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Ground characterization using shear wave velocity for assessment of rippability

This present paper details the use of shear wave velocity profiles to characterize the sub-surface ground and assess its rippability. Seismic profiling tests were conducted using multi-channel analysis of surface waves, at two different locations in a limestone mine. At each location, the tests were conducted with minimum two perpendicular scan lines, with 24 geophones in each scan line. Manual hammering was used as a source of generation of waves. The ability of seismic profiling using multi-channel analysis of surface wave for ground characterization and rippability assessment of strata has been successfully elaborated in this paper.

Introduction

Geotechnical investigations provide important input in many mining and civil areas. Geophysical methods are being increasingly applied to geotechnical investigations, as they can identify material properties and material boundaries, as well as variations in space and time of relatively large volume of strata. Seismic and sonic measurements are utilized by a large number of geo-science, geo-engineering and geo-resource disciplines. The phenomenon of seismic anisotropy giving lower stiffness perpendicular to layering than in parallel, has been used since nineteenth century, for investigating fractured rock at depth (Barton 2007). Features of the rock mass can be detected at many kilometers depth, due to shear wave splitting (Alt et. al. 1986).

Seismic profiling methods provide vital information related to geotechnical parameters like in-situ shear and bulk moduli from S-wave (Vs) and P-wave (Vp) velocities of near-surface materials. Multi-channel analysis of surface waves (MASW) is one such non-destructive testing (NDT) seismic method that can be used for geotechnical characterization of near-surface materials, to infer Vs variation with depth. A Vs profile is obtained from measurement of surface Rayleigh waves. Unlike other seismic methods, this method has advantages in several respects. The impact source for generation of surface waves energy can be either a sledge hammer or even a small blast with very less buried explosive charge. The surface waves respond most effectively to various types of near-surface anomalies that are common targets of geotechnical investigations. Determination of shear wave velocity (in-situ) has opened up new avenues in areas of rock characterization, rippability assessment, ore delineation, defect locations, weak zones in rock strata. Earlier, P-wave and S-wave velocities were determined using laboratory estimates, which seldom reflect the in-situ conditions. Moreover, researchers have also found that shear waves penetrate with less attenuation than compressional waves. Shear waves were also found to be less affected by noise compared to compressional-wave reflections (Dasios et. al 1999). The present paper details the application of seismic profiling, to characterize the rock mass, delineate ore body and assess rippability in a opencast limestone mine.

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Location and geology of study area

MASW studies were conducted at a limestone mine of M/s. Diamond Cements located in an area bounded by latitudes 23°57'30" N and 24°2'20" N and by longitudes 79°21'50" E and 79°26'45" E. This mine is situated in Narsingarh, Damoh in the state of Madhya Pradesh. Formations around Narsingarh belongs to the Bhander series of UP Vindhyan Super Group. The general sequence of the area is soil, upper shale, shaly limestone (upper), grey limestone (upper), lower shale/shaly limestone (middle), grey and purplish limestone (lower) and lower shale., Narsinghgarh, Damoh, M.P. Seismic profiling tests were conducted in both eastern and western side of the mine, on top of working benches, in order to validate the results of the test.

Laboratory studies

Rock samples from exposed benches were manually collected, from different areas of both the eastern and western side of the mine. The samples were collected from the exposed benches. These samples were taken to the laboratory to estimate both P-wave velocity and S-wave velocity, using ultrasonix tester. The results of the tests are tabulated in Table 1.

Field studies using multi-channel analysis of surface waves

Determination of P-wave and S-wave profiles was done using multi-channel analysis of surface waves (MASW) technique.

Table 1: Laboratory estimates of P-wave and S-wave velocities

Location	Sample depth from surface	Laboratory results	
		Avg. P-wave velocity (Vp), m/s	Avg. S-wave velocity (Vs), m/s
Eastern side	Within 4m	780	210
	4m to 8m	1050	400
	8m to 11m	1085	510
	11m to 20m	1500	640
	>20m	2025	690
Western side	Within 5.5m	1243	300
	5.5m to 10m	1214	640
	10m to 15m	1590	682
	> 15m	2593	901

MASW is a geophysical method, which generates a seismic-wave velocity profile, i.e. Vs versus depth, by Rayleigh-type surface waves on a multi-channel record. Fig.1 provides a schematic layout of the MASW system. 24 channel in-field seismographs were used with two built-in high speed connections to interface with other geodes and a PC compatible controller. The geophones used were vertical 4.5 Hz and digital grade type. The geophones were housed in water proof cases. The spread cables are multi-conductor reversible cable with 24 wire-wrap takeouts spaced at equal intervals of 3-5 m. Seismic profiling was conducted on top benches of both the eastern side and western side. At each of the location, two scan lines, each perpendicular to the other was investigated. Geophones were placed at different spacing along the scan lines as shown in Fig. 2. A sledge hammer source is used to provide number of impacts (shots) at one end of the scan line and the generated Rayleigh wave data is acquired and stored, for further analysis.

