APPLICATION OF PHASE LOCKING FOR SEPARATION OF UPGOING AND DOWNGOING WAVES IN VSP DATA

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ABSTRACT

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The theories of dip steering after phase locking is disccused. This method has applicability in the seismic event separation that is primarily introduced for seismic automatic horizon picking in the interpretation phase. In this paper, primarily a deep literature review is done on the methods of VSP wavefield separation and thereafter a method based on following local dips for similar phases is presented. The output is two ensembles for upgoing and downgoing wavefiels. In these two ensembles, the wavefields are separeted and also the issue of cross dip in some samples is considered.

KEY WORDS: VSP, phase locking, dip steering, wavefield separation, seismic processing.

INTRODUCTION

In VSP processing, it is quite important to separate intrinsic modes. These are naturally different from physical point of view, namely transmission vs. reflection data or based on their geometrical aspects of downgoing vs. upgoing linear events. Although many efforts are done recently to process both the transmission and reflection modes simultaneously in seismic interferometry, but still in conventional VSP processing operations like Q-compensation, deconvolution and corridor stacking separated wavefields are needed. Downgoings are used for estimation of the seismic anelastic quality factor Q, and upgoing wavefields

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are utilized to obtain VSP-CDP images, which can be tied to surface seismic section for better subsurface imaging. Effective wavefield separation is important because the removal of undesired wave modes is a precondition for optimal imaging. The purpose of this processing step is the extraction of upgoing and downgoing wavefields such as P- waves, S-waves. Downgoing and upgoing P- and S-waves are used for different objectives. Downgoing waves are used to derive seismic P- and S-velocities used in estimation of the seismic anelastic quality factor Q, whereas upgoing wavefields are used to obtain VSP-CDP images (Blias, 2005), which can be tied to surface seismic section for better subsurface imaging. Blias (2007) presented a new method that permits independent vatiation of amplitudes and arrival times while propagating across the array. The method practices an iterative global nonlinear optimization arrangement that consists of several least-squares and two eigenvalues at each step. Events are taken out from the data one at a time. As stronger events are predicted and attenuated, weaker events then become noticeable and can be modeled in turn. As each new event is approximately modeled, the fit for all previously removed events is then revisited and updated. Iterations last until no remaining coherent events can be distinguished.

There are separation techniques like f-k or median filters in commercial applications (Seeman and Horowicz, 1983). Also some innovitive approaches exist like wave-by-wave (Blias, 2005) or curvlet analysis of VSP gathers (Heravi et al., 2011). Although good results in most cases is obtained, yet they have their own limitations in the case of processing speed and especially in difficult contexts (waves of near slowness or/and very close energies). These techniques can be divided up into three main categories: region passing filters, inversion based, and matrix one (Glangeaud, 1994). The f-k filter belongs to the region passing category, the parametric method (Esmersoy, 1984) to the inversion category and SMF method (Mari, 1989) to the matrix one. Curvelet transform is a multiscale transform with strong directional character in which elements are highly anisotropic at fine scales, and has found several applications in processing of seismic data. Heravi et al. (2011) utilize directionality of curvelet frame to deal with wavefield separation. Hashemi and Fakhari (2020) used tensor structure to find the intrinsic directivity in the seismic VSP images and separate down going and up going energy accordingly.

In this paper, the concept of dip-steering that is formerly used as a powerful automatic horizon picking in seismic data is used for wavefield separation.

METHOD

The concept of dip-steering in seismic is firstly discussed by Tingdahl in his publications (e.g., Tingdahl et al., 2001). It enables user to calculate many directivity-based seismic attributes. Dip steering is presented as a new method in domain of workstation seismic interpretation. Its application is in calculating dip based seismic attributes and automatic horizon picking. Parameterization of dip steering is mostly determined by finding an optimum processing algorithm/spatial search constraints/window size. In this paper we come with this fact that the method is applicable for phase locking of seismic events in VSP gathers. The idea is simply finding similar phase of a seismic sample in nearby traces and lock the phase thereafter. So If the input depth stacked VSP gather has the size of M*N, the resultant matrix of dips is in the same size. Fig. 1 shows the concept of phase locking algorithm. The simple idea is to start with a seismic sample and finding its related phase in the nearby trace. The process is repeated for the next sample/trace thereafter.

