

Impedance Matching Algorithm for Selection of Suitable Explosives for Any Rock Mass—A Case Study

Ajay Kumar Jha

BioID GmbH, Nürnberg 90489, Germany

Abstract: Proper selection of the explosive is an important part of blast design. The judicious selection of explosives is governed by economic considerations and site/field conditions. The mine management desires to select an explosive that will give the lowest cost per unit of rock broken, while assuring that fragmentation, fragment size distribution, muck pile profile, muck pile diggability, displacement of the rock, onset of movement, face movement, burden relief rate, ground vibration and noise remains within control limits. Factors which influence the selection of an explosive include explosive cost, charge diameter, cost of drilling, fragmentation difficulties and fragment size requirement with loose muck pile condition, water conditions, atmospheric temperature, propagating ground, storage considerations, sensitivity considerations, explosive atmospheres and nearness of communities from mine. All these concerns can be handled effectively by using the impedance matching technology where explosive impedance is matched with rock impedance for optimal blast performance with due concern to productivity, economics and environment. This paper discusses a case study in limestone mines where rock impedance was determined by carrying out surface refraction test and a patented algorithm was used to estimate the explosives' properties i.e. VOD (velocity of detonation) and density of explosives required.

Key words: Explosive selection, impedance matching, rock impedance, explosive impedance.

1. Introduction

Rock mass properties influence the blast design and knowledge of these properties is very important for blast design [1]. Rock breakage by explosives involves the action of an explosive and the response of the surrounding rock mass within the realms of energy, time and mass [1]. Proper selection of the explosive is an important part of blast design needed to assure a successful blasting program [2]. The rock properties are uncontrollable variables comprising of many parameters i.e. geology, strength, structural discontinuities, state of weathering of rock mass, etc. It is very difficult to quantify a blast as good or bad on any one single parameter but there are numbers of parameters which characterise the blast results to define a good blast or a bad blast. A good blast may be defined which yields the following outputs [3].

- Optimum fragmentation;
- Optimal muck pile displacement;
- Optimal muck pile profile with ease of digging;
- Lower level of ground vibration generation;
- Lower level of air overpressure generation;
- Non ejection of fly rock;
- Practically no back or over break;
- No misfires, etc.

In order to achieve the above objectives, selection of suitable explosives is very pertinent [4]. The strength of the rock is an important criterion for selecting the explosives for achieving desired/optimum fragmentation in consonance with the loading equipment in use. In order to meet the optimum fragmentation, the explosives characteristic plays a pivotal role with due regard to environmental nuisances i.e. vibration, fly rock and air over pressure [5]. The determination of these parameters by direct or laboratory methods is very costly, time consuming and difficult, as the samples tested do not usually include discontinuities and the lithological changes of the rock mass from

Corresponding author: Ajay Kumar Jha, Ph.D., president, research fields: AI, numerical modelling, simulation, advanced data analytics in mining.

where they were taken.

2. Materials and Methods

The study was carried out in one of the mines of UltraTech Cement Limited supplying limestone to 4.0 MTPA plant. The plant manufactures clinker and cement (OPC-43 (Ordinary Portland Cement-43), OPC-53 and PPC (Portland Pozzolana Cement) grades). The mine has ten operating benches with primarily three types of lithology as mentioned below.

- Limestone;
- Siliceous Limestone;
- Dolomitic Limestone.

The mine has a unique lithology where magnesia is between 3.5%-5% and silica varies between 8%-10%, making the formation very hard and abrasive.

The latitudes and longitudes of mining lease boundary pillars are shown in Table 1.

The three locations of the mine on the basis of direction of advancement of mine and mine lease hold area are enumerated below.

- Zero North side;
- Dhola West side;
- Hill 2 East side.

2.1 Methodology

The methodology implemented for layer wise and bench wise selection of explosives is enumerated below.

- Use of SRT (surface refraction geophysical test) technique to characterize the rock mass [6, 7];
- Use of patented impedance matching algorithm to determine the layer wise VOD (velocity of detonation) and density of explosives.

2.1.1 SRT Based Geo Physical Investigation

Twenty-four (24) channel engineering seismographs with HGS geophone were mounted at three locations (i.e. Zero North side, Dhola west side, Hill 2 east side) to generate three traverses/profiles capturing all rock mass types prevailing in the mine. The spacing of geophone was kept as 5 m. Explosive

was used to generate the stress waves. For each traverse or line seven shots were fired using 32 mm permitted small diameter explosives. Using 7 instantaneous (Copper Electrical Detonator/Aluminium Electrical Detonator/Zero delay) for each traverse line, the refraction data were generated. The methodology of firing is enumerated below.