The acquired Rayleigh wave was analyzed using SurfSeis software, to generate seismic velocity profiles, using a simple three step procedure, viz (a) Preparation of a multi-channel record (called a shot gather or a field file), (b) Dispersion-curve analysis, and (c) Inversion. The term 'Multi-channel Record' indicates a seismic data set acquired by using a recording

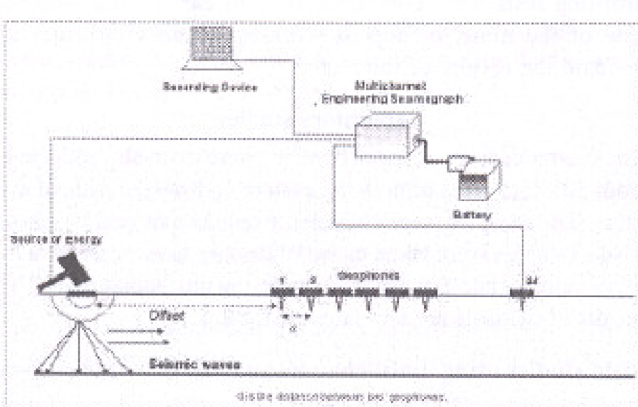

Fig.1 MASW components

Fig.2 Field setup

instrument with more than one channel using geode seismograph. A dispersion curve is extracted from the raw data by analysing all traces of shot gathered. During analysis, the signal to noise ratio above 0.75 is generally considered acceptable and the data points lying within this zone are used for further analysis. The dispersion curve is then inverted for a 1-D depth-velocity (Vs) profile.

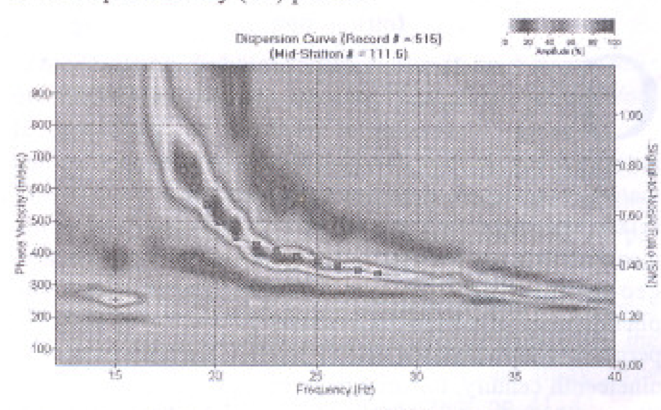

Fig.3 Overtone trace

The data is filtered taking into consideration high signal-to-noise ratio (S/N), frequency and phase velocity during both acquisition and processing. During acquisition this is accomplished by using walk-away test for selecting an optimum window for obtaining fundamental mode of the dispersion curve and avoiding those offsets where body waves and higher modes dominate (Park et al., 1999). Fig.3 illustrates the overtone curve (curve showing the signal strength amplitude). Inversion process is then carried out, on the final dispersion data, to arrive at the shear wave (Vs) profile.

In the present scenario, Poisson's ratio of 0.22 is assumed to compute the in-situ compressional wave velocity values from the in-situ shear wave velocity profile. The variation of S-wave velocity and P-wave velocity with depth is shown in Fig.4.

