Simultaneous VSP acquisition: A Full Waveform Inversion approach

Akshay Vishwakarma
Email: avishwakarma91@gmail.com, Oil and Natural Gas Corporation Limited

Introduction

In conventional seismic survey, two consecutive shots are fired after record length of a single shot. This prevents overlapping of signals from first shot with the signals arriving from second shot. In simultaneous shooting, the shots are fired at a time interval shorter than the record length; blending of sources. The signals arriving from an individual source are then recovered from the method of deblending. The methodology of simultaneous firing of sources reduces the operational cost as it saves a lot of production time. Over the years, methods of seismic deblending have evolved for conventional seismic. For example, iterative estimation and removal of blending noise (Mahdad et al, 2011), using median filter as deblending tool (Chen, 2014), using independent component analysis (Ikelle, 2008) etc.

The same concept of simultaneous shooting when applied to VSP acquisition can save a lot of rig time and can amount to huge cost savings, especially for offshore wells. Earlier, Soni and Verschuur (2015) have explored the imaging method of simultaneously shot VSP data using full wave field migration. Gulati et al (2011) have also proposed methodology to acquire 3D VSP data using simultaneous firing of sources.

In this study, blended shot gathers are generated from an initial P-wave velocity model. These gathers act as observed data. The iterative process in Full Waveform Inversion (FWI), updates the velocity model in order to reduce the misfit between observed data and calculated data. The end result of this study is the velocity model through which the individual shot records may be generated (these individual shot records are not presented in this paper). The objective of this study is to test, if the VSP data is acquired with simultaneous shooting method then, whether the sub surface velocity model can be generated using FWI or not. If yes, then it will reduce the cost of VSP operation as the acquisition will be faster in this mode compared to conventional mode. The misfit between observed data and calculated gathers is less and the results are encouraging.

Method

a) Forward Modelling

The forward modelling was carried out using finite difference scheme in time domain with the absorbing boundary conditions (Spa et al. 2014). For the purpose of forward modelling, a MATLAB program was implemented. The 2D grid of P-velocity model was padded with absorbing boundaries from 3 sided to avoid numerical reflections from the boundaries of the grid. (Equation 1)

$$\frac{\partial^2 p(x,y,t)}{\partial t^2} + \sigma \frac{\partial p(x,y,t)}{\partial t} = c^2 \Delta p(x,y,t), \quad \text{......equation (1)}$$

'p' is the acoustic wave field 'c' is the p wave velocity
'sigma' σ is the damping coefficient
σ =0 inside the computational grid and σ >0 inside PML.

b) Inversion

For the purpose of this study, The FWI method described by Singh et al, (2016) is followed. The FWI code in MATLAB (made available online by Singh et al, 2016) was used for carrying out this step. In Full Waveform Inversion, synthetic data is generated with an initial model and the model is updated iteratively in order to match it with the observed data. (Equation 2)

$$E(v)=0.5*|| d_{obs}-d_{cal}||^2 \quad \text{... equation (2)}$$

dobs : observed data (Generated with True Model)
dcal : Synthetic data generated with updated velocity model 'v'
E(v) : The Error (misfit) between observed data and synthetic data forvelocity model 'v'

The goal of FWI process is to minimize the E(v) using Conjugate gradient descent method. misfit is minimized using following equation 3

$$v(k+1) = v(k) + alpha(k)*P(k) \quad \text{...... equation (3)}$$

v(k): velocity model at 'k'th iteration alpha(k): step length at 'k' th iteration
P(k): direction of update at 'k'th iteration

Gradient of objective function was calculated using adjoint state method (Singh, et al 2016). The algorithm stores the value of objective function, E(vk) at each iteration. If at any 'k+1', E(v k+1) < E(vk), then the model at 'k+1' is stored as final model.

Example

In this study, horizontal layered model of P wave velocity was used to generate blended shot gather. The starting model was taken as a smoother version of the true model as shown in figure 1 below. The velocity ranges from 2 km/sec – 5 km/sec.

