On the Importance of Seismic Wave Velocity in Rock Blasting

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ABSTRACT

The peak particle velocity and associated frequency of ground motion are considered important parameters for arriving at realistic safety criteria against blast vibrations. These parameters are controlled significantly by the seismic wave velocity through the transmitting medium, in addition to the various blast design parameters. The particle velocity depends on the powder factor, which is found to be dependent on seismic wave velocity. The present paper highlights the importance and utility of seismic wave velocity for safe and effective blasting operations.

***Key words** : Ground vibration, Particle velocity, Predominant frequency, Attenuation constants, Compressional wave velocity, Powder factor, Blastability*

INTRODUCTION

Explosives are used extensively in civil engineering projects for excavation of rock mass. The effectiveness of rock blasting using explosives depends on three important parameters; viz., properties of the rock mass, type and properties of explosive used, and the blast design parameters. The results of blasting are influenced more by the rock properties than those by the characteristics of the explosive and the blast design parameters. The rock properties of interest for this purpose are the modulus of elasticity, density, compressive and tensile strengths, wave propagation velocities, etc. A very small part of the total explosive energy is exhibited in the form of seismic waves having enough potential to cause structural damage.

Body waves and surface waves are the two main types of seismic waves generated from blasting. The surface waves are more prominent in the ground vibrations observed from shallow explosions. The basic characteristics of the wave motion which are important from the point of view of structural safety are the particle velocity, frequency and duration of the ground motion. These parameters are affected significantly by the properties of the transmitting medium and the various blast design parameters. The propagation velocity of compressional wave is one of the most important rock properties, which may be useful in selecting suitable explosives, effective method for excavation, deciding the safe vibration level for a structure, designing a blast and utilizing the explosive energy in an efficient way. The present paper describes the importance of compressional wave velocity in rock blasting and analyses the important characteristics of blast-induced ground vibrations.

ROCK PROPERTIES AFFECTING THE WAVE VELOCITIES

When a rock mass is subjected to the transient dynamic loading due to blasting, the effect of the force is not transmitted throughout the rock mass instantaneously. The stress wave radiating from the dynamic source propagates through the medium with a finite velocity, called the propagation velocity of the medium. The propagation velocities of compressional and shear waves are related to the modulus of elasticity by the following relations:

$$V_c = \sqrt{\frac{E_d(1-\nu)}{2\rho(1+\nu)(1-2\nu)}} \qquad (1)$$

$$V_s = \sqrt{\frac{E_d}{2\rho(1+2\nu)}} \qquad (2)$$

In these expressions, ρ is the density, ν is the Poison's ratio and E_d is the dynamic Young's modulus ·f the rock. Because ρ and ν do not vary much for different types of rock, the dynamic Young's modulus is related closely to the wave velocity. The dynamic modulus is, in general, higher than the corresponding static modulus by a factor of 1 to 3 (Stacey et al., 1987). This factor increases with increase in the degree of joints and fractures in the in-situ rock mass.

The compressional wave velocity is also found to increase with saturation of the transmitting medium, with a consequent increase in the value of the dynamic elastic modulus. This is because when the material is located below water table, the small intervening spaces of the rock mass are filled with water providing continuous travel path. However, the presence of pore-water causes decrease in static strengths of many rocks (Farmer, 1968). The strength of saturated specimen is only about one-half of that for the dry specimen (Colback and Wiid, 1965). With the increase in ground water level, the peak particle velocity of blast vibration observed at a point also increases (Beattie, 1992).

COMPRESSIONAL WAVE VELOCITY AND ROCK BLASTING

The compressional wave (P- wave) velocity is one of the most useful parameters in evaluating the performance of rock blasting. At the initial stage of a project, P- wave velocity data are useful in selecting a suitable method for removing the earth materials. Fig. 1 shows the rippability with variation in seismic wave velocity. Blasting is suitable for earth materials with P- wave velocity greater than 2100 m/s (Verma, 1988).