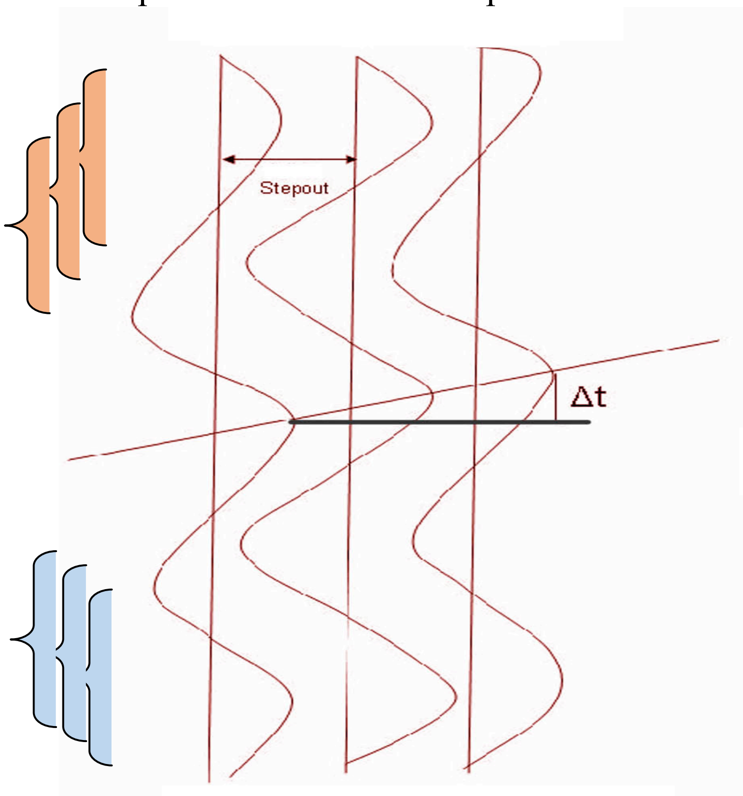

Fig. 1. Phase Locking Concept. Similar phases are found and locked within a sliding spatial window. Orange window slides from top to bottom, Blue window slides from bottom to top.

Steeghs (1997) presented a methodology based on conversion of the discrete wavenumber-frequency spectrum to a discrete slowness frequency spectrum using interpolation operator of Lagrange's. To complete the transformation from a k-p spectrum to a p-spectrum, all the corresponding values in the p-f domain with the same frequencies will be added. The p-spectrum can be seen as an energy-density function of that dip.

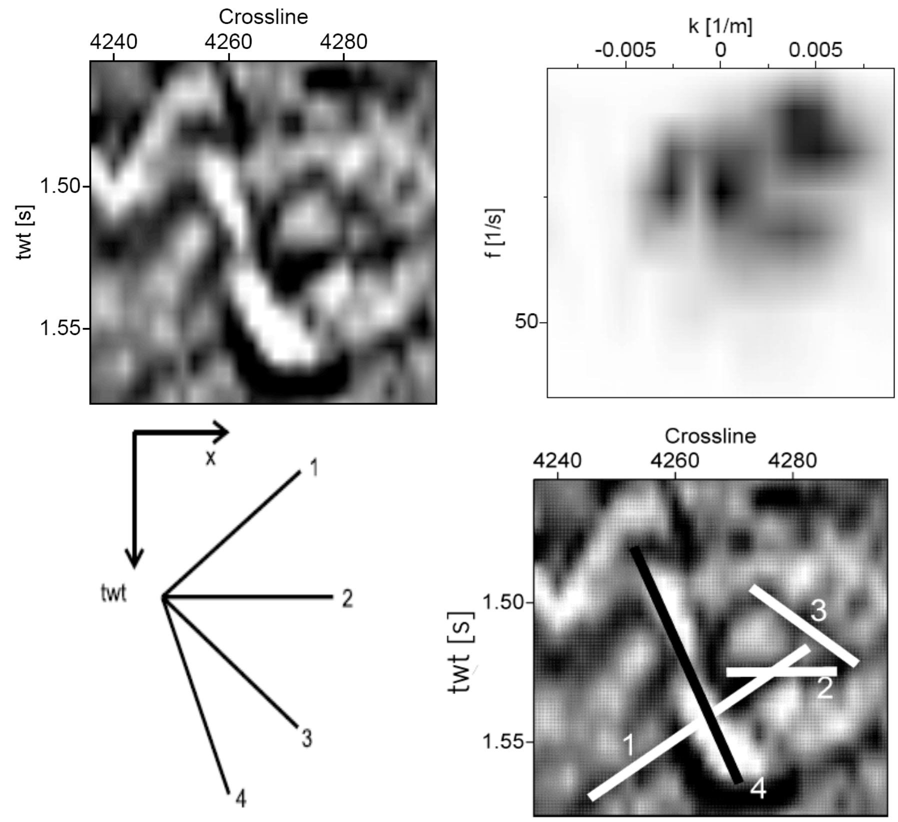

Fig. 2. An example of dip steering application on real Post-stack seismic data. Possibility of reporting cross-dips for each sample is the plus of algorithm for using in VSP, e.g., for dip 1 and dip 4 or dip 1 and dip 2. Upper right figure is separation of 4 dips in seismic section in FK domain. (Tingdahl, 1999).

Dip-steering provides local dips of each sample. Directivity based attributes like dip can be applied on the gathers with dip-steering index. Simply primary upgoing waves and their multiples are labelled by positive and primary downgoing with negative dip index. The proposed flowchart of wavefield `separation by dip-steering is shown on Fig. 2.

