A COMPARATIVE STUDY OF CALCULATED AND MEASURED PARTICLE VELOCITIES

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ABSTRACT

After an explosive is detonated in a blasthole, seismic waves are generated in the ground surrounding the blasthole. These waves cause the particles of rock to oscillate about its position. As the wave attenuate, the particles come back to their original position. The rapidity with which the particles move is called the particle velocity. The peak or maximum velocity is the value which is of prime concern. This value of peak particle velocity can be estimated by the equations determined by the United States Bureau of Mines and by the DUPONT. A research program was conducted by the author at the "Beck Materials Quarry" situated near Rolla, Missouri, USA. The purpose was to draw a comparison between the predicted and measured particle velocities. It was generally found that the predicted peak particle velocities were quite high as compared to the velocities measured by the Seismographs.

INTRODUCTION

As soon as an explosive is detonated in a blasthole a pressure is generated in the ground surrounding the blasthole. As the pressure wave propagates away from the blasthole, it forms a seismic wave. Generally there are three types of waves that are generated i.e., primary wave, secondary wave, and surface wave. Primary and secondary waves are also called 'body waves' as it propagates through the rock; whereas 'surface wave' propagates only along the surface of the earth. The disruption of the surface by the reflection of body waves creates the surface wave.

The earth consists of many small particles of soil or of rock which are cemented together. There is a small amount of elasticity in the cementing material and even in the rock as well vibration is actually the displacement or movement of these particles caused by the seismic wave as it passes through the earth. The displacement of these particles is only a small fraction of an inch. The elastic nature of the cement causes the particles to oscillate. As the seismic wave alternate completely, the particles, come back to their original position.

It is these oscillations of the individual particles that are measured to find the magnitude of blast vibration. Sensitive instruments (Seismographs) are used to measure and record these vibrations. These are called seismograms or more commonly, vibration records. Based on the elastic wave theory, there are generally four terms used to measure the magnitude of blast vibrations.

Displacement: Usually a small fraction of an inch, it is the distance the particles move when they are oscillating.

Frequency: The number of oscillations per second which a particle undergoes when it is subjected to a seismic wave is called the frequency and is expressed as "Cycles/Second" or Hertz (Hz). The various Seismic waves have different characteristic frequencies that depend on many factors. The frequency range of concern for vibration damage is normally between 3 and 100 Hz.

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Velocity: The rapidity with which the particles move when they are oscillating. Since the velocity is continually changing, the peak or maximum velocity (PPV) is the value which is of prime concern. The peak particle velocity is expressed in inches/second, or mm/sec.

Acceleration: The rate of change of particle velocity during oscillation. It is usually measured in ins/sec^2 or mm/sec^2 or in terms of g which stands for the acceleration imparted to an object by the gravity.

Depending on the type of Seismograph, the Seismogram shows particle displacement, velocity, or acceleration. All three components are necessary to completely describe the vibration intensity because the particles oscillate in three dimensional space. For a sinusoidal vibration:

$$V = 2\pi f A$$

$$G = 4\pi^2 f^2 A$$

or $$G = 2\pi f V$$

V = Particle velocity.

G = Acceleration.

F = Frequency

A = Displacement

If *V* and *f* are measured, either acceleration or amplitude may be obtained by solving the formula. Particle velocity is considered to be the best descriptor of damage and the standards of damage are based on particle velocity. Vibration seismographs, therefore, measure particle velocity.

FACTORS AFFECTING VIBRATION

When a charge is fired, the vibration level depends on two principal factors, distance and charge size. It is obvious that being far away from a blast is safer than to be near it. Also a large explosive charge is more dangerous than a small charge.

Propagation Law

The U.S. Bureau of Mines (USBM) Bulletin, 656 (Nicholas, Johnson, and Duvall, 1971), developed a mathematical model called propagation law which relates Peak Particle velocity, charge weight, and distance. These are related as:

$$V = H(D/w^a)^b$$

V = Calculated particle velocity (in/sec.)

w = Maximum charge per delay (lbs.)

D = Distance from shot to sensor.

H = Particle velocity intercept.

a = Charge weight exponent.

b = slope factor exponent.

The USBM empirically determined values for H, a, and b for each of the three components of motion longitudinal, vertical, and transverse and reported the following equation:

$V = 100 (d/w^{0.5})^{-1.6}$

A similar equation is given in the DuPont Blaster's Handbook, 1977.

