

Attenuation of surface wave & Estimation of near surface model using Surface Wave Analysis, Modelling & Inversion (SWAMI) technique: A case study from thrust-belt area of Upper Assam Basin

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Keywords

Ground Roll, Rayleigh wave, SWAMI, Dispersion.

Abstract

In the seismic industry, the ground roll has been inherently regarded as strong coherent noise to be filtered out as soon as possible. Ground roll is one of the prominent coherent noises recorded in land seismic surveys and is characterized by relatively low frequencies, high amplitudes and low apparent velocity as compared to the seismic reflection. Ground roll is mainly composed of Rayleigh waves which constitutes a large part of the recorded energy posing a challenge for its faithful removal during the seismic data processing without affecting the signal. In conventional seismic data acquisition techniques, recorded data are coarsely sampled due to large group intervals and surface waves are often aliased which further makes the ground roll more challenging & difficult to remove during data processing. A key challenge with onshore seismic data is accurately compensating for the extreme horizontal and vertical velocity variations and the complex surface wave noise contamination that results from the highly heterogeneous near-surface geology. In this paper instead of treating surface waves as a noise to only be removed in signal processing, we extracted valuable information from them. In a geophysical advancement environment, we can now model and subtract ground roll from the recorded signal and also acquire a greater understanding of the near-surface velocities. Surface-wave analysis modelling and inversion is finding growing applications in the oil & gas exploration industry. We applied surface-wave analysis modelling and inversion method (SWAMI) technique to remove the aliased ground roll noise and obtained near-surface model by using the dispersion characteristics of Rayleigh wave. In this paper we discuss a workflow and methodology for the analysis, modelling, inversion, and attenuation of surface waves with 3D land data, showing examples from a land 3D seismic survey in Kumchai, thrust-belt area of Assam-Arakan

basin present in the state of Arunachal Pradesh. SWAMI surface wave analysis, modelling, and inversion enable the extraction of the phase velocity characteristics per frequency from the surface waves to facilitate both velocity model building and advanced coherent noise attenuation.

Introduction

The surface wave can be eliminated easily by using simple F-X filtering by defining the frequency & velocity of surface wave upto a great extent when seismic data is acquired in simple geological formation with fine group sampling. However, in complex geological formation like thrust belt area where the horizontal near surface velocity changes rapidly, it became very challenging & difficult to remove the ground roll faithfully without affecting the signal. In conventional seismic data acquisition, the recorded data are coarsely sampled due to the large group interval led to the aliasing and distortion of ground roll which further makes it more difficult to eliminate them by using simple F-K filtering. However, SWAMI also have limitation in handling of highly aliased & deteriorated ground roll velocity which is discussed in methodology & result part.

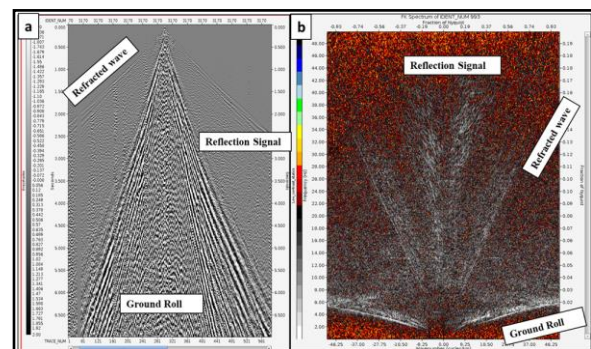
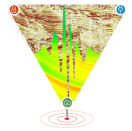


Figure 01:(a) Recorded shot gather; (b) F-K spectra showing the different recorded event in shot gather



This Study is based on simple concept of the surface wave characteristics that is called dispersion. The dispersion is defined as the different frequency components travel with different phase velocities but also have different intrinsic attenuation i.e., their penetration depth depends on their wavelengths. Dispersion of surface wave is strictly related to the near subsurface properties and hence can be inverted to a near surface velocity and attenuation model. The processes involve in elimination of ground roll and estimation of near surface model is shown in Figure 1(c).

referred as supra-thrust and sub-thrust respectively. The study area has been shown in Figure 02.