- Two shots fired from 200 m from recording device;
- Two shots fired from 140 m from recording device;
- Two shots fired from around 90 m from recording device;
- One centre fired from 20 m from recording device.

Depending on the direction of mine movement and mine leasehold area, three lines were chosen for SRT survey.

- Zero North side;
- Dhola West side;
- Hill 2 East side.

The photograph of Zero North side is shown in Fig. 1.

The photograph of site for Dhola west side is shown in Fig. 2.

The photograph of site for Hill 2 east side is shown in Fig. 3.

2.1.2 Methodology for Explosive Selection for Given Rock Mass

The acoustic impedance (Z) for any material is defined as:

$$Z = \rho \times V_p$$

where, Z = acoustic impedance,

ρ = density of material,

V_p = sonic velocity of material.

The rock impedance (Z_1) may be approximated by product of rock propagation velocity and rock density whereas explosives impedance (Z_2) may be approximated by the product of detonation velocity of explosives and its density. In order to maximise the transfer of explosives energy to the rock mass, the

impedance of the explosives should be close to that of the rock mass. When the impedance of the explosives is close to that of the rock mass, explosives energy is better transmitted to the target rock. Under such condition the maximum pressure transmitted to the rock is nearly equivalent to the detonation pressure

generated inside the pressurised borehole. When the impedance of the rock is less than the impedance of the explosives, then the major part of the explosives energy transmitted to rock mass will be reflected back as tensile wave and will be responsible for breakage of the rock [8].

Table 1 Latitudes and longitudes of mining lease boundary.

Pillar	Latitude	Longitude
A	27°40'26.34"	76°06'27.61"
B	27°41'40.74"	76°08'00.89"
C	27°41'02.07"	76°08'40.21"
D	27°39'47.68"	76°07'06.95"



Fig. 1 Photograph of the Zero North Side.



Fig. 2 Photograph of the Dhola West side.



Fig. 3 Photograph of the Hill 2 East side.

The minimum/limiting condition can be expressed as:

$$Z_1 = Z_2$$

If the wave encounters diverse material in its path, with different impedances and in correspondence with separating surfaces that can be in contact or separated by air or water, the transmission of the strain wave will be governed by the ratios of the acoustic impedances of the different types of rock, where part of the wave energy is transferred in the material and at the same time some is reflected back, as a function of the ratio.

When the impedances of the mediums are equal ($\rho_{r2} \times VC_2 = \rho_{r1} \times VC_1$), a large part of the energy will be transmitted and the rest will be reflected, arriving at the limit, when $\rho_{r2} \times VC_2 \ll \rho_{r1} \times VC_1$ as for example, between rock and air, where almost all of the energy will be reflected back as a tensile wave which could be especially important in the breakage of the rock.

where,

VC = Propagation velocity of the waves through rock mass (m/s);

ρ_r = Rock density (g/cm^3).

The above mentioned relationship is valid for the wave pressures as well as for the transmitted energies.

If the ratio of characteristic impedances for the two materials is:

$$n'_z = \frac{\rho_{r1} \times VC_1}{\rho_{r2} \times VC_2}$$

The following relationships will be obtained.

$$PT = 2 \frac{PI}{(1 + n'_z)}$$

$$PR = PI \frac{(1 - n'_z)}{(1 + n'_z)}$$

where,

PI = Pressure of the incident wave,

PT = Pressure of the transmitted wave,

PR = Pressure of the reflected wave.

3. Results and Discussion

3.1 Analysis Obtained from SRT Study

Multiple software (Viz SeisOptPicker, SeisOpt@2D, Optim's, MT134, Minitab, SPSS, DADisp, MATLAB) was used to investigate the rock layers, layer wise VOD profile and detonation pressure. The output showing rock impedance, density profile, seismic profile spectrum, VOD profile for Zero North side is shown in Figs. 4-7 respectively.