The fracture-index (ratio between the compressive strength and the tensile strength) controls the blastability; i.e, the resistance of a rock to blasting. This ratio varies between 10 and 100. Rocks with higher fracture-index are better to blast. The compressive and tensile strengths of rock are influenced by the wave propagation velocity, thereby influencing the blastability of the rock.

The propagation velocity also governs the selection of a suitable explosive for rock blasting. Rocks with higher propagation velocities are expected to break with high velocity explosives, whereas low velocity medium, such as overburden at mines and quarry sites, could be blasted using explosives with lower detonation velocity.

The powder factor, defined as the consumption of explosive per cubic meter of rock excavation, is one of the major factors used to assess the efficiency of a blasting operation. The powder factor is dependent on the seismic wave velocity. Under identical conditions, rocks with higher compressional wave velocity require more charge per cubic meter to break. In addition, the powder factor is also influenced by the borehole diameter for conventional production blasting and by cross sectional area for the tunnel blasting (Mancini and Cardu, 1995). During several field studies, it was observed that blasts with small diameter holes and identical powder factor produce better fragmentation.

Several investigators have correlated the powder factor with seismic wave velocity (Heinen and Dimock, 1976; Hoek and Bray, 1977; Jimeno et al., 1995). Figure 2 illustrates the variation of powder factor with seismic wave velocity as obtained by the author in different geological formations. It is observed that the powder factor increases very fast with seismic wave velocity. The main causes of large scattering in the observed data may be the large variations in geological condition and the geometry of blast design parameters. The presence of excessive fractures and joints in a rock mass reduces its seismic wave velocity, whereas this type of rock creates several difficulties during blasting operations and requires comparatively more quantity of charge per cubic meter to break.

The powder factor in turn governs the generation of ground vibration and the fly-rock. Hence, to control the vibration problems it is commonly thought to reduce the powder factor in the first instance. However, minimizing the powder factor below certain optimum value may alleviate the vibration problems as illustrated by the results in Fig. 3. From this figure it is apparent that using a powder factor between 0.3 and 0.7 kg/m^3 helps in mitigating the ground vibration effects. Andrews (1981) has concluded that if the powder factor is reduced by about 20% of the optimum value, the ground vibrations increase by a factor of 2 to 3. The increase in vibration level with decrease in powder factor may be due to higher confinement and poor distribution of explosives, causing lack of displacement of rock mass and poor fragmentation. During several field studies it was observed that use of a powder factor of more than 0.7 kg/m^3 during surface excavation gives rise to excessive fly-rock. The maximum throw of fly-rock is a function of powder factor and blasthole diameter (Jimeno et al., 1995). The choice of powder factor being first and one of the most essential parameter of blast design, its prior knowledge will help in accomplishing the job in a more efficient way.

In addition to this, various blasting techniques such as line drilling, presplitting and smooth blasting used for controlling the overbreaking of rock are largely influenced by the seismic wave velocity. The effectiveness of these techniques increases with increase in the compressional wave velocity of the rock mass.

GROUND VIBRATION CHARACTERISTICS

The ground vibrations generated from blasting may be sufficient to cause damage to the nearby structures. It is, thus, necessary to conduct a blasting operation in such a way that the ground vibrations are maintained within acceptable safe limits. This is a two fold problem. First it is imperative to evaluate the safe vibration level which a nearby structure could withstand. Then, it is essential to develop site specific attenuation equation for predicting the ground vibration levels at different distances from known charge weights.

The structural damage produced by blast-induced ground motion is commonly correlated with the peak particle velocity (Dowding, 1992; Langefors and Kihlstrom, 1968; New, 1990; Siskind et al., 1980; Gupta et al., 1991; Marwadi et al., 1993; etc.) and safety criteria are suggested accordingly. However, the mechanism of damage can not be explained only in terms of the peak particle velocity. For example, a structure may be damaged due to differential motion of its foundation .