$V = 160 (d/w^{0.5})^{-1.6}$

Charge weight and distance are the principal factors that affect vibrations and are subject to control. The values of "a", "b" and "H" are dependent on rock type, rock density, rock bedding, slope of beds, thickness of over burden, nature of terrain, blasthole conditions, presence or absence of water. They also affect the transmission of vibrations, but are beyond control. Variations from area to area will apply. The values of a = 0.5 and b = -1.6 are generally accepted as workable first approximations until applicable data indicate a change. The value of H, however, is highly variable and is influenced by varying factors.

Scaled Distance

The corner stone of propagation law developed by USBM is $d/\sqrt{w}$ and it has been designated as scaled distance. It provides a practical and effective means to control vibration.

Scaled distance (SD), like ordinary distance, is safer when the value is large, and hazardous when the value is small. Large values (SD>50) indicate safe vibration conditions (low probability of damage), whereas small values (SD>25) indicates a higher probability of damage. The value (SD = 50) originally proposed by USBM, was considered safe and the seismograph measurement was not necessary. It is a conservative limit, but still for increased safety, many regulatory agencies follow a SD of 60 or greater. SD is a simple calculation if the distance and charge weight are known. The blaster can compare the value for SD with the regulatory value, and can judge the relative safety of the vibration.

DESIGN AND METHOD

Based on the current blasting practice and orientation of the quarry face, it was decided to place seismographs in a line parallel to the double row of holes at the quarry face, or bench. Twelve holes on 8 ft x 10 ft spacings were loaded with 100 pounds of explosive per hole, per delay. The holes were 30 feet deep and the face measured 28 feet high. The wind was blowing from N 33 W at 10 – 15 mph. Three seismographs were aligned parallel to the two rows of holes on a bearing of N 40 E, and another set of three seismographs were aligned on a bearing of N 30 W, perpendicular to the face. This arrangement is shown schematically in Figure 1. The peak particle velocities expected under the stated conditions were calculated from the following formula and are presented in Table I.

$$V = 160 \left(\frac{R}{\sqrt{w}} \right)^{-1.6}$$

After the blast occurred, the peak particle velocities were recorded on each of the six seismograph, three aligned parallel to the quarry face, and three aligned perpendicular to the face. The data is presented in table II and table III respectively.

CONCLUSIONS

Because of the varying ground conditions that cannot be anticipated accurately, the equations developed by USBM and Dupont for predicting peak particle velocity should be used with caution as they do not yield exact values. These values serve merely as guides, and give approximated figure that can be too conservative.

Development of a site specific scaled distance is a more reliable method. The average value obtained of a modified scaled distance serves as a basis for calculating safe charges and safe distances. The value of the modified scaled distance should be checked from time to time, as the site develops and goes to deeper levels, or as the sites advance towards properties.

