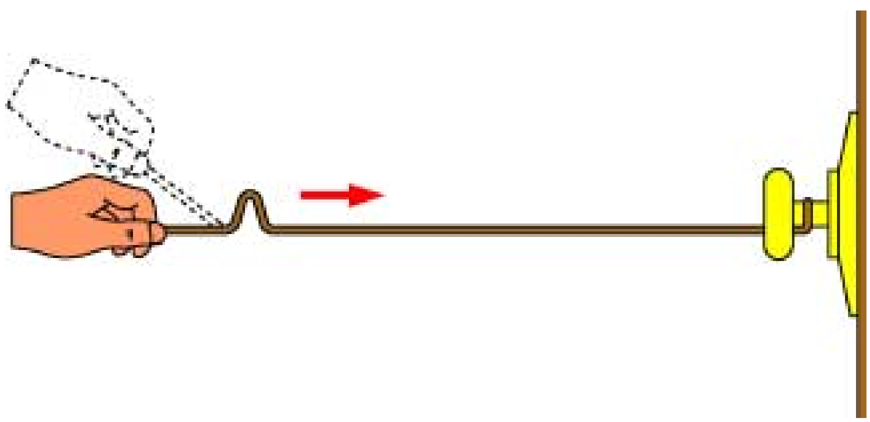
A Guide to the Differences Between Blasting and Earthquakes

A Special Publication from **SubTerra, Inc. ®**

What do earthquakes and blasting have in common?

A simple clap of the hands produces energy that travels through the air as *vibrations*, or *waves*, thereby creating noise. A stone dropped into a puddle of water transfers energy that spreads out across the water as ripples, or *waves*. Earthquakes and blasting also produce energy that travels through the ground in the form of *waves* (even if they can't be seen as easily as those produced in water).

Waves are classified according to their different characteristics, such as speed, shape, direction of movement, and so on. Different types of energy can produce different types of waves. A helpful way to visualize one common type of wave is to picture what would happen to a string tied to a doorknob, if you flipped the loose end up and down:



The energy you apply to the string by flipping the end up and down moves along the string as a wave. It travels at a certain speed, which depends on the type of string, and how tightly it is stretched. The wave is nothing more than a temporary disturbance of the string—a temporary change in its normal shape.

As a wave moves away from the source that created it, the energy it is carrying is *dissipated* or reduced. At some distance from the energy source, all of the initial energy generated by the source completely disappears. This happens through different processes, one of which is *absorption* by the material through which the energy is passing. An example of how this works is the way you absorb heat (energy) from a fire when you stand directly in front of it. To get the most energy from the fire, you stand as close to it as possible. If you stand too far away, you won't be able to feel the heat at all. The energy from the fire will have spread out and been absorbed by people and objects near to it.

Energy is reduced with distance no matter what it's traveling through. With the string analogy described above, if you only flip the string slightly, the energy pulse won't even travel as far as the doorknob before it disappears completely. In similar fashion, the sound from a clap of the hands cannot be heard across town, only within close proximity to the person clapping. And the ripples formed when a pebble is dropped into a lake do not keep spreading forever—they disappear within a short distance of where the pebble was dropped. The same is true for energy waves created by earthquakes or blasting—they dissipate with distance from their source.

What are the important differences between blasting and earthquakes?

Although both earthquakes and blasting apply energy to the ground, there are five major ways in which the two processes are substantially different.

1. <u>Magnitude</u>:

Magnitude is a term used to define the amount of energy associated with an earthquake. Numerous earthquakes of very small magnitude occur all the time, but they are of no consequence to most people, since they can’t be felt, and can only be registered by very sensitive instruments. However, much larger earthquakes also occur, and these can cause devastating consequences. A magnitude 7 earthquake releases about 1000 times more energy than a magnitude 5 earthquake, and 15 million times more energy than a magnitude 2 earthquake!

In contrast to the range of magnitudes associated with naturally-occuring earthquakes, blasting events used for civil construction or quarry operations are restricted by design and operating practice to a very limited energy range. In fact, it would not be economical to generate larger blasts than necessary, due to the costs of additional blasting materials. Thus, it is a simple matter to define a “typical” blast event.