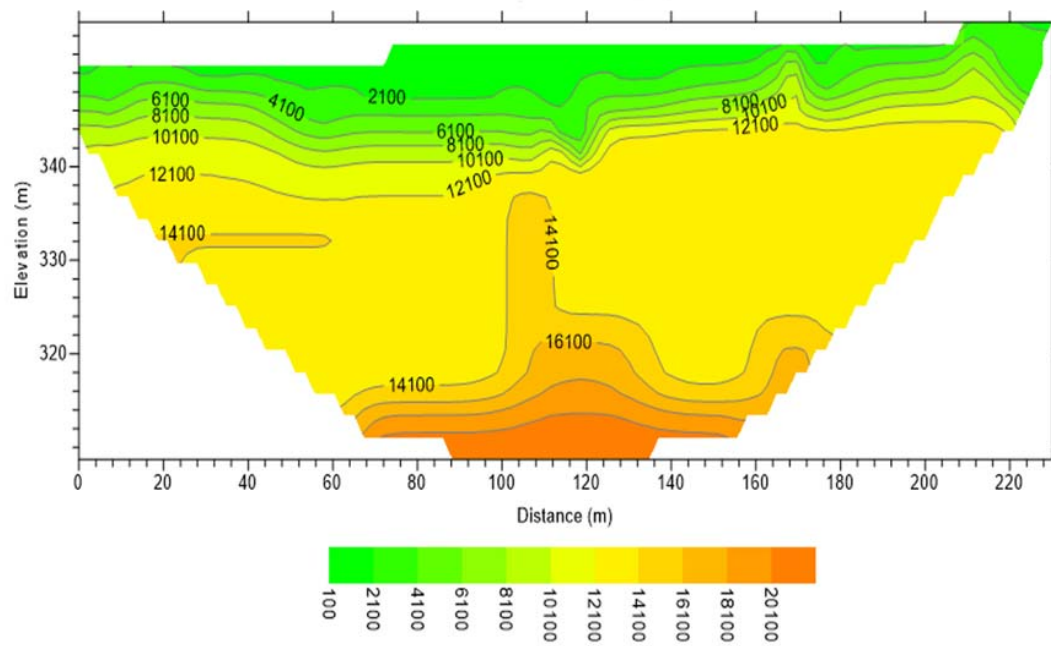


Fig. 4 Rock impedance at Zero North side.

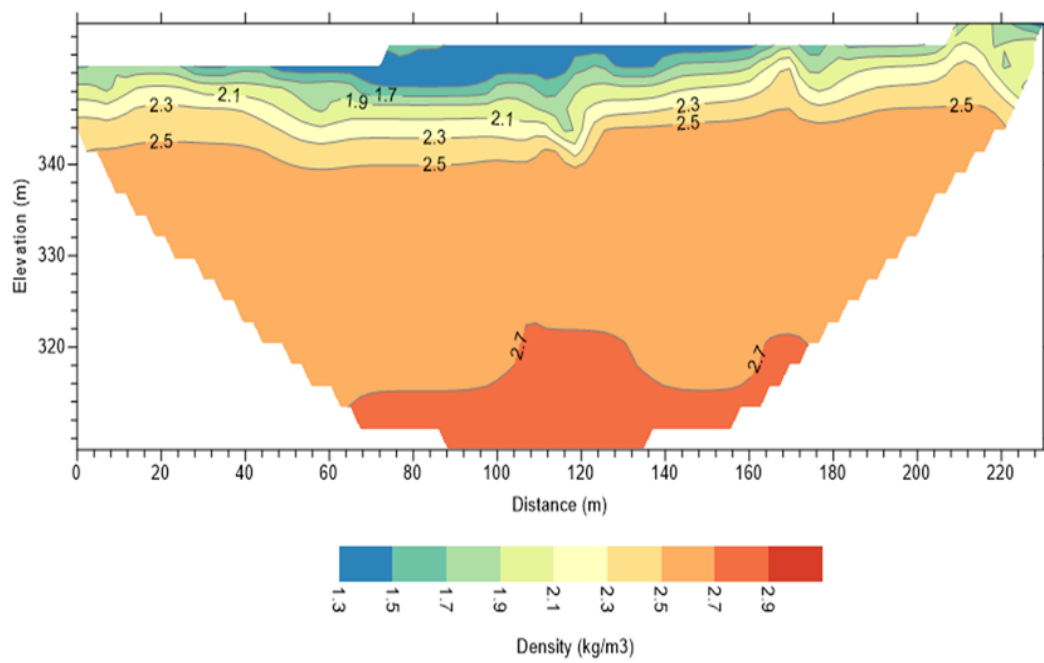


Fig. 5 Density profile at Zero North side.