Use of peak particle velocity criteria without much regards to the structural and the predominant ground frequencies is approximate at best and could many times be misleading. Blast-induced vibrations in the overburden and in the structures supported on the overburden are frequency dependent. The predominant frequencies may vary from 5 - 10 Hz for soil to 40 - 90 Hz for rock sites (Liu et al., 1974). It is apparent that the materials having lower seismic wave velocities also have low predominant frequencies and vice-versa. Therefore, different threshold values for damage are defined for different wave velocities in the foundation rock (Langefors and Kihlstrom, 1968; IS-6922, 1973; Esteves, 1978). The effect of seismic wave velocity of the medium in controlling the frequency content of blast vibration is illustrated by the results in Fig. 4. In this figure, the time-history records and their corresponding Fourier spectra for two sites with similar distances and identical charges are presented. One site is located on thick overburden and the other site is directly on hard rock. The frequency spectrum observed on rock is dominated by high frequencies, whereas the high frequency components are filtered out and low frequencies are predominant on the overburden. In addition to seismic wave velocity of the transmitting media, the predominant frequency of ground motion at a point is also dependent on charge size of the blast and distance of observation from the blast.

The importance of prior knowledge about the level of ground vibration which will be experienced at a site from the detonation of a known charge weight per delay at different distances need not be over-emphasized. The ground vibrations generated from a blasting operation attenuates with distance. The attenuation characteristics of ground motion depends on several parameters such as distance, charge weight and characteristic properties of the transmitting media. The following form of attenuation relation is commonly used for blast vibration prediction :

$$V = K\left(\frac{R}{\sqrt{Q}}\right)^{-n} \qquad (3)$$

Here, V is the resultant peak particle velocity (mm/s), R is the distance (m) between the observation and blast points and Q is the quantity (kg) of explosive charge used per delay. K and n are site specific constants, which are evaluated by regression analysis of observed data. The attenuation constants obtained for different sets of data with different seismic wave velocities are given in the Table 1.

Table 1 - Influence of seismic wave velocity on attenuation constants, K and n

S.No.	Type of Rock	Seismic Wave Velocity (m/s)	Values of Constants	
			K	n
1.	Basalt	5490	160	1.01
2.	Basalt	4000	295	1.06
3.	Sandstone	4400	245	1.31
4.	Quartzite	3500	506	1.52

From the above Table it is apparent that the site specific attenuation constants, K and n are also dependent on seismic wave velocity of the transmitting medium.

CONCLUSIONS

The compressional wave velocity is an important parameter controlling the elastic properties of rock. The compressional wave velocity plays significant role in controlling the performance of a blast and is useful in selecting suitable explosives for blasting operation. The rocks with higher P- wave velocities correspond to fine grained high density rocks and are expected to break with high velocity explosives. The powder factor is also closely related to the rock properties. Use of very low or very high powder factors alleviates the unwanted effects of blasting, such as ground vibrations and flyrock. The frequency contents of blast induced ground vibration is influenced by the seismic wave velocities of the transmitting medium. The knowledge of seismic velocity also helps in deciding the safe vibration level for a structure, designing a blast and utilizing the explosive energy in most efficient way.