But in order to compare the difference in energies between an earthquake and a “typical” blast, we need to select a specific earthquake to look at, since it would be impossible to define a “typical” earthquake in the same way we can a blast.

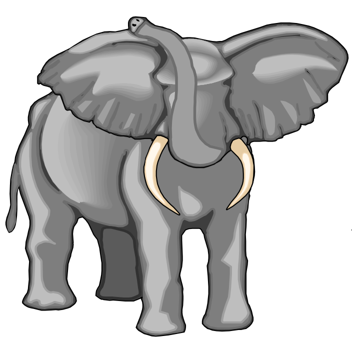
The Nisqually Earthquake of February 28, 2001 is a good earthquake to use for comparison. It was large enough (magnitude 6.8) that most people throughout the Puget Sound Region could feel the associated ground vibrations. This makes it appropriate for comparison to blasting, because people in the vicinity of a typical blast can often feel the resulting ground vibrations.

So how much energy did the Nisqually earthquake release compared to what is released in a blast? *Approximately 750 million times as much!*

This difference is so large, it’s impossible to visualize. However, it can be helpful to think about the following comparisons, which are rough quantitative equivalents:

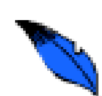
Comparison 1:

<u>Nisqually Earthquake</u>
Weight of an elephant . . .



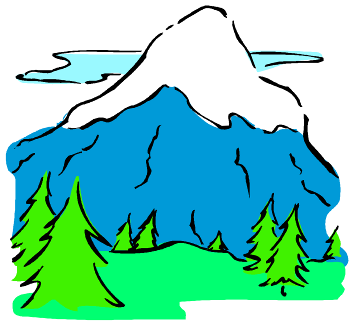
vs.

<u>Blasting</u>:
Weight of a feather . . .



Comparison 2:

*Nisqually Earthquake***:**
Height of Mt. Rainier . . .

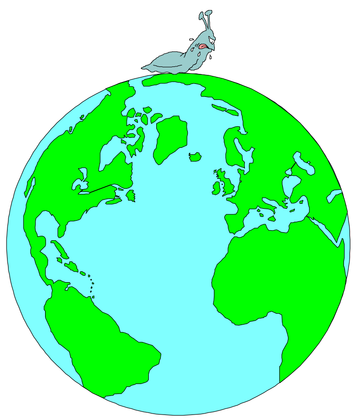


vs.

Blasting:
Height of an ant . . .

Comparison 3:

Nisqually Earthquake:
Time for a slug to travel around the world . . .



vs.

Blasting:

An hour’s drive . . .

2. **Velocity**:

What is generally of more interest when an earthquake or blast occurs is not the velocity at which the energy waves travel through the ground. Instead, the velocity at which the ground might vibrate in response to the energy waves traveling through it is of greater concern. This is because structures or other facilities are not isolated from the ground and its movement. They rest on the ground through footings or other types of foundations.

Seismographs are instruments used to measure ground response from events such as earthquakes or blasts. They record how sensors called *geophones* actually respond to ground movement. In the simplest form, a geophone is nothing more than a magnet contained within an electrical coil. It is designed so that the magnet can move from side to side or up and down within the coil whenever there is any ground vibration. The coil generates an electrical signal in response to the motion of the magnet. The signal is recorded by the seismograph, and can be “translated” into a velocity.

Researchers have worked on developing sensitive geophones for many years that can accurately respond to ground motion. However, a geophone is still just a magnet within an electrical coil—it is a rigid instrument, not a model version of the actual ground. Thus, while its response is related to ground movement, it cannot physically be an exact representation of what may be going on within the ground.

Regardless, the measurements obtained from geophones are extremely valuable for establishing standards for blasting activities. This has most frequently been done in terms of what is called the “peak particle velocity” or “PPV”, which is nothing more than the highest velocity recorded at a particular geophone location. If this measurement is kept below a certain value, established from many different studies and considerable research, then damage to nearby buildings or structures should not occur.

3. Frequency:

Another measurement that can be made with a geophone is the frequency of ground vibration in response to the energy wave—in other words, how often movement recurs in a given period of time. It is typically expressed in *hertz* (Hz), i.e., the number of cycles per second.