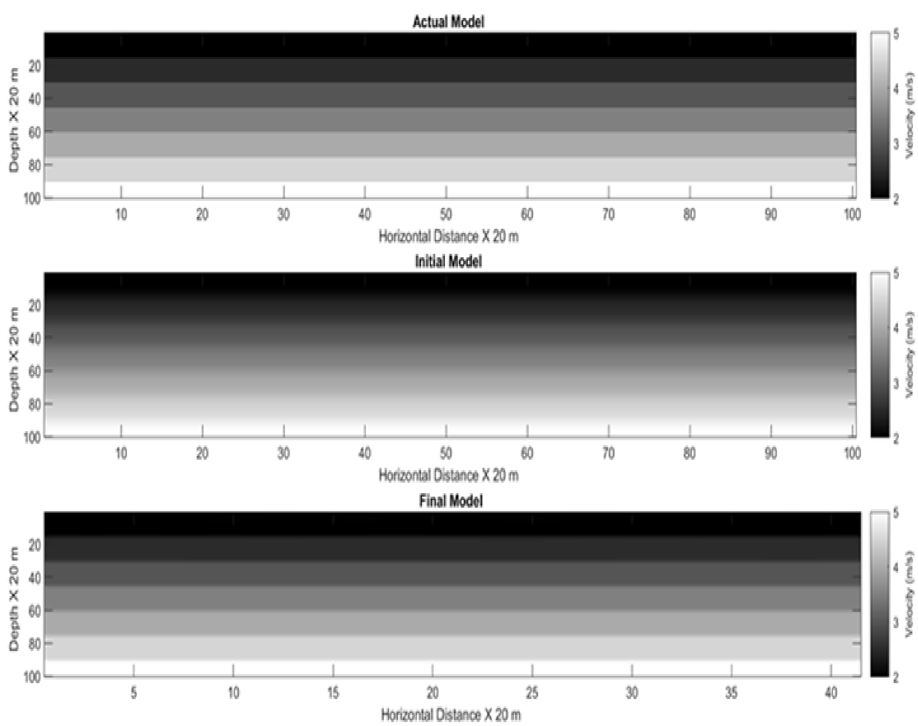

Figure 1 True model on the top; Starting model in middle and final model at the bottom

There were 6 Nos. of horizontal layers taken (In future more realistic models will be taken).
16 sources were placed at the top of surface and 1 vertical well placed which was placed at the center of the grid.

There were receivers placed at 10m interval through the well. In each gather, four sources were blended with some random time delays (ranging from 250 ms – 1000 ms). Record length was 2000 ms. The red marked stars are the simultaneously fired shots at delays which were blended in a single gather (figure 2).

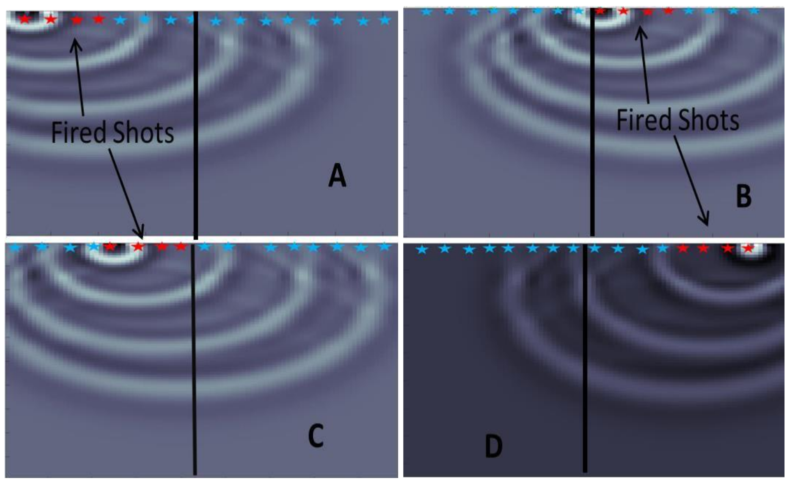

Figure 2 (A-D) Snap of the wave-field from four sources fired after some time delay from each other with well and source configuration, the blue marked sources are not fired for that particular gather

