ISEE

Richter Scale and PPV

by Wilfrid Comeau

From the author: The question of Richter Scale vs. PPV has come up recently on the ISEE Blastserve. Below is a small contribution, which may add useful information concerning this question. Although there is no direct relationship between Richter numbers and PPV, the proposed approach shows that for blasting, a large quantity of explosives is required to attain even imperceptible Richter numbers.

Introduction

The RICHTER scale is used in classifying earthquake severity. It is an energy scale giving the estimated energy liberated at the source of the earthquake. Earthquake damage on the earth's surface, for example at the epicenter - spot on the earth's surface directly above the earthquake, for a given RICHTER number can vary. This depends on the depth of the earthquake focus. Deeper earthquakes will generally cause a lower level of damage at the epicenter but the damage will be spread over a greater area. As mentioned by Randy Wheeler on Blastserve, each successive RICHTER number represents about a 30-fold increase in energy. This scale is open at both ends with "0" RICHTER equal to about 10^4 Joules. The lowest level detected by sensitive instruments is about 2 on the RICHTER scale or about 10^7 Joules. The highest-level earthquake detected at 8.9 RICHTER represents a release of about 3×10^{17} Joules.

To put this in perspective ANFO has an available energy - chemical energy - of 3.7×10^6 Joules per kilogram (3.7×10^9 Joules per metric ton). The effective energy, as published in ICI's DOWNLINE in 1990, is about 63% of the available chemical energy for ANFO and goes to 77% for some high-density emulsions with somewhat lower chemical energies. These figures are approximate and may vary from source to source depending on the method of evaluation. Thus an 8.9 RICHTER scale earthquake represents a release, at the source, of some 129 million tons of ANFO or about 119 million tons of the high-density emulsion.

RICHTER - VS - PPV

RICHTER scale numbers are a measure of total energy released from a source relatively deep in the earth's crust. While PPV from blasting is a measure of the energy level passing a given point, when in most cases (pre-splitting and blasting failures excepted) the rock is fragmented and displaced. While, as mentioned by Randy Wheeler, there is no direct relationship between the RICHTER scale and PPV, it is possible to arrive at a reasonable comparison if the wave propagation velocity of the wave carrying the energy, the frequency - HZ - of the disturbance, the density - ρ - of the rock - transmitting medium - and the distance - **D** - from the seismograph to the blast site are known. This involves using the well known, simple, high school equation for Kinetic Energy, i.e.

Equation 1
K.E. = 1/2 m V², where V is the PPV

$$K.E. = \frac{1}{2} m V^2$$

The mass "**m**" must be estimated from the propagation velocity, fundamental frequency, density, and distance information. The mass of vibrating rock is represented virtually by a ring with a radius the distance to the blast, a radial thickness of 0.5 wavelengths and a height of about 0.4 wavelengths. This latter figure derives from the fact that surface wave motion disappears at about 1.2 wavelengths or so below the surface. The wavelength, known by the Greek symbol Lambda - λ - is simply the propagation velocity divided by the fundamental frequency. Since rock fragmentation by blasting is basically a surface action, i.e. extracting a mass from a surface, it has been found that, in blasting, surface waves carry over 75% of the vibration energy at the source and practically 100% at a distance of a wavelength or so and beyond. Therefore, the surface wave velocity - λ_s- is used to determine the wavelength. This is usually about 60% of the P-wave velocity, i.e. 0.6 C_P±. In order to use the resultant PPV in subsequent calculations using the above numbers, it must be reduced to its RMS value, i.e. 0.7 PPV.

The reasonable assumption made above is that the impulse given to the rock by the blast is equivalent to the energy required to initially displace a mass in a simple mass-spring system. Subsequent motion of the system, after releasing the displaced mass, does not add energy to the system. These figures will give ballpark values with hopefully a relatively small ballpark.

The mass - **m** - of this vibrating rock is of course its volume multiplied by its density. The mass is thus estimated by: $(0.2\ \lambda^2) \times (2\pi\ \mathbf{D}) \times (\rho)$. From the above, λ_s = 0.6 x C_p/Hz. Reducing, collecting constants and inserting in Equation #1 we get:

Equation 2
KE (in Joules) = 0.11 $(C_p/Hz)^2$ D ρ $(PPV)^2$

Consistent units must be used to get the correct answer, i.e. velocities in meters per second, distance in meters, density in kilograms per cubic meter, and PPV in meters/second. As a reminder, one Joule equals one Newton meter, i.e. J = N m, and one kilogram equals one Newton second squared divided by one meter, i.e. Kg = $(N\ s^2)/m$. This is obviously not an exact equation but is derived from reasonable values and assumptions.

Thus, for a well blasted granite rock mass with a C_P of 5000 m/s and a density of 2650 kg/m³, a resultant vibration of 50 mm/s or 0.05 m/s with a major frequency of 25 Hz measured at a distance of 50 meters will give a KE of about 0.15 x 10^7 Joules, a RICHTER value of about 1.5. Using the Hydro-Quebec-Comeau or BED (ISEE, New Orleans) system for blast vibration prediction, this PPV measurement would require some 150 kilograms of explosive detonated instantaneously. This vibration would be carrying almost 0.5% of the effective explosive energy. **Equation #2** does not include the body-wave energy, which, has been stated, is only a quarter of the total vibration energy at the source, and reduces to practically zero at, say, 1.5 λ_s ±. A simple correction factor multiplying **Equation #2**, which has a minimum value of one, can be used to allow for this body-wave energy close-in, i.e.

Equation 3
$(1+(0.33\ \lambda s - 0.22\ D)/\ \lambda_s)$: for D = or <1.5 λ_s

The value of this correction factor ranges from 1.33 to 1 as D goes from 0 to 1.5 λ_s. This correction has little effect on the PPV - RICHTER correspondence and only a slight effect on the percent effective energy carried by the vibration.

DISCUSSION

It will be appreciated that while most blasts will generally register very low on the RICHTER scale, the higher frequency vibrations associated with blasting are more bothersome to humans. The scale relating energy values to the RICHTER scale numbers is not easily interpreted. There appears to be no way of knowing how much of the earthquake energy goes to seismic waves and how much goes to local damage at the focus. It may be assumed that the energy relationship is simply the elastic energy emanating from the source and does not include the energy causing damage or plastic deformation. Any model used to estimate the energy partition would necessarily be very complex. The approach used here for blasting is very simple and appears to show that the vibration energy emanating from a blast is a small fraction of the explosive energy liberated. Some sources place this vibration energy as high as 85% of the explosive energy liberated. However, this value appears excessive when it has been established that for some carefully measured blasts, 30% or more is consumed in producing fines smaller than 1 mm (Fragmentation Workshop, Fragblast 5). Most sources place the vibration energy from blasting at less than 10% of the explosive energy liberated. When blasts are highly confined, the above equation yields percentages up to 8+. **Equation #2** is quite sensitive to the fundamental frequency. Higher fundamental frequencies give much lower energy values due to the squaring of λ in the equation. This is quite reasonable, as higher frequencies tend to attenuate more rapidly.

This article was written in response to a question on Blastserve asking about the relationship of Richter Scale vs PPV. Blastserve is an e-mail discussion list for ISEE members. ISEE members can join by going to the ISEE website www.isee.org

E-mail : GLOBEAGC@DEL2.VSNL.NET.IN

Jagdeepak Sharma Question to ISEE Blastserve