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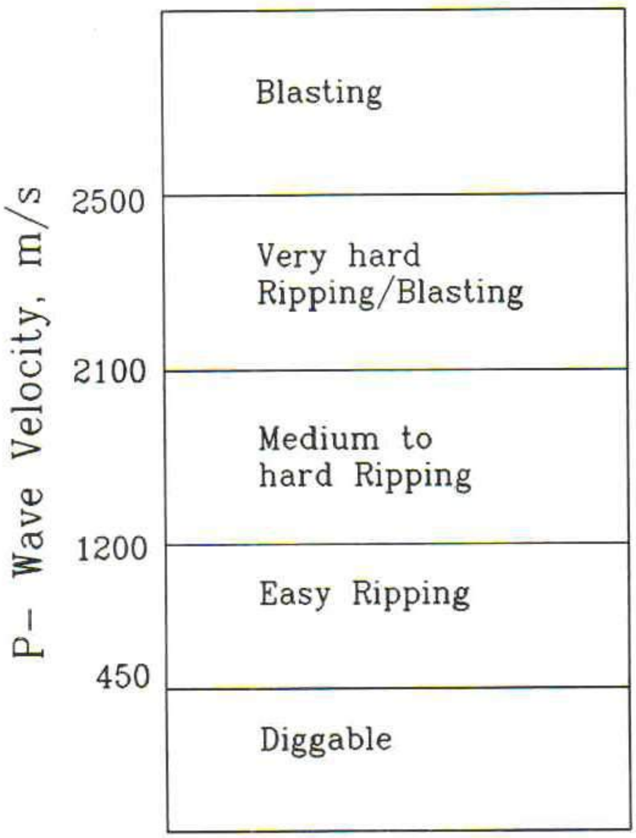

Fig. 1 : The methods suitable for removing earth materials with different seismic wave velocities