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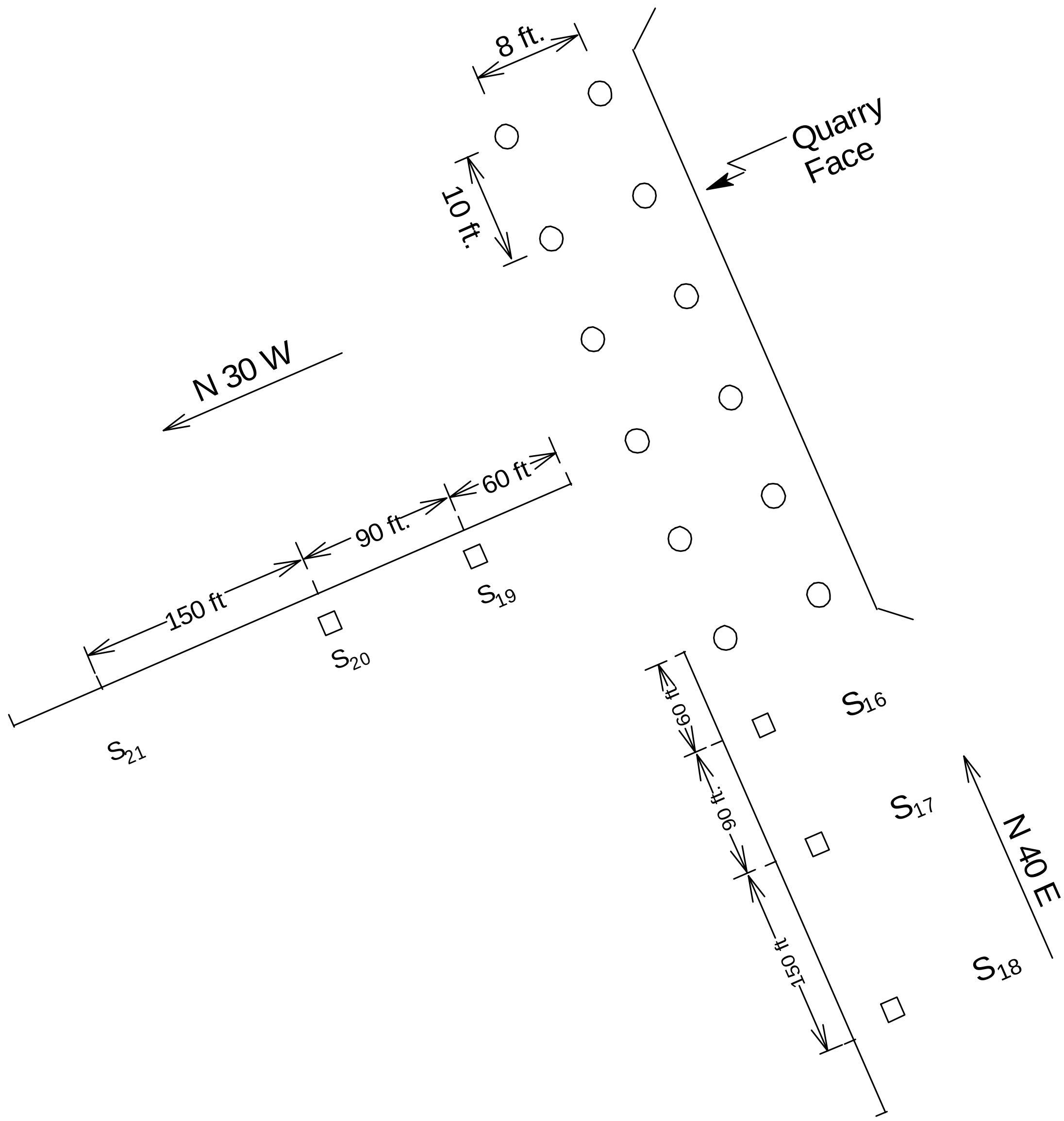

Fig. 1 Schematic Diagram Showing the Location of Seismographs in Relation to Quarry Face.