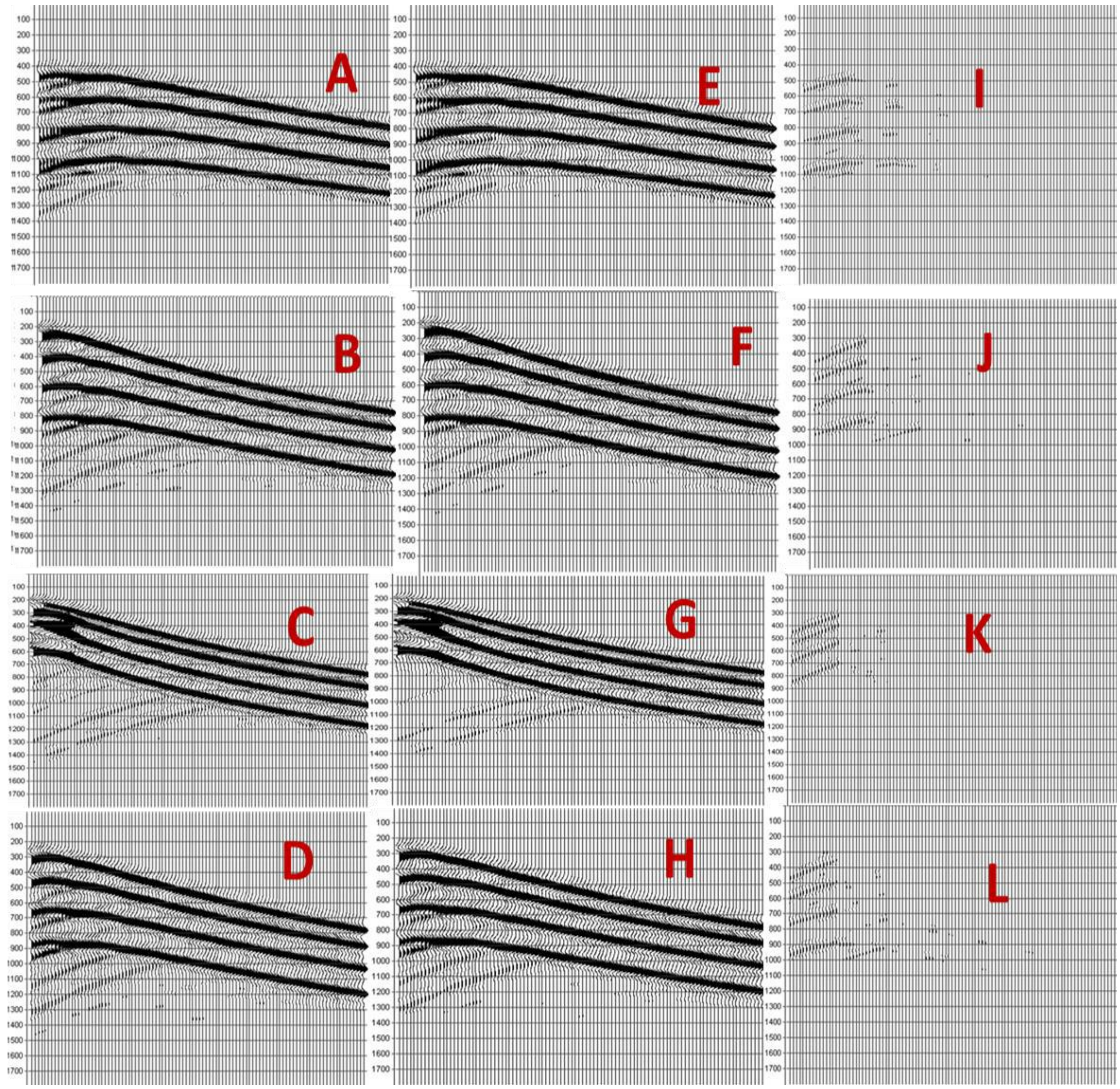

Figure 3 (A-D) 4-Blended shot gathers generated from true model; (E-H) 4-Blended shot gathers generated from final model; (I-L) the misfit corresponding to each blended gather

The value of objective function with each iteration is shown in figure 4 below.