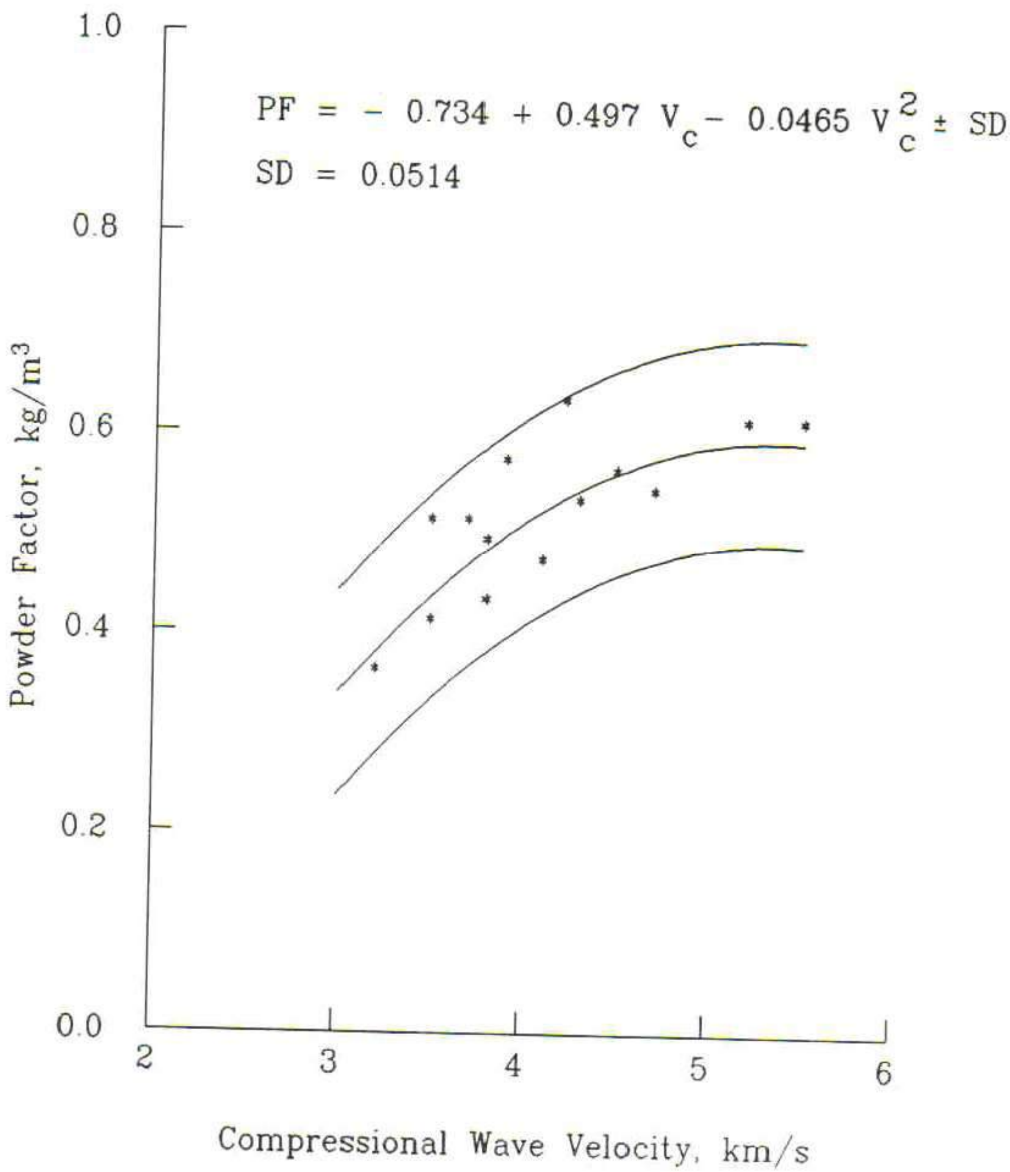

Fig. 2 : Variation of powder factor as a function of compressional wave velocity

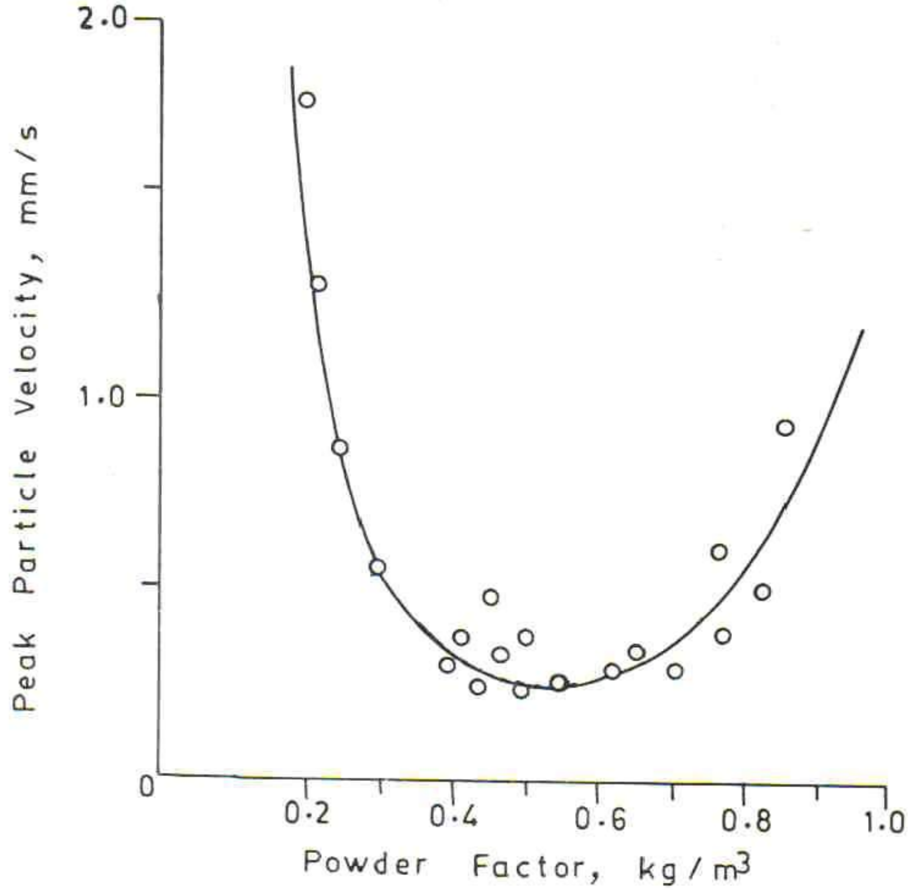

