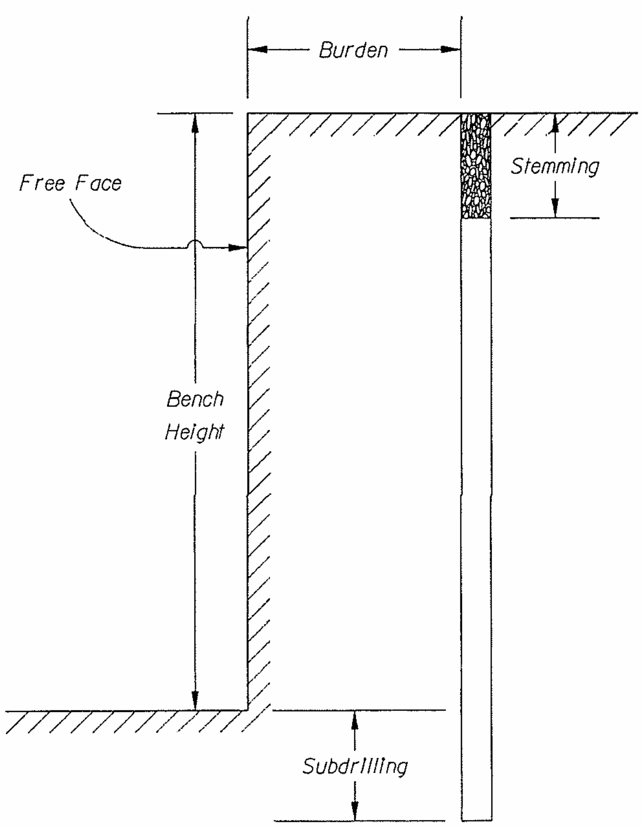

Figure 3. Profile of a Typical Quarry Blast Hole

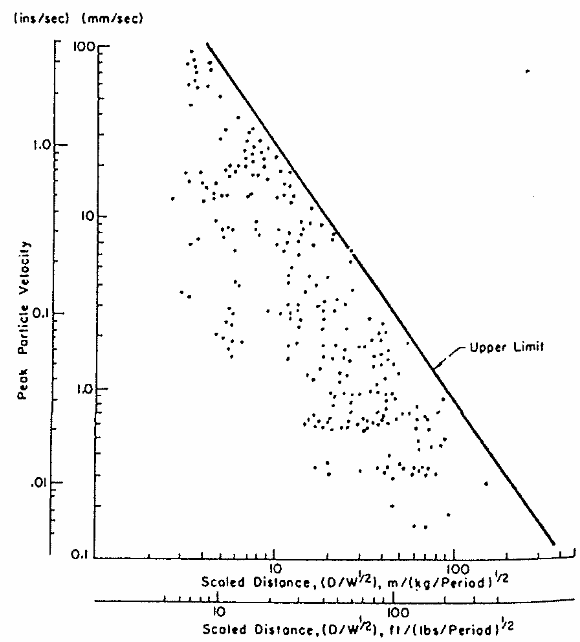

Fig. 4. Typical vibration data from multiperiod delay blasts in open pits and strip mines.