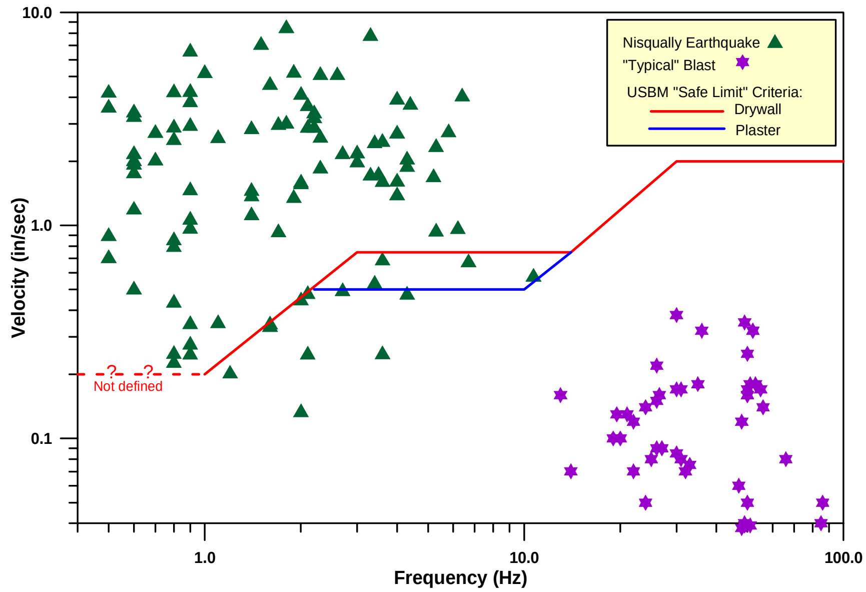
There is a significant difference between frequencies associated with earthquakes such as the Nisqually and the frequencies associated with blasting. Earthquakes characteristically produce a large range of frequencies. In fact, engineers refer to the *frequency content* of earthquakes, because ground motion at many different frequencies is generated by earthquakes. Of particular significance, however, is the significant percentage of *low-frequency* ground oscillations typically generated by earthquakes. In other words, the ground moves up and down or back and forth slowly in a given period of time. In contrast, blasting produces *high-frequency* oscillations in the ground—i.e., fast up and down or back and forth movement.

So how does vibration frequency affect buildings or other types of structures? When the ground vibrates in response to an earthquake or blast, it can also cause any structures resting on it to vibrate, just as it causes movement of the magnet in a geophone. Some of the energy from a ground vibration can therefore be passed along to overlying and nearby structures, and they may react by vibrating themselves.

Because of the geometry, composition and other characteristics of structures, they tend to vibrate at low frequencies. Now the most dangerous condition that can develop is when buildings vibrate at a similar frequency to the ground. This increases the sway or oscillation of the building, and can result in significant damage. This is why earthquakes can be so devastating. Because they generate many low frequency ground vibrations, the resulting motion may match the way in which a building vibrates.

In contrast, the vibration frequencies associated with typical blasting events are much higher—outside the vibration response range of structures. This has been recognized in building design. In fact, one approach used by some structural engineers is to simply eliminate from consideration any ground motions above 8 to 9 Hz that could occur during the lifetime of a structure, because they are simply at too high of a frequency for any kind of structural response.

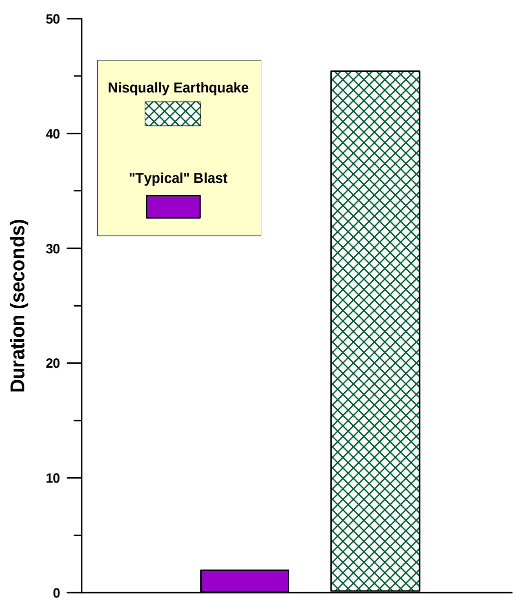
The figure on the next page illustrates the different velocities and frequencies measured during the Nisqually Earthquake and during a typical blasting event. It is evident from this figure that virtually all measured frequencies of ground motion associated with the Nisqually Earthquake are below 10 Hz, with an average in the range of 1.5 Hz. On the other hand, measurements associated with a typical blast are all above 10 Hz, with an average in the range of 40 Hz. This is an extremely important difference between blasting and earthquakes.