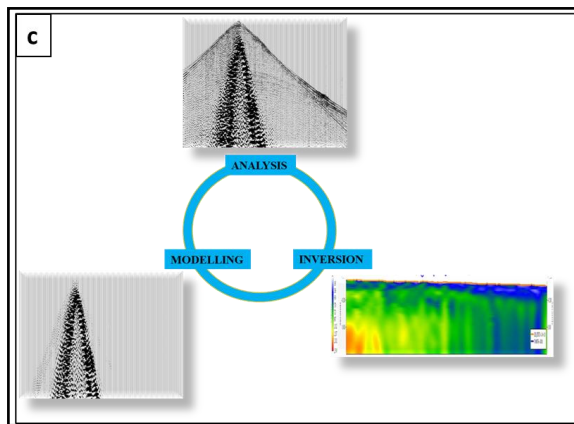


Figure 01(c): Steps involve in ground roll removal & estimation of near surface model

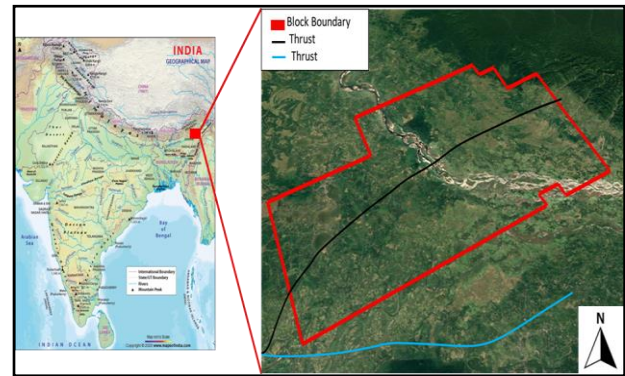


Figure 02: Study area

Methodology Adopted & Result Obtained

1. Analysis, Modelling & Attenuation of Ground Roll

SWAMI is a model-based approach to surface wave attenuation, where the local properties of the multi-mode surface waves are estimated from the seismic data and used to generate a detailed model of surface-wave noise, spatially variable over the survey area. The method has significant advantages with respect to the handling of aliased coherent noise energy, and robustness to spatial irregularities. The attenuation of ground roll mainly involves three-step processing, 1) Analysis & Extraction of dispersion volume 2) Modelling of ground roll and 3) Elimination of modelled ground roll from input seismic data.

Before the extraction of dispersion volume, analysis of input seismic data has been performed in order to identify the following characteristics of surface wave presence in our dataset by using simple band pass filtering:

- i. Defined minimum & maximum frequency range of surface wave
- ii. Defined minimum & maximum velocity range of surface wave
- iii. Maximum offset upto which surface wave energy travels

The analysis of the above characteristics of surface wave provides suitable starting parameters for the extraction of dispersion volume throughout the survey area.

Study Area & Dataset used

The 3D seismic survey over a producing hydrocarbon field, located in extreme eastern part of OIL's operational areas in Arunachal Pradesh acquired in the year 2006. Following table comprises of the acquisition parameters.

Parameters	Value
Receiver & Source Interval (m)	50 & 100
Receiver Line & Source Line Interval (m)	400 & 500
Bin Size (m)	25*50
Nominal Fold	48

Structurally, the area is characterized by the presence of the eastern extension of the Naga thrust, which however, manifests mainly in the sub-surface. The east-north-east trending thrust fault is prominent below the Dhekiajuli and divides the area into two structural blocks (segments), the southern hanging wall region and the northern foot wall blocks which are also

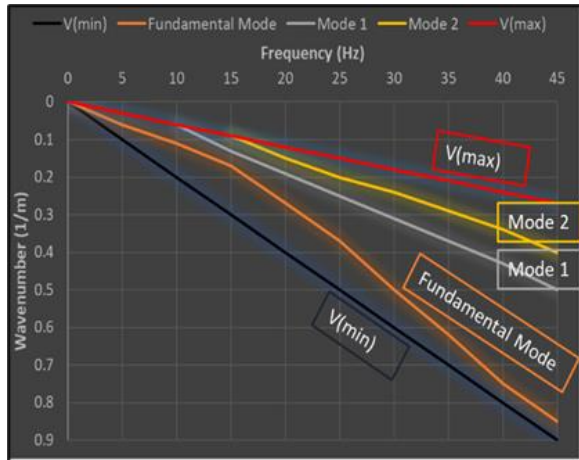
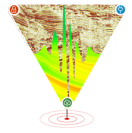


Figure 03: Illustration of different mode of propagation of surface wave

The dispersion curve is estimated at each receiver group by transforming the data from X-T domain to F-K domain. After transforming the data to F-K domain of each receiver group for different shot points the high-resolution stacked spectra or semblance is calculated which shows the different modes of the surface wave propagation. Figure 03 shows an example of the propagation of different modes of surface wave in F-K domain. The calculated spectra or semblance is shown in Figure 04. The fundamental mode of Rayleigh waves is representing the lowest frequency, lowest velocity and usually has the highest energy. The calculated high-resolution spectra are shown in Figure 04 where the yellow graph in Figure 04 (left) is showing the picked fundamental mode and Figure 04 (right) is showing the picked higher mode (mode 1) after the modelling & elimination of fundamental mode in 1st iteration. These picked maxima describe wavenumber as a function of frequency at each location.