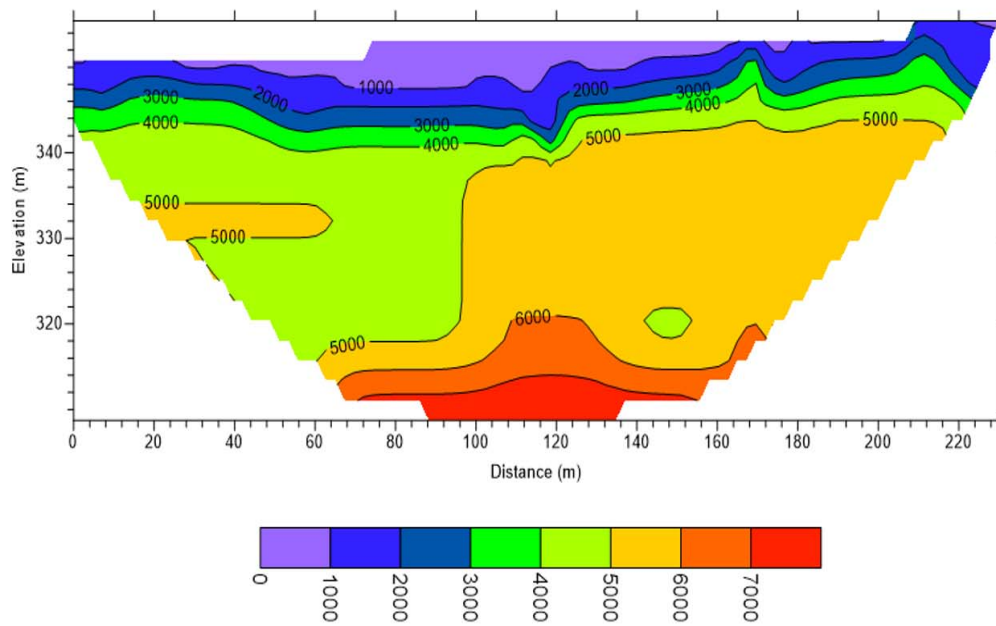


Fig. 6 Seismic profile spectrum at Zero North side.

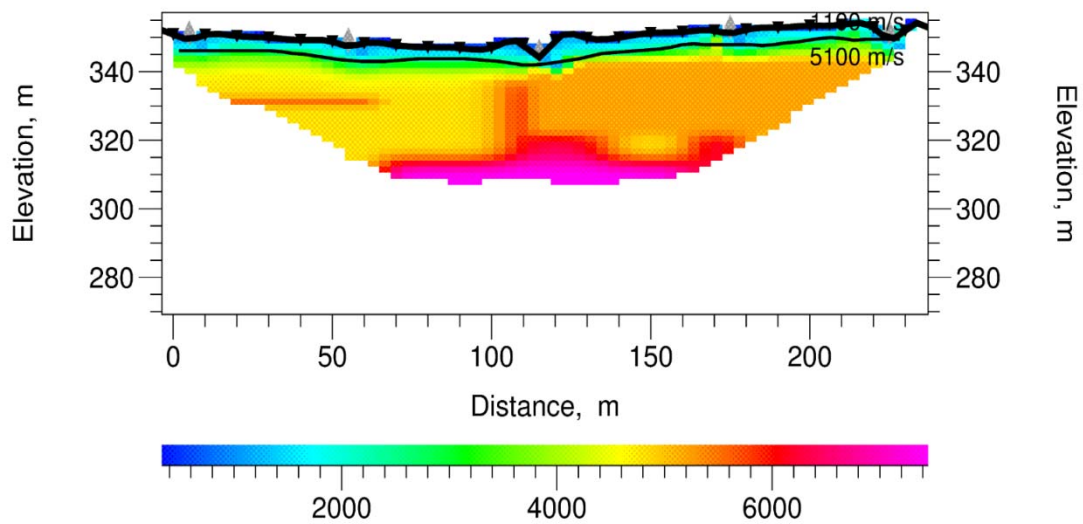


Fig. 7 Layer wise VOD Profile at Zero North side.

The rock impedance, density profile, seismic profile spectrum, VOD profile for Dhola west side, are shown in Figs. 8-11 respectively.

The rock impedance, density profile, seismic profile spectrum, VOD profile for Hill 2 east side, are shown in Figs. 12-15 respectively.

