9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-254

Estimation of near-surface shear velocity structure by ground-roll

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Summary

Besides groundwater, engineering, and environmental studies, the near-surface shear wave (S-wave) velocity is of fundamental interest for static correction application during S-wave reflection data processing. The frequency dependent characteristics of Rayleigh-wave, which is considered to be noise during body-wave prospecting, can be utilized to infer near surface elastic properties. In the early 1980s, a wave propagation method to generate the near surface VS profile, called spectral analysis of surface waves (SASW) was introduced. SASW uses the spectral analysis of ground roll generated by an impulsive source and recorded by a pair of receivers. Low signal-noise ratio recording of ground roll data and high degree of change in near surface elastic properties necessitate multi-channel analysis of surface waves (MASW). Multi-channel surface waves can be extracted from conventional seismic records, although dedicated techniques are available for continuous acquisition of noise-free, broad-band, multi-channel surface wave data. The multi-channel analysis includes the construction of dispersion curves from observed Rayleigh- waves, and inversion of VS profile from the calculated dispersion curves.

Keywords: *Rayleigh-Wave, Dispersion, Earth-parameters, Inversion, Multi-channel analysis of surface wave (MASW).*

Introduction

During conventional land seismic surveys, when a compressional (P) wave source is used, more than two-third of total seismic energy from an impulsive source is imparted into ground roll. Ground roll is basically surface elastic wave which travels along the free surface of the earth. Rayleigh-waves are the dominant element of ground-roll, along with modest quantity of Love-waves. Rayleigh-waves are generated due to interference of P and S_V waves, and particles move in retrograde-elliptical fashion during wave propagation. These surface waves are characterized in a shot gather by relatively low-velocity, low-frequency and high amplitude compared with body waves. In a layered earth model, each frequency component of Rayleigh-wave travels with a different propagation velocity (called phase velocity). These unique characteristic results in a different wavelength for each frequency propagated; this property is called dispersion. Higher frequency components of Rayleigh-wave exhibit higher phase velocity, and are more sensitive to the elastic properties of deeper layers; whereas lower wavelengths are more sensitive to the physical properties of surficial layers (Figure-1). When more than one phase velocities exist for a given frequency, the slowest one is called fundamental mode (M0) and faster ones are called higher modes (M1, M2… etc) of Rayleigh wave. Dispersion analysis is being done traditionally by fundamental mode of Rayleigh wave, although now-a-days higher modes are also being utilized occasionally.

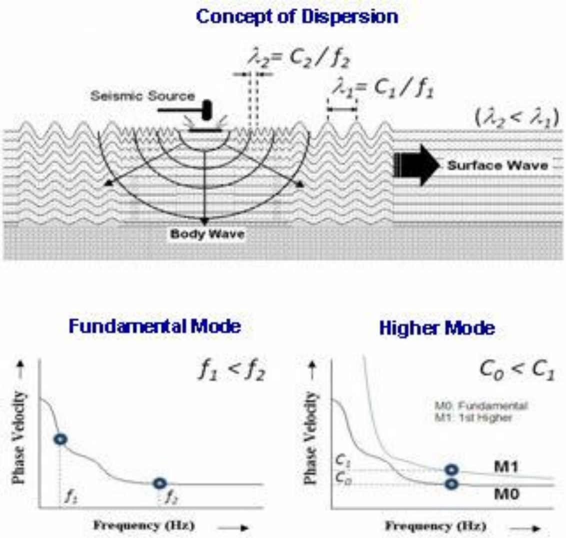

Figure 1: (a) Illustration showing a longer wavelength surface wave influances deeper depth subsurface materials. In the normal case of velocity incerease with depth, the longer wavelength propagates faster as a result; (b) Dispersion curves for fundamental mode and higher modes of Rayleigh waves.

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The dispersion of Rayleigh-wave is primarily governed by four groups of earth parameters i.e. compressional-wave velocity (V_P), shear-wave velocity (V_S), density and thickness of layers. Each of these parameters contributes to the dispersion curve in a unique way; density and V_P influence dispersion curves negligibly whereas layer thickness modifies the dispersion curves such that a thicker propagating layer causes a steeper dispersion curve and thinner layers cause the curves to move towards higher frequencies. Variations in S-wave velocities have a dramatic effect on Rayleigh-wave phase velocity; a little change in V_S modifies the dispersion curve greatly compared to other three parameters (Figure-2). The domination of V_S on Rayleigh-wave dispersion curve is utilized to generate vertical V_S profile.