Extracted dispersion volume from the analysis part used to model the ground roll. Prior to using the dispersion volume, preconditioning is applied to remove the outliers and mis-fitting picks and smoothed picks are used for the modelling. The phase velocity is calculated for each frequency on smoothed picks. The frequency of each pick measurement is roughly associated with a depth, where the depth is approximately inversely proportional to the frequency ($1/f$). The velocity associated with each pick measurement is approximately the frequency divided by the wavenumber (f/k).

The picked mode (fundamental & higher) along with seismic data is used to create the ground roll noise model and subtracted from the original input. Model

preconditioning is applied to generate the Ground Roll models, such as muting or band-pass filtering. The modelled surface wave noise is shown in Figure 06. A cascaded approach is used to remove the surface wave i.e., one mode of surface wave is eliminated in each iteration. In this case, initially fundamental mode is removed in the first iteration after removing the fundamental mode the higher mode (mode 1) became dominant and easy to pick for the second iteration (Figure 04 (right)). Figure 06 shows the input data, predicted ground roll modelled and output data using 2 iteration process. However, remnant ground roll is still present in shot gather (Figure 06 (e)) due to presence of highly deteriorated ground roll velocity which led to non-estimation of pickable high-resolution spectra in further iteration.

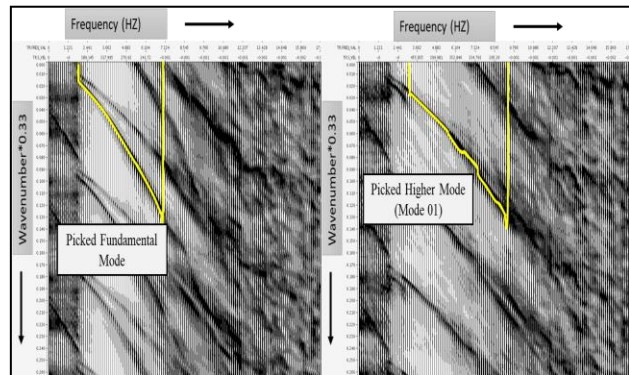


Figure 04: Calculated high resolution spectra or semblance, fundamental mode (picked: yellow graph) and higher mode (mode 1) is visible (left) and after elimination of fundamental mode the higher mode (picked: yellow graph) became prominent (right).

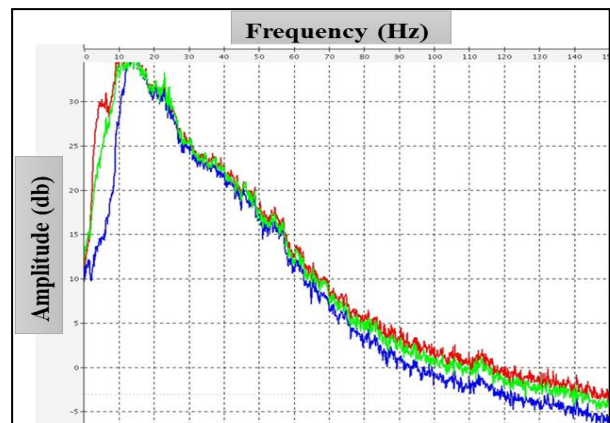
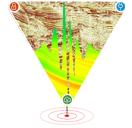


Figure 05: Amplitude Spectra; Red: Input; Blue: Conventional Noise Attenuated output & Green: SWAMI applied output



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The amplitude spectra of input data (red), final conventional noise attenuated output (blue) and final SWAMI applied output (green) shown in Figure 05.

The analysis of amplitude spectra (Figure 05) clearly shows how SWAMI technique preserve the low frequency primary masked within the ground roll and in conventional method there may be low frequency primary leakage along with the ground roll.