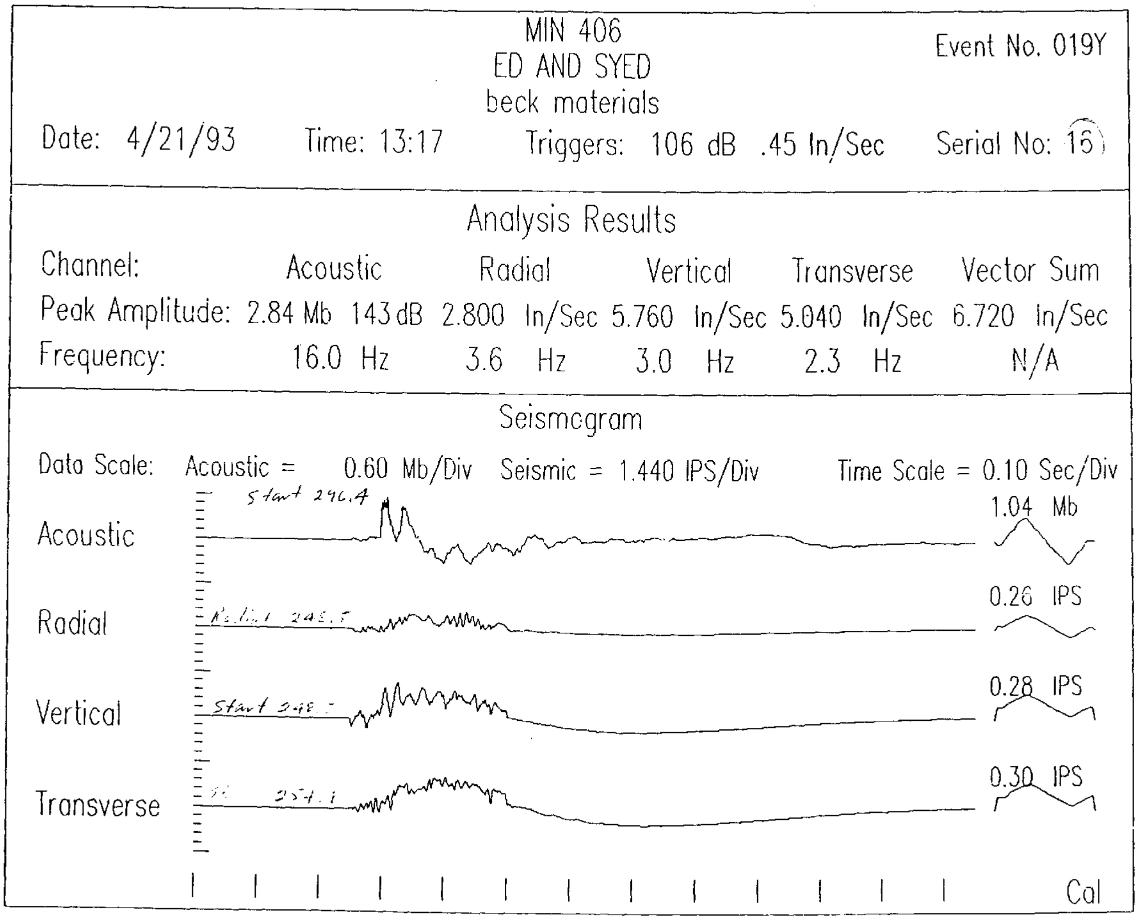

Fig. 2 A Sample Print-out of a Seismograph Reading.

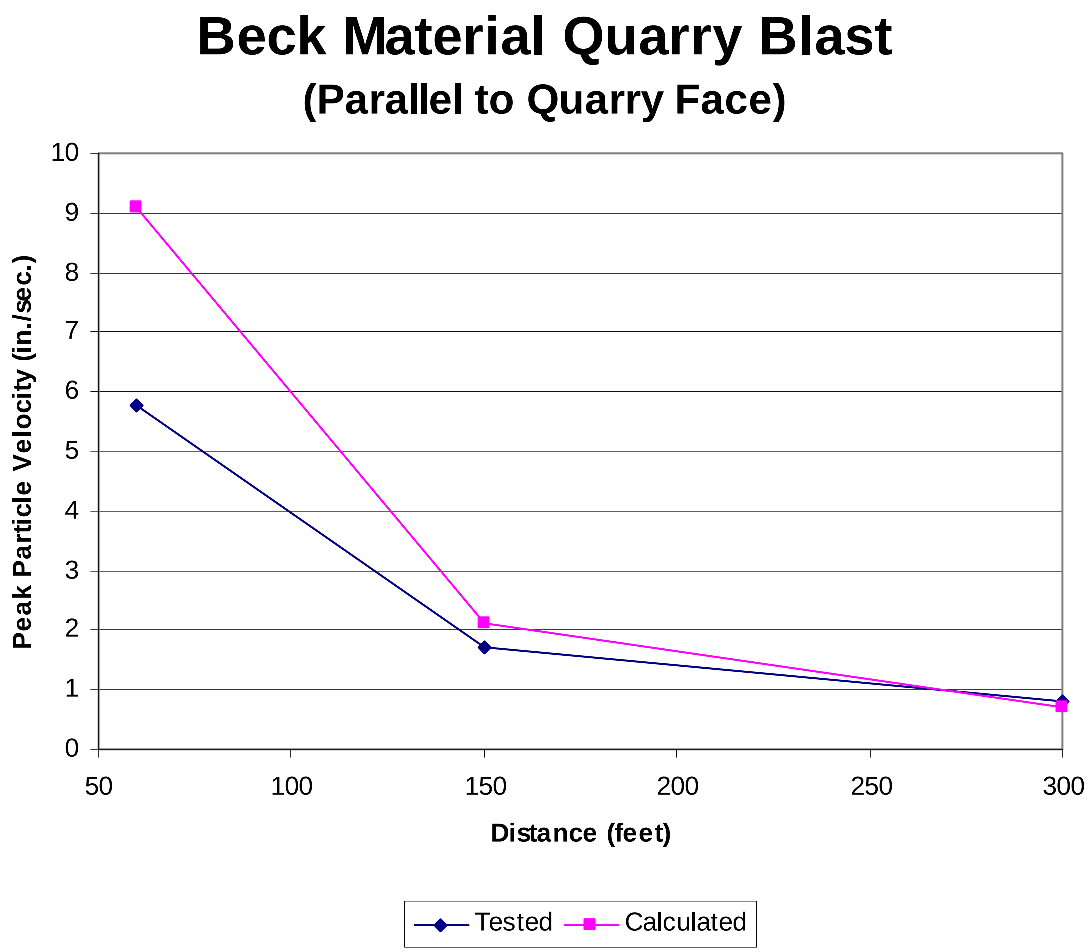

Fig. 3 Comparison of Peak Particle Velocities for Seismographs Located Parallel to Quarry Face.