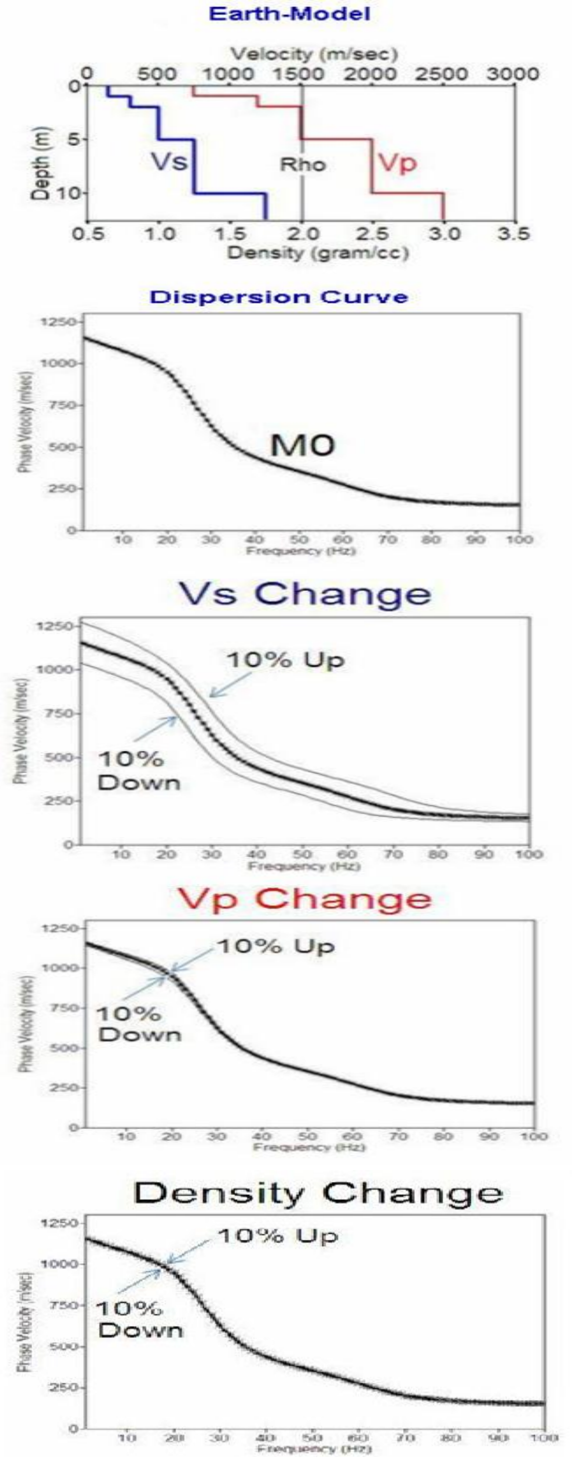

Figure 2: Rayleigh wave dispersion curves for varying earth parameters.

Extraction of Ground Roll

In the present study, ground roll is extracted from conventional 2D seismic profile acquired in the central part of Upper Assam basin viz. in Moran area. The data were acquired through impulsive source with 10m near offset and 20m receiver spacing. The deployment of single low frequency digital sensor (H"2Hz) at each receiver location created the favorable condition for ground roll recording along with reflection events. Ground roll were extracted from the shot-gathers up to limited offsets of 400m, because at the higher offsets body-waves contaminate the low frequency ground roll data severely. The low velocity and low frequency characteristics of these surface waves provide an assessable separation from reflection data in frequency-wavenumber (f-k) domain (Figure-3).