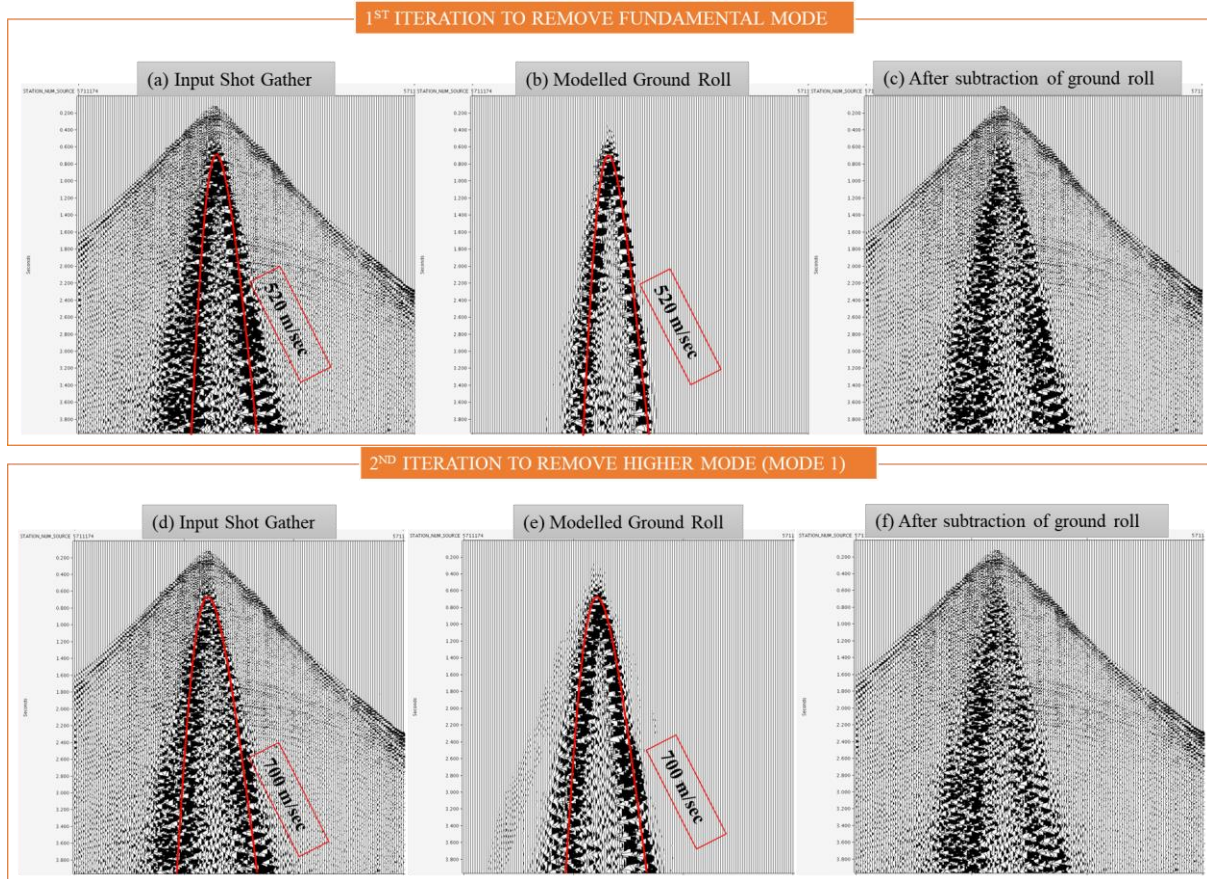


Figure 06: (a) Input shot gather for the 1st iteration; (b) Predicted aliased ground roll-fundamental mode; (c) output after subtraction of Predicted ground roll; (d) input shot gather for iteration 2; (e) predicted aliased ground roll-mode 1 and (f) output after subtraction of predicted ground roll