In time samples that an upgoing and a downgoing event crossing each other, hence ambiguity in dip determination happens. This implies both positive and negative dips for a specific sample in practice. F-K and median filtering has problems in these cross-dip samples. By running sliding time window in both directions (from deeper geophone traces to shallower and vice versa), the drawback of conventional methods will be covered in cross-dip samples. Fig. 3 is VSP stack data used for dip-steering with the sliding window size of 40 (ms). The problem is solved with two upward and downward sliding windows.

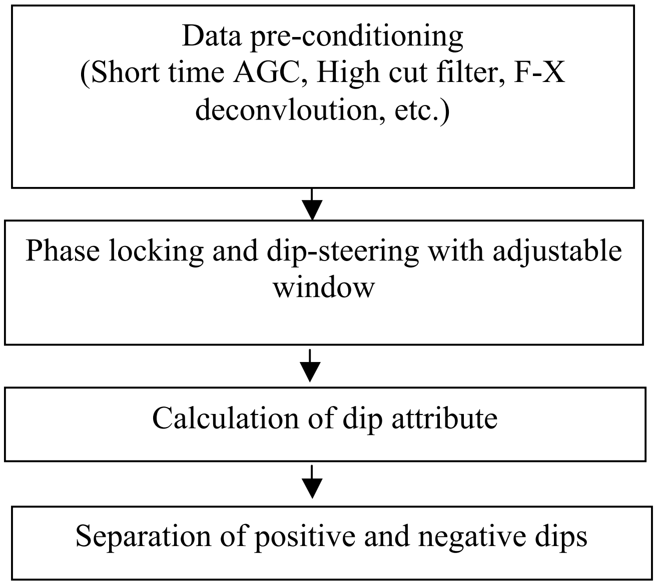

Fig. 2. Flowchart of dip-steering followed by dip attribute for VSP wavefield separation.

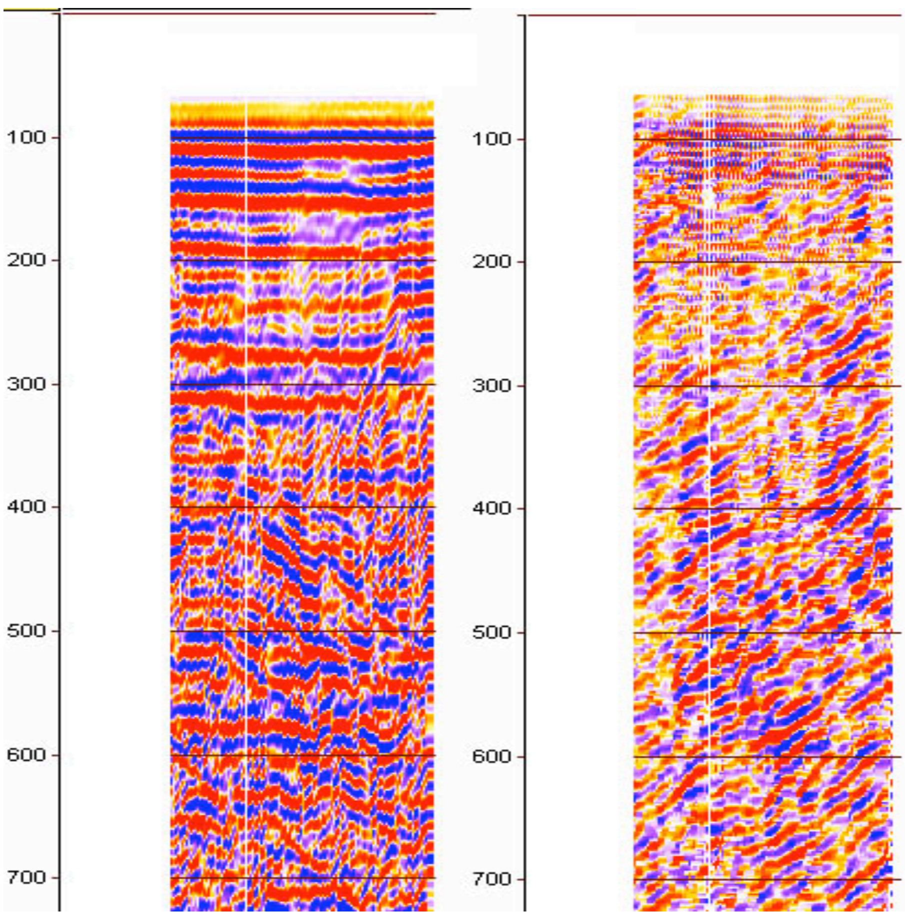

Fig. 3. (a) Input flattened VSP with all events (b) upgoing after applying dip-steering + dip filtering.

CONCLUSIONS

The dip-steering algorithm is able to find local dips per samples by running a sliding window on VSP dataset. Using these local dip values, one can find dip attributes. Unlike most of conventional methods, the proposed method is completely independent of irregular geophone depth levels. This is a common problem in deviated wells where the trace spacing (in depth) is not kept constant, so most of directivity methods relying on coherency of trace by trace fail. On the other hand, the wisdom of algorithm is to find different possible dips in crossing of upgoings and downgoings. So every sample can have more than dips that is a plus for further separation of upgoing and downgoing wavefield.

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