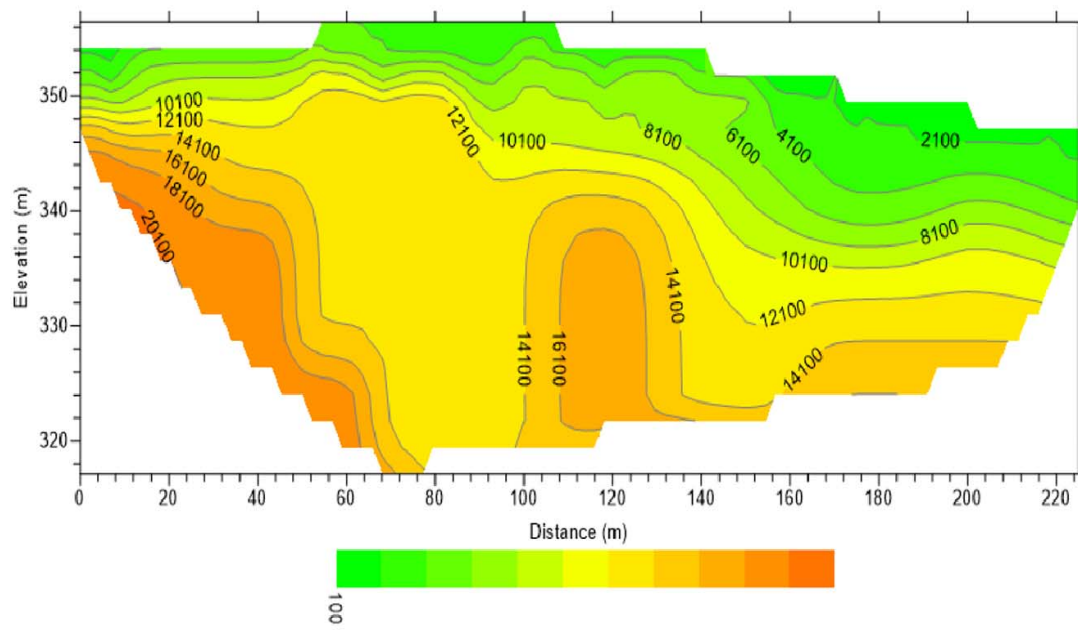


Fig. 8 Rock impedance of the Dhola west side.

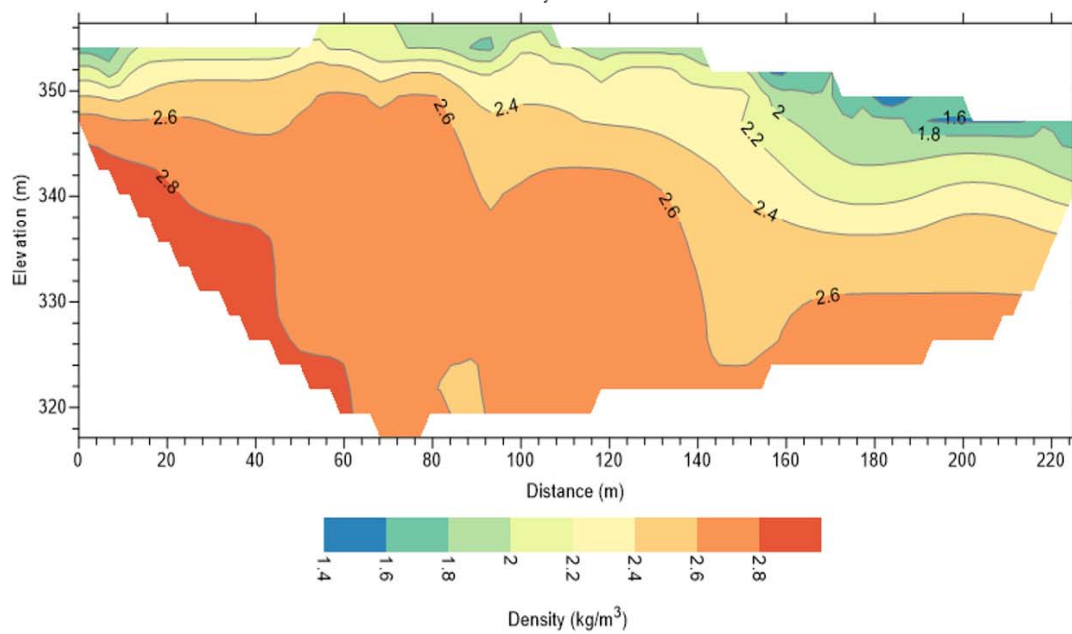


Fig. 9 Density profile at Dhola west side.