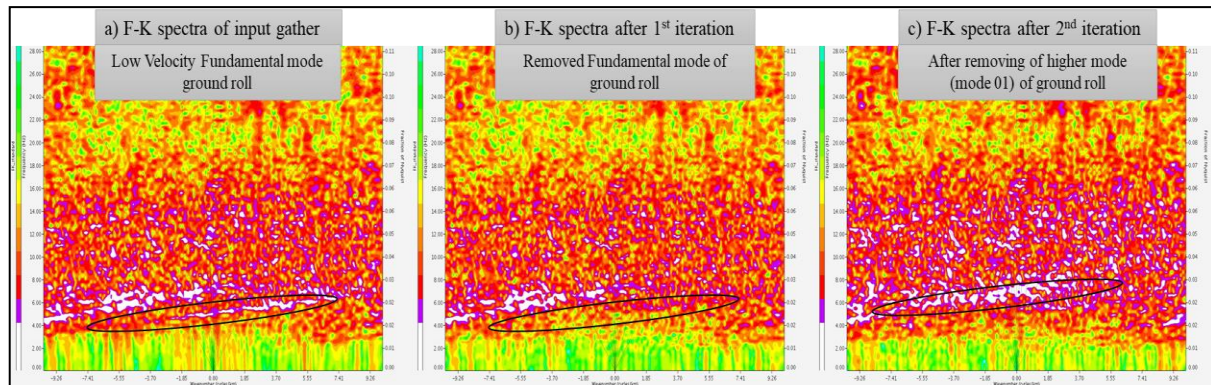
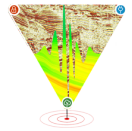


Figure 07: (a) FK spectra of input shot gather; (b) after removing the fundamental mode; and (c) after removing higher mode (mode 1)



2. Estimation of Near Surface Model

Different modes of dispersion curve can be inverted to obtain near surface properties but in the instant case study only the fundamental mode is inverted, the output is a near-surface S-wave velocity section, as a function of depth.

Phase-velocity as a function of frequency is obtained from the picked maxima. Converting phase velocity, as a function of frequency, to S-wave velocity, as a function of depth is the ultimate goal of inversion of surface wave (Figure 08). A shear-wave velocity model can be used as such or converted to a compression-wave velocity model which further can be used for near-surface statics or velocity model building.

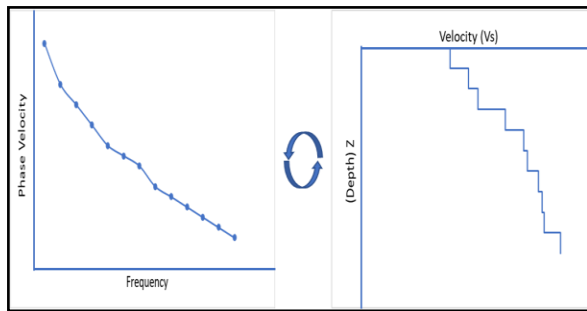


Figure 08: Dispersion curve (left) is transformed into a shear-wave-velocity model (right), using an iterative forward-modelling and inversion process.

The relationship between dispersion curves and a subsurface-model is non-linear and complex and requires solving a non-linear inverse problem. An initial Vs versus depth model is estimated from dispersion curves or a simple gradient model is assumed. In our case a simple gradient model is assumed and a synthetic dispersion curve numerically calculated (forward model) (Figure 09 (a)).

The synthetic dispersion curve is compared to the original dispersion curve, and the velocity model is updated using a damped linear least-squares inversion. A new synthetic dispersion curve is forward-modelled from the new velocity model, and so on, until convergence. The QC of each iteration is performed by plotting the misfit values on Vs section which represent the misfit between the input dispersion curve picks and forward modelled picks that came from the inversion model. The smaller the misfit value, closer the convergence of the model. Figure 09(b) shows the final velocity model after 3 iterations (resolution is not so good due to the sparse receiver interval), misfit value plotted on section in blue color line. From a velocity model to a dispersion curve requires information on the elastic properties of the medium, such as shear-wave velocity, compression wave velocity and density. In practice, surface waves are not at all sensitive to either compression-wave velocity or density. Rayleigh waves are mainly sensitive to S-wave velocity. Therefore, only S-wave velocity is varied in each iteration.

For the computation of Static corrections, Vp volume was derived (Figure 10 (left)) using a Vp/Vs ratio of 3.5, replacement velocity of 1700m/s, intermediate datum at a depth of 100m and final datum of 200m. Shear velocity (Vs) as function of depth is estimated from inversion and compressional velocity (Vp) as function of depth from the uphole data. The Vp from uphole data is calculated using the depth dividing by travel time at each location. Further Vp versus depth cross-plot generated (shown in Figure 10 (right)) and Vp/Vs ratio estimated as 3.5. A comparison of elevation statics and inverted velocity model statics is shown in Figure 11 for validation purpose, the stack section derived using inverted velocity model has better resolution than elevation statics.