4. Duration:

The longer something is subjected to vibration, the more time there is for changes that can cause damage. One of the reasons that low frequency vibrations are more damaging to buildings or structures than high frequency vibrations is because they last longer. High frequency vibration energy dissipates rapidly with distance; low frequency vibration takes much longer.

A specific example of the much longer duration of the Nisqually Earthquake, compared to a typical blasting event, can be seen in the following figure:



5. <u>Ground Acceleration</u>:

For earthquakes and blasting events, acceleration is expressed in terms of "g's." This is a way of relating an acceleration value to the acceleration of gravity, which is 32.2 ft/sec^2. If an acceleration measurement is "0.2g", this is the same as saying the acceleration is 0.2 x (32.2 ft/sec^2), or 6.4 ft/sec^2.

A direct measurement of ground acceleration by itself is not a very useful indicator of possible structural damage. Acceleration needs to be considered in relation to other quantities such as the frequency and the duration of ground motion.

To illustrate why acceleration doesn't mean much without a consideration of other things going on at the same time, consider the example of a car. Suppose you are told that a car accelerates at a certain value. Unless you know the circumstances, there is no way to tell if this is a dangerous or a safe level of acceleration. If a car is being merged onto a freeway and the driver is barely stepping on the accelerator, chances are very good that the acceleration level is entirely too low and the stage is set for slammed brakes and a possible accident.

On the other hand, suppose a car is stopped for a red light at a slick intersection. If the driver accelerates too quickly when the light turns green, the car will probably skid.

There have been earthquakes with measured peak accelerations in excess of 0.5g that have caused no damage, because the acceleration occurred at a very high frequency and for only a short duration. On the other hand, earthquakes that produced much lower ground accelerations have caused damage because the generated vibrations were at low frequencies and of long duration. This is a good example of why a measured ground acceleration by itself is not a reliable indicator of potential structural damage. This also explains why an earthquake-generated ground acceleration of only 0.2g might easily cause damage to a building, if it is of long duration and low frequency. In contrast, the same measured ground acceleration, associated with a short duration, high frequency blast event, would not be capable of damaging a building.

When discussing acceleration, it's also useful to look at specific examples of actual acceleration values:

> <u>Example 1</u>: Today's roller coasters reach momentary acceleration values as high as 5g! That's five times the acceleration of gravity, or 161 ft/sec^2! No harm is done to humans because these values are only reached for a brief moment. The human body could not sustain being subjected to such a force for a long period of time, but for a short instant, this acceleration level produces a thrill that is avidly sought by many. Again, notice the importance of time, or duration, in this example.
>
> <u>Example 2</u>: A 25-lb. turkey dropped from the top of a 6-ft. stepladder onto your kitchen floor, while messy, wouldn't produce any concern for possible structural damage to your home! Yet a geophone placed just out of the "drop path" would likely report acceleration values as high as 0.2 g, depending on the type of floor (since energy is transmitted differently through different materials).

Thus, the numerical value of a ground acceleration measurement by itself does not give much information about possible damage to buildings and other structures.

Acceleration vs. Seismic Zone Factor:

Another important point of discussion on the subject of acceleration is the difference between a ground acceleration value and the *acceleration design parameters* used by engineers.

An example of such a parameter is the *Seismic Zone Factor* associated with the Uniform Building Code (UBC). This factor is not the same as a measured ground acceleration, although this assumption is often made. The Seismic Zone Factor has no units. Thus, a factor of 0.3 does not directly correlate to an anticipated ground acceleration of 0.3g's.

Different values of the factor have been assigned to different geographic areas, based on probable earthquake magnitudes that might be expected in the particular region. These values have been determined using a variety of information, and have evolved over the years as additional information and research have become available.