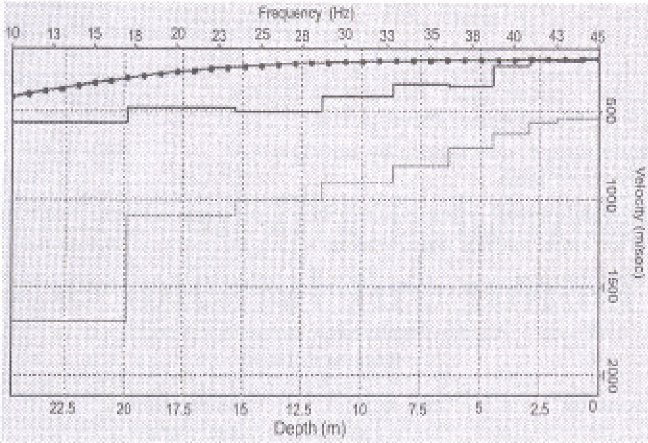

Fig.4 Typical velocity profile

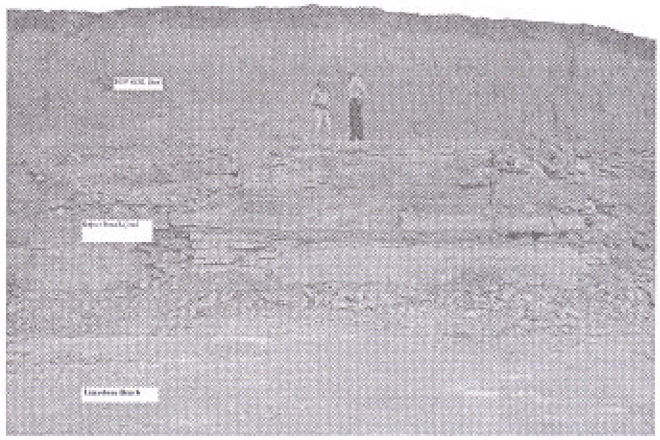

Fig.5 Eastern side of mine

Ground characterization

Seismic profiling using MASW, helps in characterizing the subsurface strata (Figs. 5 and 6) by providing plots (1D or 2D) of variation of in-situ shear and compressional wave velocities with depth. The knowledge regarding the type of rock existing in the subsurface stratum, helps in proper planning, execution method selection and equipment selection. The quality of rock existing below ground can be very well judged by rock quality designation (RQD). Seismic profiling also provides estimates of RQD, using velocity ratio methods. In the present scenario, 'CMRI_ROCK' (Choudhury, 2003) software has been used to provide the RQD estimates for ground characterization. The results obtained from MASW tests and the RQD value are tabulated in Table 2.

Ore body delineation

MASW tests also have a capability to delineate the subsurface profile. Fig. 5 illustrates both the S-wave and P-wave velocity profile with depth. It can be seen that up to a depth of 8m from the surface, the range of Vs values is around 250 m/s to 360m/s, then from a depth of 8m to 11m, there is a plateau at 430 m/s. With depth varying from 11m to 20m, the Vs values are nearly constant at 500m/s, and beyond 20m there is a jump in the velocities.

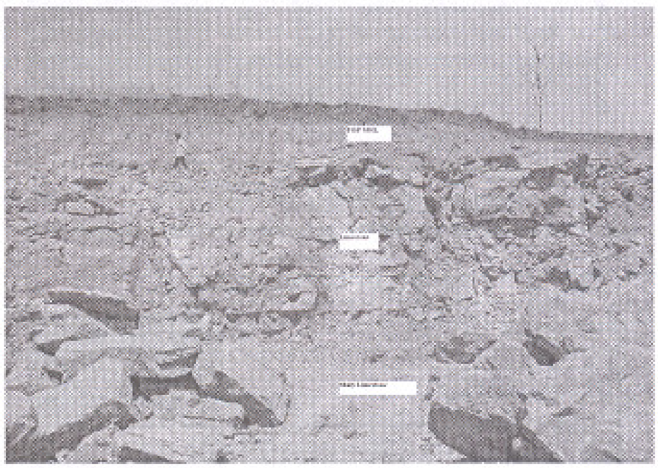

Fig.6 Western side of the mine

Similarly, trends are observed in seismic profiles of the western side of the mine. However, correlating these results with other geotechnical methods, in virgin areas, are advisable in order to improve the reliability of geophysical investigations.

Table 2: In-situ shear wave and compressional wave velocity

Location	Sample depth from surface	P-wave velocity (m/s)		RQD	Rock type
		Field/in-situ	Laboratory		
Eastern side	Within 4m	600	780	59	Fair
	4m to 8m	800	1050	58	Fair
	8m to 11m	900	1085	69	Fair
	11m to 20m	1100	1500	60	Fair
	>20m	1650	2025	66	Fair
Western side	Within 5.5m	900	1243	52	Fair
	5.5m to 10m	1120	1214	85	Good
	10m to 15m	1300	1590	67	Fair
	> 15m	2175	2593	70	Fair

TABLE 3: EXCAVATION CHARACTERISTICS BASED ON VP (AFTER HAGAN & GIBSON, 1983 AND RZHEVSKY, 1985)

Strata	Vp (m/s)	Excavation	Ai
Dense soft jointed rock with boulder	<1500	Easily rippable, strata excavable by scrapers or by large dragline, shovel or BWE	0.6 to 0.9
Soft jointed	1500 to 2000	Easy ripping, slow digging by large dragline, shovel or BWE	0.6 to 0.9
Strong highly jointed rocks	2500 to 4000	Medium ripping	< 0.4
Strong medium jointed rocks	2000 to 2500	Slow costly ripping, light blasting	0.4 to 0.6
Strong finely bedded rocks	2500 to 3000	Light blasting	> 0.6