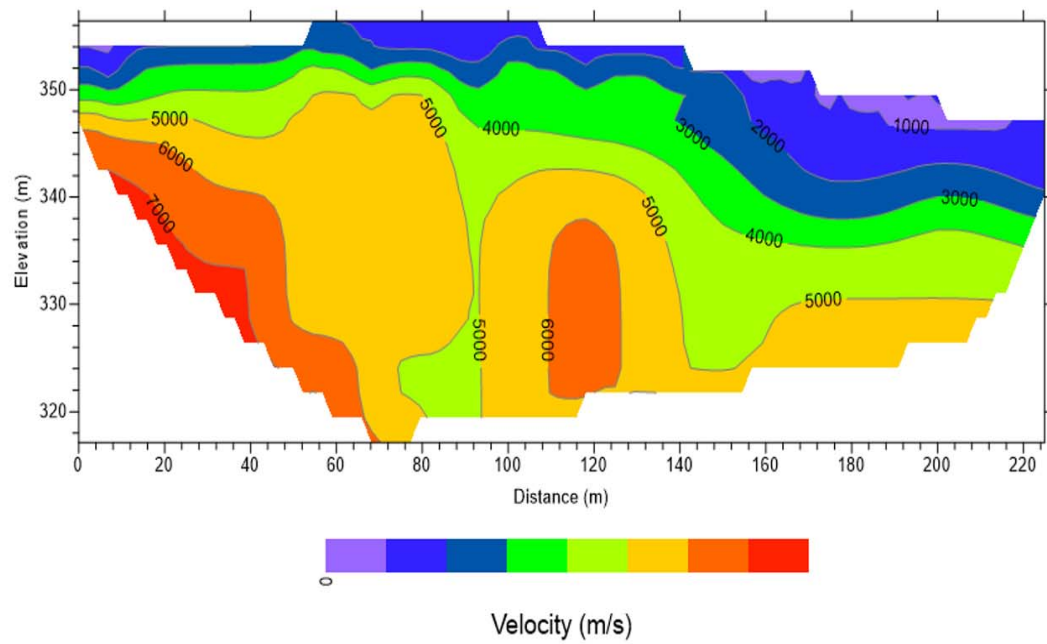


Fig. 10 Seismic profile spectrum at Dhola west side.

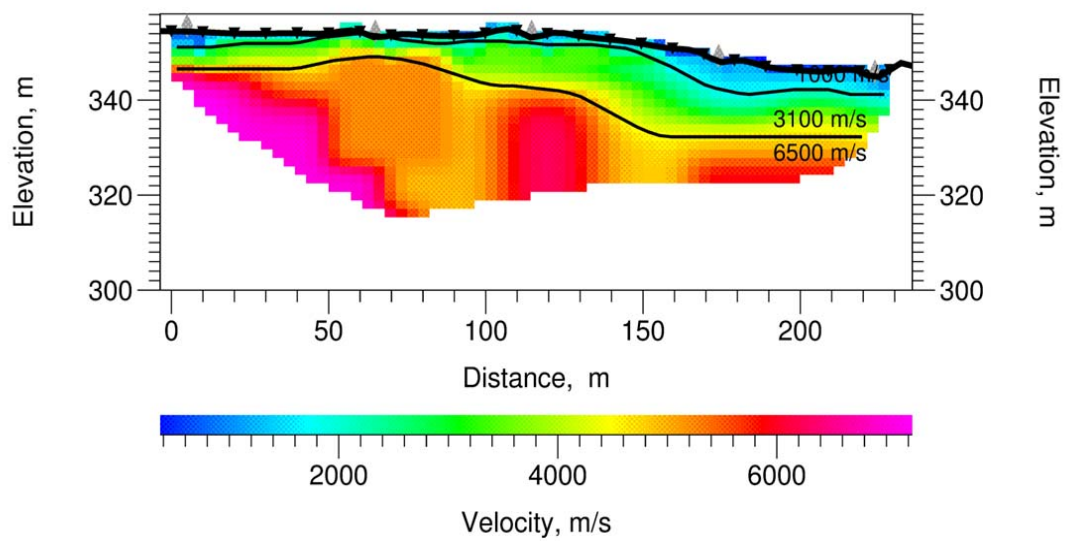


Fig. 11 VOD profile at Dhola west side.