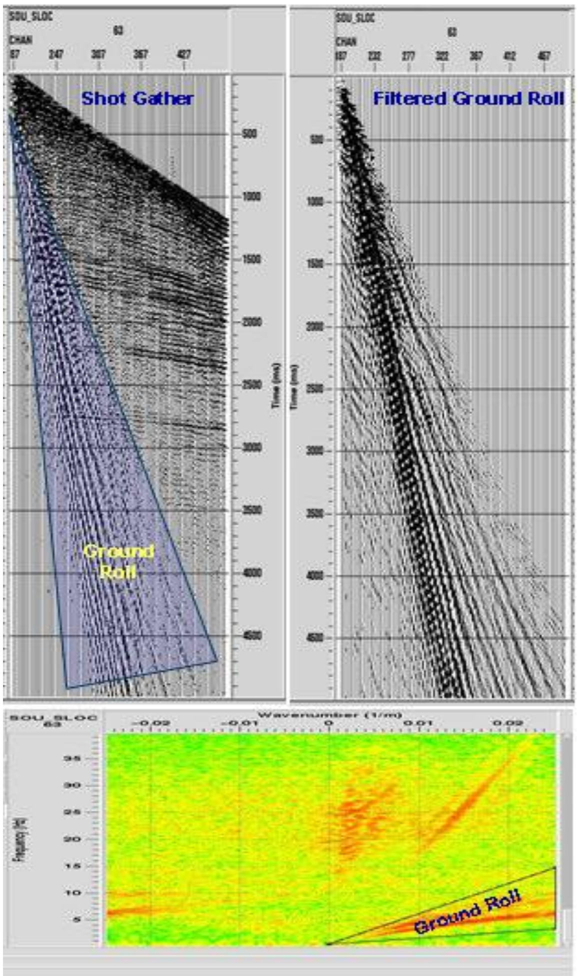

Figure 3: Filtering of ground roll from recorded shot gather in f-k spectra.

Dispersion Curve

Generation of dispersion curves from the shot-gather is the most critical part of multi-channel analysis of ground roll data. The accuracy of dispersion curves highly depends on the cleaner extraction of Rayleigh-wave. The extracted Rayleigh-wave is first decomposed using Fast Fourier Transform (FFT) into individual frequency components, and then amplitude normalization is applied to the each component. Necessary phase shifts are applied to compensate for the time delay corresponding to various offsets (10m-400m) in the velocity range of 200m/sec- 700 m /sec. The display of summed energy in frequency-phase velocity space shows pattern of energy accumulation and represents a dispersion curve (Figure-4). A high quality multi-channel coherency between each frequency component of Rayleigh wave is observed and produced excellent estimation of dispersion curves.

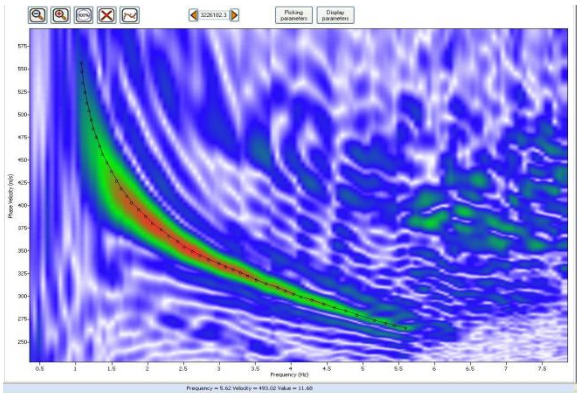

Figure 4: Accumulation of energy in frequency-phase velocity space shows dispersion pattern of rayleigh wave.

Inversion

The process of inversion of vertical V_S profiles from the resulted dispersion curves include the estimation of initial model (layered earth model) of the near surface, calculation of the theoretical dispersion curves (forward modeling), and finally minimization of the rms-error between calculated and observed dispersion curves by updating V_S by iterative least square approach. Selection of initial model is the key step during inversion process; low frequency dispersion curves demand higher investigation depth while high frequencies necessitate thinner layers in the earth model. Here, the initial model is taken as a 40 m thick layered earth model, consisting of 10 nos. of layers.

The thickness of individual layers is allowed to increase progressively with depth whereas density and Poisson's ratio of all the layers kept constant (Figure-5). During the process of inversion, density & V_P remained steady, and V_S is updated iteratively to get a convergent solution. Inversion of each dispersion curve (one for each shot gather) produced the 1D profile of V_S, and the 2D near surface structure of V_S was generated by horizontal interpolation of individual vertical profiles (Figure-6).

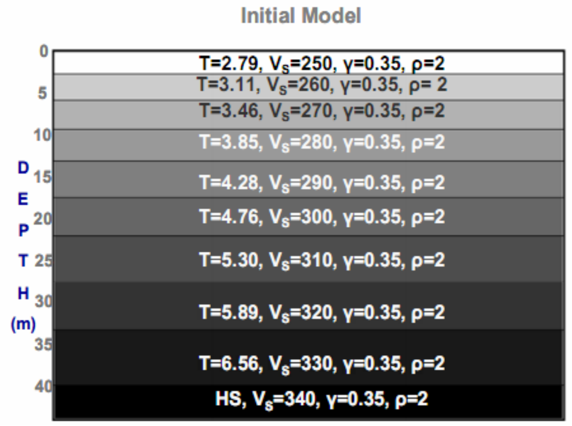

Figure 5: Initial Layered Earth Model.