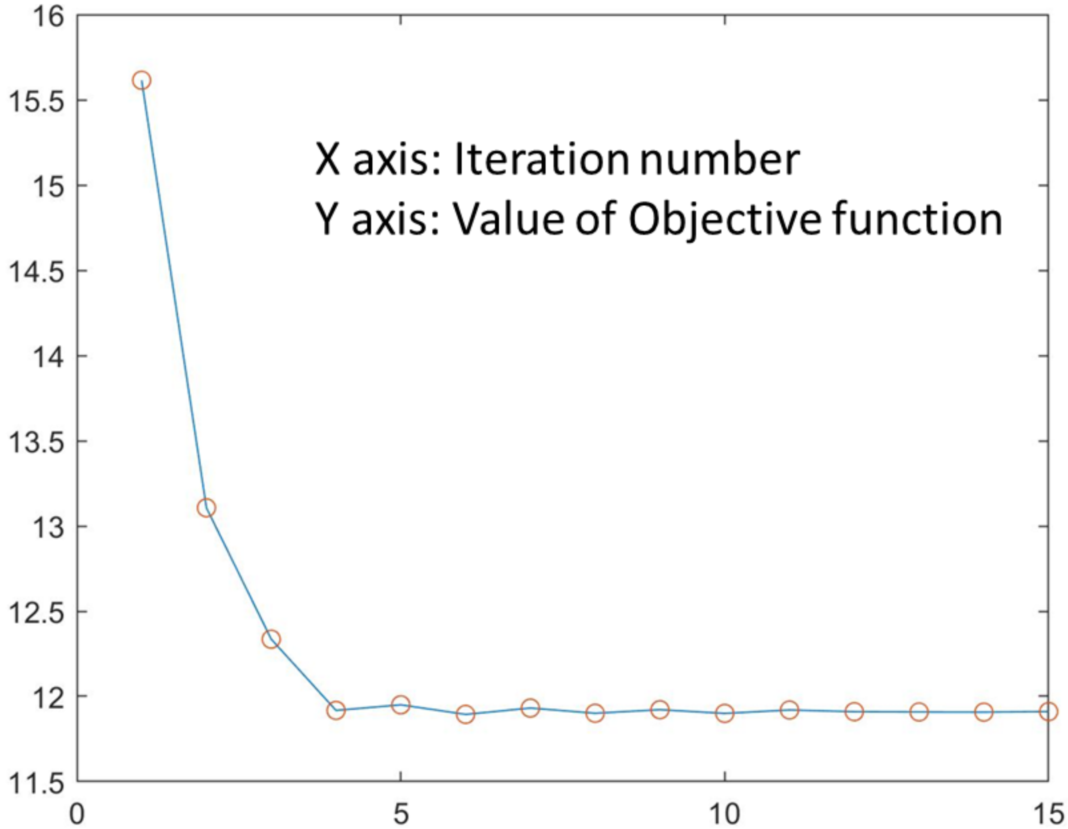

Figure 4 The change in the value of objective function with iteration

Conclusions

The feasibility of Full waveform Inversion for simultaneous VSP acquisition was tested in this study. The methodology was tested on synthetic data generated from a layered homogenous model of P wave velocity. The forward modeling was carried out in time domain using finite difference method. 4 source locations were blended for a vertical well with random time delays among them. The goal of this study was to test the misfit between blended gathers generated after FWI and the blended records generated with true model.

In figure 1, the true model and final model are shown. The wave field snap with time delays among 4 sources is shown in figure 2. In figure 3, the gathers generated before and after FWI are compared. It can be seen that there is some misfit between them. This is due to the fact that there is some difference between final model retrieved and the original model. The events which can be seen in figure 3 (I, J, K, L) are reflection events which could not be exactly generated during FWI process. It was observed that after few iterations, there was no substantial change in the objective function (figure 4) and the algorithm may have stuck in local minima.

The proposed methodology is yet to be tested on more complicated velocity models with varying geometry i.e., deviated wells, walkaway VSP, 3D VSP etc. Also, global optimization algorithms may provide better results. The results shown in this study are promising; however more research work is to be carried out to further strengthen this methodology.

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*View(s) expressed in this paper of the author only and not necessarily be that of the Oil and Natural Gas Corporation

References

Chen, Y., and Yuan, J., [2014], Median filter as a preprocessing tool in deblending, SEG Global Meeting Abstracts: 183-187.

Gulati, J., S., Salama, A., Leaney, L., W., Beasely, J., C., Coste, E., Menkiti, H., and Tulett, J., [2011] Faster 3D VSP acquisition using simultaneous sources, SEG Technical Program Expanded Abstracts : 4249-4252

Ikelle, L., [2007], Coding and decoding: Seismic data modeling, acquisition and processing, SEG Technical Program Expanded Abstracts : 66-70.

Mahdad, A., Doulgeris, P., and Blacquiere, G. [2011] Separation of blended data by iterative estimation and subtraction of blending interference noise GEOPHYSICS, VOL.76, NO.3 (MAYJUNE 2011); P. Q9–Q17

Singh, S., Kanli, A., I., and Mukopadhyay, S., [2016] Full Waveform Inversion in Seismic Imaging Studies: Marmousi Velocity Modelling with FWISIMATConference: 6th International Conference on Computer Applications in the Minerals Industries At: Istanbul, Turkey

Soni, A., K and Verschuur, D., K., [2015] Imaging blended vertical seismic profiling data using fullwavefield migration in the common-receiver domain," GEOPHYSICS 80: R123-R138

Spa, C., Lopez, R., P., and Hernandez, E., [2014] Numerical Absorbing Boundary Conditions Based on a Damped Wave Equation for Pseudospectral Time-Domain Acoustic Simulations, The Scientific World Journal Volume 2014, p 1-9