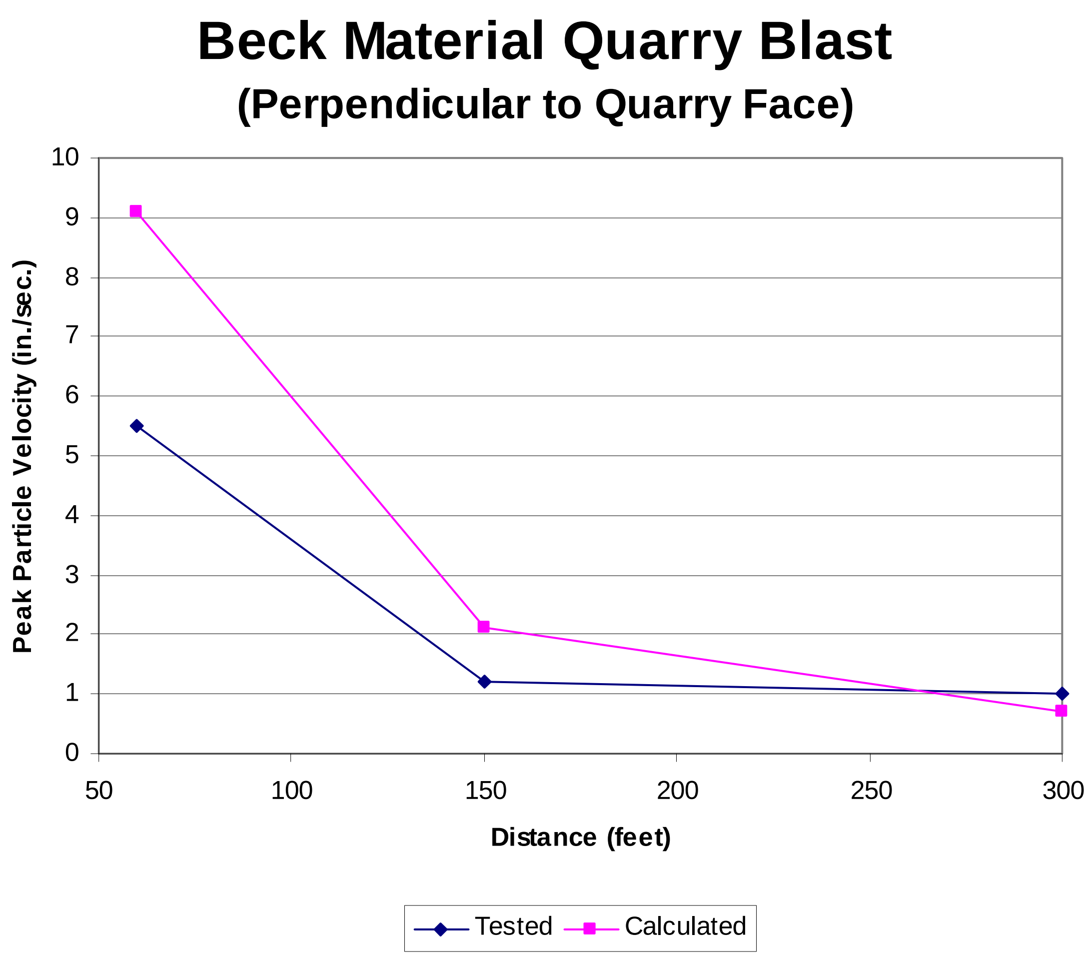

Fig. 4 Comparison of Peak Particle Velocities for Seismographs Located Perpendicular to Quarry face.

Table I: Calculated Peak Particle Velocities at Varying Distance

Distance from Blast (ft)	Peak Particle velocity (in./sec.)
60	9.10
150	2.10
300	0.69

Table II: Data showing Peak Particle Velocities for Seismographs Located Parallel to Quarry Face.

Seismograph No.	Distance (ft.)	PPV (Recorded) (in/sec.)	PPV (Calculated) (in/sec.)
16	60	5.76	9.10
17	150	1.72	2.10
18	300	0.81	0.69

Table III: Data Showing the Peak Particle Velocities for Seismographs Located Perpendicular to Quarry Face.

Seismograph No.	Distance (ft.)	PPV (Recorded) (in/sec.)	PPV (Calculated) (in/sec.)
19	60	5.52	9.10
20	150	1.20	2.10
21	300	1.02	0.69