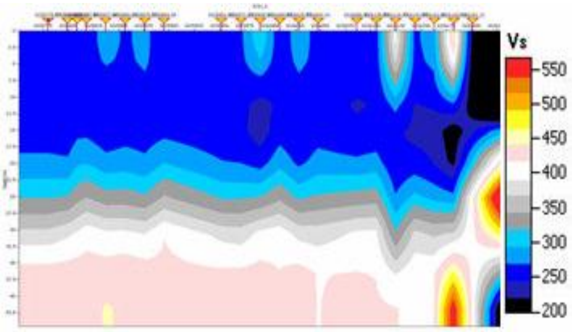

Figure 6: Near Surface V_S structure.

Results and Discussion

The near surface 1D V_S profiles, derived from the extracted ground roll provides a good estimation of the vertical shear structure, and an excellent match between theoretical and observed dispersion curves is observed (Figure-7). The V_S derived in this analysis varies from 200 m/sec (near the surface) to about 450 m/sec at about 40 m depth. The results are validated with the available 3C-LVL, and a good correlation between both the results is established. The resolution of the observed velocity structure is suffered in vertical direction due to presence of only low frequency ground roll data in shot gathers. As per horizontal resolution is concerned, it can be enhanced by minimizing the short distances. A high resolution model of shear velocity structure can be obtained by proper spatial sampling during dedicated ground roll data recording.

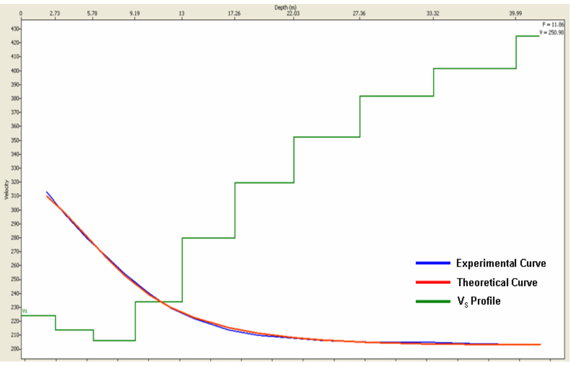

Figure 7: 1D V_S profile and correlation between observed and theoratical dispersion curves.

The Road Ahead- Dedicated Recording of Ground Roll

A broad-band continuous ground-roll data can be recorded with the minimal field efforts using small seismic recorders like LVL instrument. The field geometry for such data acquisition requires usually 24 low frequency receivers; and hammer or weight drop may be used as an energy source. A typical layout for multi-channel dedicated recording of ground roll is shown in Figure-8. The high degree of dispersion observed in Rayleigh wave requires very low near offset (1-2 m) to record higher frequency components of ground roll. The length of the receiver spread may be taken as 50-70 m because higher spread length will introduce noise at far end and lower spread length will protect the recording of lower frequency components. A dense spatial sampling (2-3 m) is required for fine frequency sampling, which ensures the highly precise dispersion curves. Ground roll must be recorded with smaller sampling intervals like 0.5 msec in order to resolve the distant frequencies and velocities.

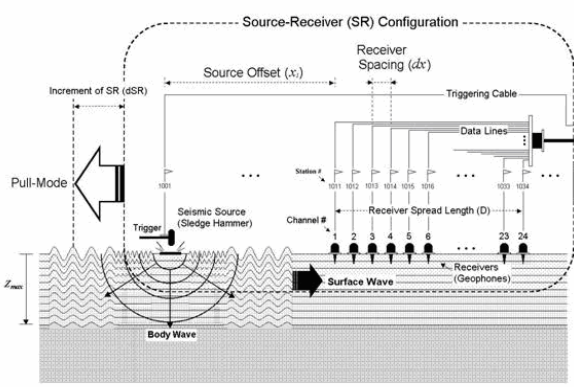

Figure 8: A typical field geometry for dedicated recording of surface wave (MASW).

Conclusions

High degree anisotropy in near surface creates multi-direction particle polarization during shear wave propagation, which in turn associates complex near surface shear velocity structure. Multi-channel analysis of ground-roll is a potential tool for accurate estimation of near surface shear wave velocity structure; and the derived VS can serve as a initial input for computation of shear-statics for land multi-component seismic processing.

A lower resolution model of near surface shear structure can be derived from extracted ground roll from conventional shot gathers; though, a high resolution image of near surface structure can be derived from the dedicated wide-band recording of ground roll. Since, the dedicated schemes for recording ground roll requires minimal field efforts, it can be done along the land multi-component profiles on the regular basis.

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Acknowledgement

Author thanks Oil India Ltd. (OIL) for providing permission for publishing this study.

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