Fig. 3 : Dependence of ground vibration on powder factor

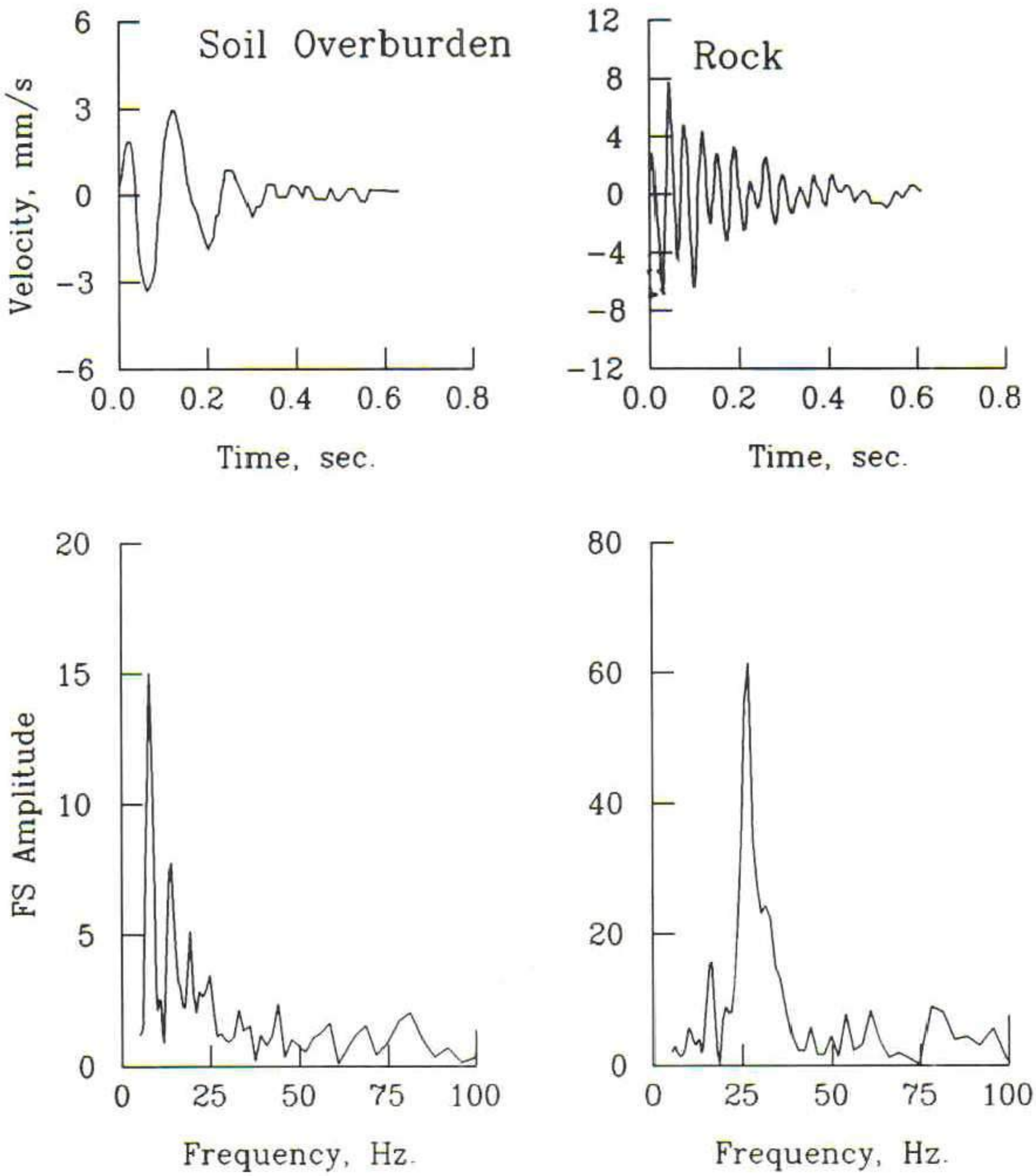

Fig. 4 : Typical blast vibration records on soil overburden and on rock with their corresponding Fourier spectra