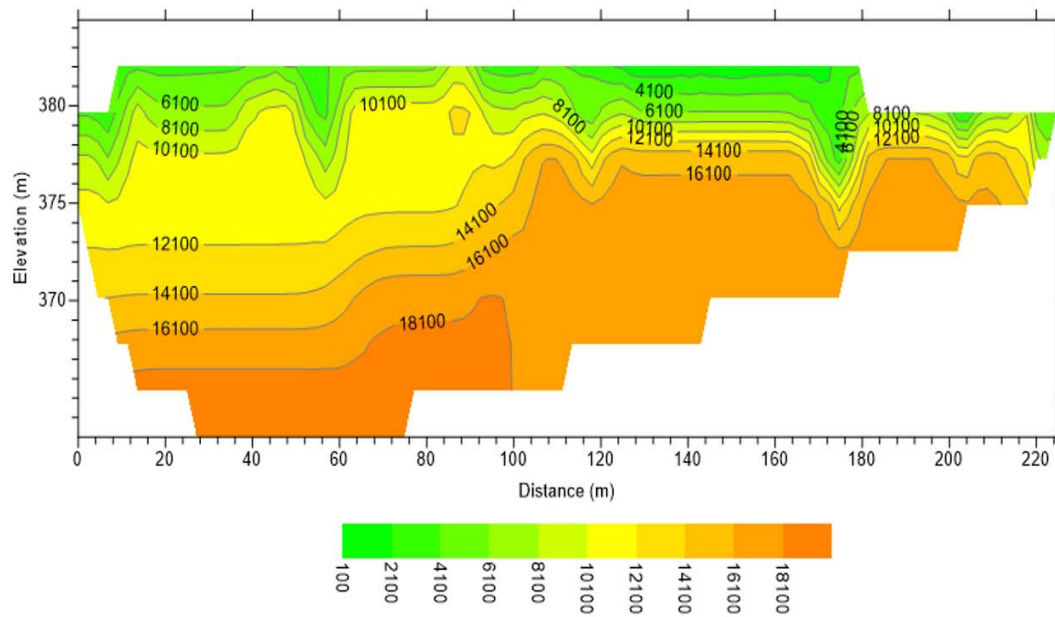


Fig. 12 Rock impedance of the Hill 2 east side.

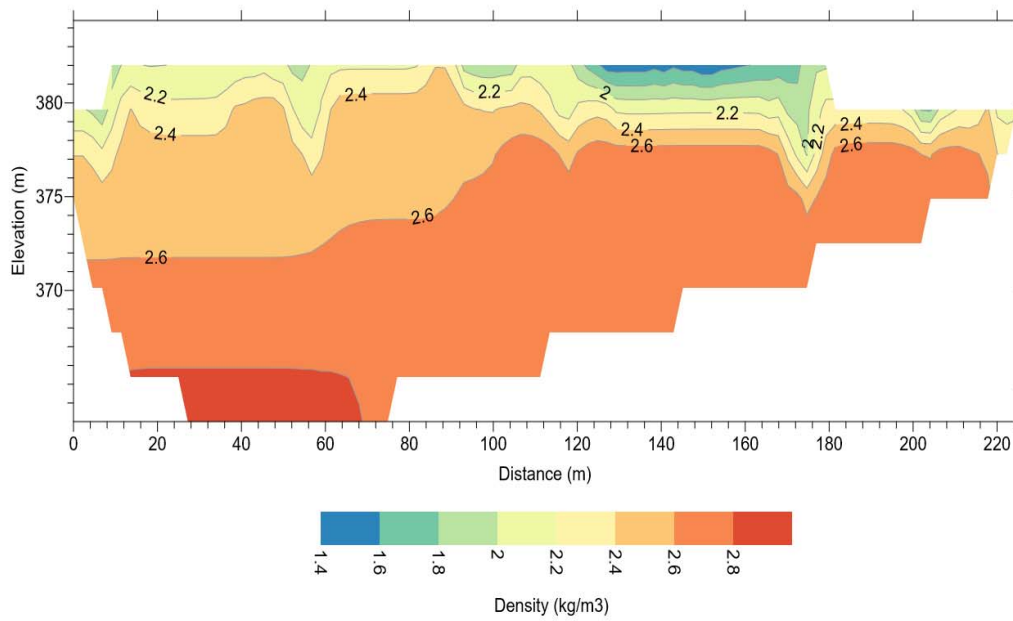


Fig. 13 Density profile at Hill 2 east side.