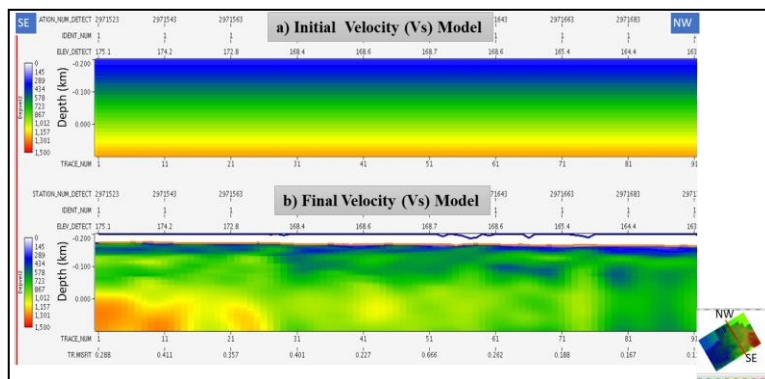
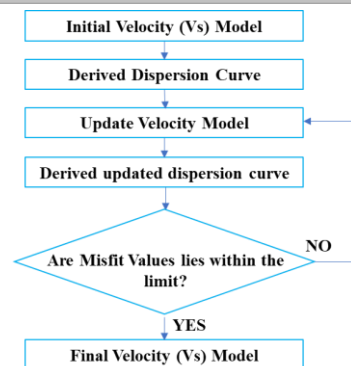


Figure 09: Velocity (Vs) model; (a) Initial velocity (Vs) model and (b) Final velocity (Vs) model

Workflow for the estimation of Vs model



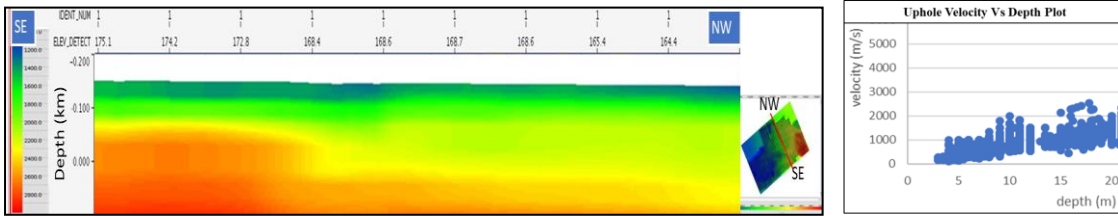
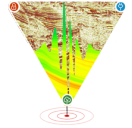


Figure 10: Derived Vp volume (left) Velocity vs Depth cross-plot using uphole data (right)

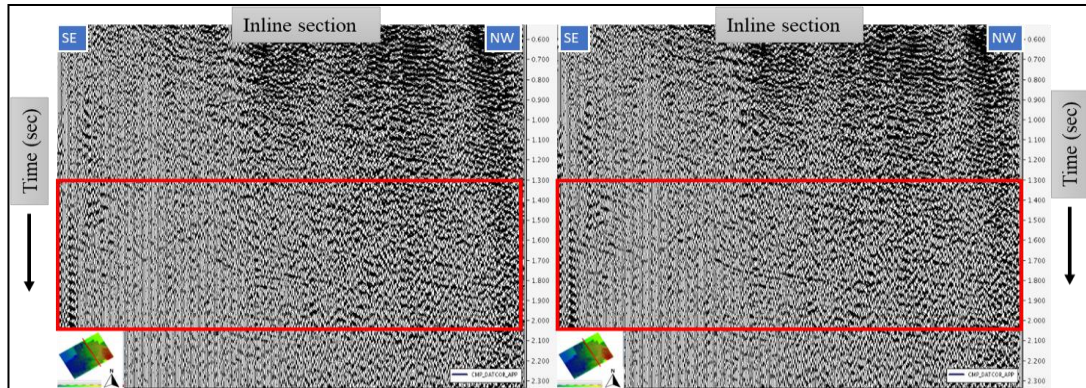


Figure 11: Stack section (a) with elevation statics and (b) with inverted velocity model derived statics

Conclusions

The analysis modelling & inversion of surface wave is a very useful technique for the attenuation of ground roll & estimation of the near surface model. In oil & gas exploration field, during the processing of acquired seismic data, the surface wave is treated as strong coherent noise which needs to be eliminated as soon as possible. In geophysical advancement environment, we consider surface waves as a useful tool to extract the near surface properties. The 3D dataset used in this paper were acquired using the sparse sampling of receiver and in complex near surface condition like thrust belt area which led to the aliasing of the recorded ground roll. This model-based noise prediction technique is used to predict the ground roll even beyond aliasing without affecting the signal component.

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