Two points should be emphasized:

1) the Seismic Zone Factor has been established based on earthquake data, because earthquakes generate the types of ground motion of most concern in structural design (i.e., low frequency, high velocity, long duration); and,
2) if a comparable factor *were* established for blast data, using the same techniques, the values would be quite different. In other words, the Seismic Zone Factor used in the UBC has little applicability to blast events.

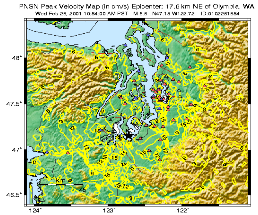
The preceding discussion should hopefully provide a better understanding of the important differences between the nature of earthquakes and blasting events, and corresponding responses of structures.

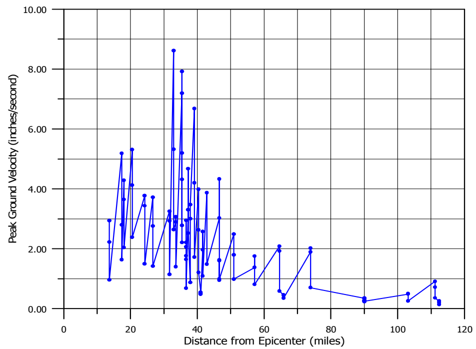
Nisqually Earthquake: February 28, 2001

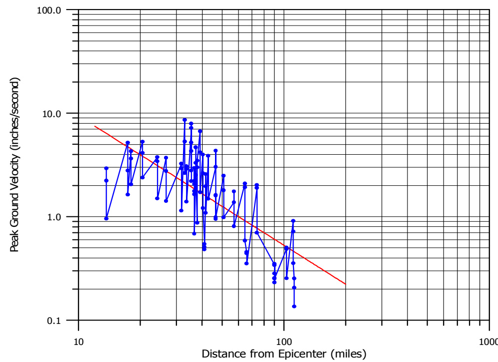
The magnitude 6.8 (see inset) Nisqually Earthquake struck western Washington at 10:54 am. Named after its epicenter location in the Nisqually Valley, approximately 37 miles southwest of Seattle, the quake produced ground shaking over a wide area. Shaking persisted for 45 seconds, a relatively long duration for an earthquake.

The earthquake was due to normal (tensional) faulting in the subducting Juan de Fuca tectonic plate. Rupture propagated approximately 8 ½ miles north and 5 miles south of the hypocenter (source), with a maximum vertical movement along the fault of almost ten feet.

Digital accelerographs recorded strong-motion data at numerous locations (see Table). These data were used to generate the following graphs of Peak Ground Velocity vs. Distance:







Strong Motion Parameters at Various Stations

Station	Distance (Miles)	Peak Ground Velocity (in/sec)	Relative Duration (sec)	Peak Ground Acceleration (g)	Dominant Frequency (Hz)
UPS	13.67	2.94	46.2	5.51	2.1
UPS	13.67	2.22	44.1	6.07	3
UPS	13.67	0.96	48.8	5.49	5.3
PCFR	17.40	5.19	17.7	11.03	2.6
PCFR	17.40	2.79	17	13.08	5.8
PCFR	17.40	1.63	16.5	14.09	3.6
TBPA	18.02	4.29	67.7	6.39	0.5
TBPA	18.02	3.65	69.5	6.49	0.5
TBPA	18.02	2.04	81.2	4.66	0.6
PCEP	20.51	5.31	13.2	20.39	1
PCEP	20.51	4.12	14.8	21.33	6.4
PCEP	20.51	2.39	16.2	15.48	5.3
KIMR	24.23	3.77	17.8	16.28	4.4
KIMR	24.23	3.43	17.3	15.02	2.2
KIMR	24.23	1.50	26.1	7.05	0.9
PCMD	26.72	3.71	13.1	15.76	2.1
PCMD	26.72	2.76	18.8	11.04	4
PCMD	26.72	1.41	18.4	6.76	4
RBEN	31.69	3.25	28.3	10.97	2.2
RBEN	31.69	2.93	18.5	10.93	2.2
RBEN	31.69	1.14	33.6	4.55	1.4
TKCO	32.93	8.62	14.5	27.28	1.8
TKCO	32.93	5.32	20.1	17.04	1.9
TKCO	32.93	2.64	24.4	7.77	2.3
MPL	33.55	2.89	15.2	9.77	1.4
MPL	33.55	3.07	17.5	8.12	1.8
MPL	33.55	1.40	27.1	4.95	1.4
KIMB	35.42	7.19	19.8	13.52	1.5
KIMB	35.42	4.31	28.6	9.25	0.8
KIMB	35.42	2.78	35	4.71	0.7
SP2	35.42	7.92	7.4	30.77	3.3
SP2	35.42	5.20	12.1	19.00	2.3
SP2	35.42	2.21	20	11.70	2.7
KITP	36.66	2.21	43.9	4.82	0.6
KITP	36.66	2.95	35.3	4.93	0.8
KITP	36.66	2.06	45.9	2.67	0.7
RHAZ	36.66	1.64	17	4.54	4
RHAZ	36.66	1.77	23.6	3.93	3.5
RHAZ	36.66	0.68	23.5	3.65	6.7
QAW	37.28	3.30	33.2	10.47	0.6
QAW	37.28	4.67	30.5	11.40	1.6
QAW	37.28	2.52	31.5	7.65	3.6
LAWT	37.90	0.87	70.8	3.19	0.8
LAWT	37.90	3.00	29.4	5.56	0.9
LAWT	37.90	3.47	28	6.53	0.6
RAW	39.15	6.68	9.7	17.27	0.9
RAW	39.15	4.20	13.9	12.47	2
RAW	39.15	1.72	21.6	5.59	5.2
WISC	40.39	3.98	23.7	11.34	4
WISC	40.39	2.63	33.8	9.44	1.1
WISC	40.39	1.21	64.8	3.44	0.6
RWW	41.01	0.54	38.4	5.80	3.4
RWW	41.01	0.48	35.7	5.64	4.3
RWW	41.01	0.51	41.7	5.26	0.6
KINR	41.63	1.97	44.4	7.55	0.6
KINR	41.63	2.57	38	4.94	0.8
KINR	41.63	1.09	45.6	3.14	0.9
NOWS	42.87	3.87	35.5	8.77	0.9
NOWS	42.87	1.48	60.6	2.92	1.4
BRKS	46.60	3.03	37.6	7.71	1.7
BRKS	46.60	4.33	36	10.38	0.9
BRKS	46.60	0.95	47.1	4.58	1.7
ELW	46.60	1.62	20.6	5.63	2
ELW	46.60	1.60	19.6	5.54	2
ELW	46.60	0.99	26.4	3.48	0.9
LEOT	50.95	2.48	37.8	6.37	3.4

Earthquake Magnitude Scales

Magnitude is a measure of the size or energy release from an earthquake. It is based on the ground motion produced by an earthquake at an arbitrary site. Moment calculations account for the natural decrease in ground motion with distance from the ***epicenter*** (the location on the ground surface directly above the earthquake source, or ***hypocenter***). Thus, approximately the same magnitude will be determined from a ***seismogram*** (record of ground motion) at any given site, regardless of the distance between the earthquake and the site.

The magnitude scale is ***logarithmic***, which means that an earthquake of magnitude 5 produces 10 times the shaking of a magnitude 4. A magnitude 6 earthquake produces motion 100 times that of a magnitude 4.

Several different methods have been developed over the years for determining magnitude:

• Ms – Surface Wave Magnitude; most often used for shallow earthquakes; based on amplitude of *surface waves* (those traveling along ground surface).

• mb – Body Wave Magnitude; often used for "intermediate" depth earthquakes; based on amplitude of body ("P" or "primary") waves (those typically arriving first at a sensor).

• Mw – Moment Magnitude; best for deep-seated earthquakes; based on amplitude of ground motion at very low frequency.

Each of the magnitude scales is based on different parts of the seismogram over a different range of frequencies. Thus, the "best" magnitude scale for quantifying the energy of a given earthquake depends on the characteristics of the earthquake. For deep subduction zone earthquakes, such as the Nisqually Earthquake, moment magnitude provides the best estimate of energy release.