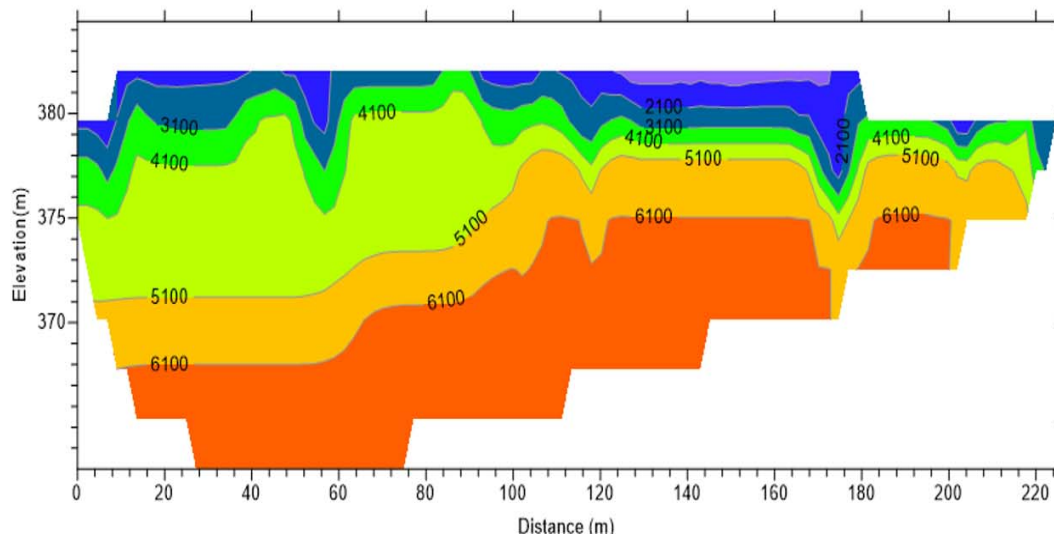


Fig. 14 Seismic profile spectrum at Hill 2 east side.

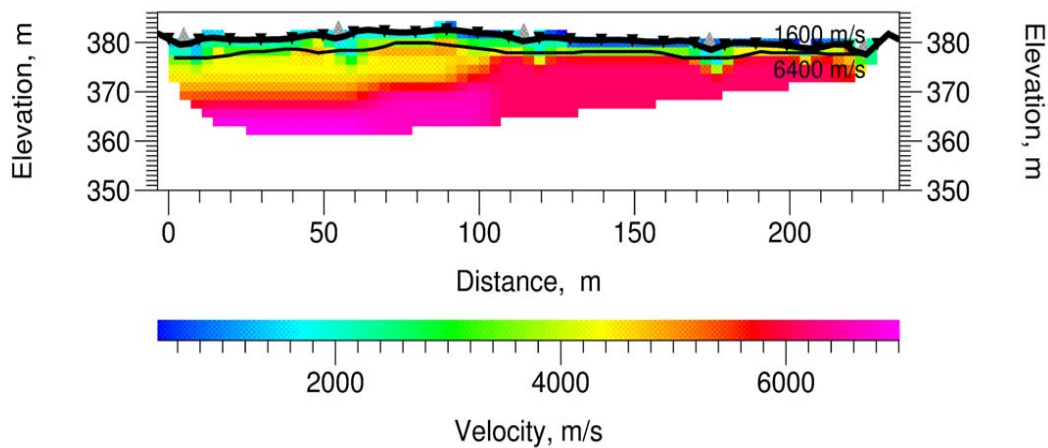


Fig. 15 VOD profile at Hill 2 east side.

3.2 Analysis Obtained from Impedance Matching Algorithm

Based on the impedance matching software program, layer wise VOD profiling as well as detonation pressure of the required explosive product

was estimated as discussed in Table 2.

Considering the geological formation and *in-situ* rock mass, bench wise VOD profiling as well as detonation pressure of the required explosive product was estimated and is discussed in Table 3.

Table 2 Layer wise VOD profiling.

Name of mine side	Required VOD (m/s)	Required detonation pressure (GPa)
Zero North Side	3,000-5,100	2.7-8.1
Dhola West Side	3,000-6,500	2.7-13.20
Hill 2 Side	3,000-6,400	2.7-12.8

Table 3 Bench wise VOD profiling.

Name of mine side	Required VOD (m/s)	Required detonation pressure (GPa)
Limestone	6,500 ± 100	13.2 ± 0.01
Siliceous limestone	6,100 ± 100	12.4 ± 0.01
Dolomitic limestone	5,900 ± 100	11.90 ± 0.01

4. Conclusions

It may be concluded that impedance matching algorithm can be used for selecting the right type of explosive in any mine. Under such scenario, bench wise or layer wise explosives selection would be techno-commercially possible. The key explosives characteristics in terms of selection of explosives i.e. VOD, density, detonation pressure may be estimated using impedance matching to achieve optimal blast performance. This methodology would also help in choosing the right explosive product also i.e. ANFO (ammonium nitrate fuel oil), heavy ANFO, non-permitted large diameter cartridge explosives, straight emulsion or doped emulsion. The selection of explosive with site specific characteristics would improve blast performance, mine productivity and economics with reduced environmental nuisances in terms of fly rock, air overpressure, ground vibration and noise.

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