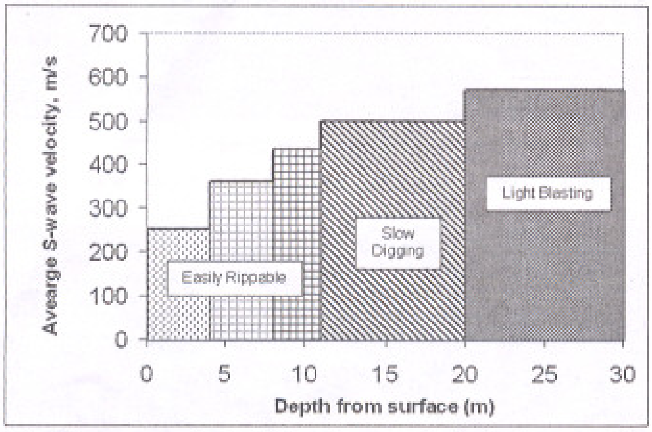

Fig.7 Assessment of rippability of strata with depth (eastern end)

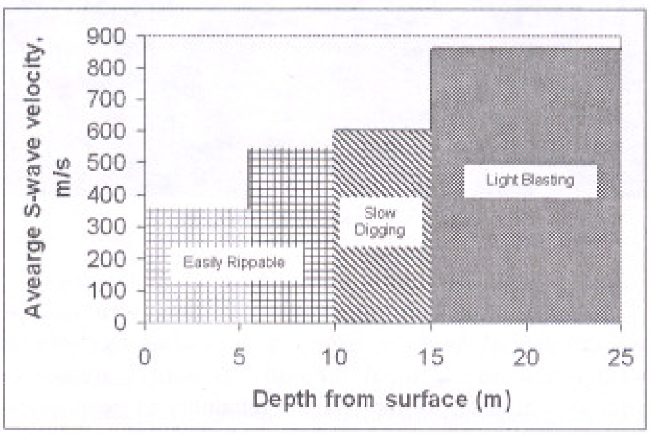

Fig.8 Assessment of rippability of strata with depth (western end)

Rippability assessment

With stringent environmental enforcements, mining in urban areas and mines approaching habitats or settlements, search for other alternatives has become a necessity. Ripping is one such alternative. Seismic profiling provides vital inputs to assess the rippability of strata. Acoustic index (Ai), an indicator of seismic wave travel characteristic of rocks, is assess rock rippability. It is the square of ratio of average in-situ P-wave velocity obtained from field experiments and P-wave velocity of samples measured in the laboratory. The excavation characteristics for various sonic ranges, based on P-wave velocities, as proposed by Hagan and Gibson (1983) are tabulated in Table 3.

TABLE 4: ACOUSTIC INDICES FOR DIFFERENT LAYERS, AI (AFTER RZHEVSKY, 1985)

Location	Rock type	Sample depth from surface	Ai
Eastern side	Top soil	Within 4m	0.59
	Top soil	4m to 8m	0.58
	Reject	8m to 11m	0.69
	Limestone	11m to 20m	0.54
	Shaly limestone	>20m	0.66
Western side	Top soil	Within 5.5m	0.52
	Limestone	5.5m to 10m	0.85
	Shaly limestone	10m to 15m	0.67
	Base rock	> 15m	0.7

Based on the above classification, rippability assessment of strata of eastern side and western side of the mine, are shown in Figs.7 and 8 respectively.

Acoustic index (Ai) is calculated from laboratory and field compressional wave velocity values and is tabulated in Table 4.

Acoustic index (Ai), obtained from P-wave velocity (Table 4), also substantiates the assessment of rippability on the basis of shear wave velocities of limestone.

Conclusions

Seismic profiling using multi-channel analysis of surface waves provides vital first hand information about the subsurface profile, with varying depth. The ability to determine in-situ shear wave velocities by MASW technique, in virgin areas, opens up new horizons for its application. The use of seismic profiling using MASW for ground characterization has been successfully elaborated in this paper. Moreover, the ability to provide information regarding demarcation of subsurface layers also helps in delineation of ore bodies. Seismic profiling also adds to component of decision making, wherein the methodology to work out a virgin deposit can be assessed based on rippability characteristics of the strata. The information of shear wave velocities is also required to match the specification of machinery or equipment like rippers, dozers, tractor, etc, which can be employed for ripping the strata.

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