Introduction

The seismic processing technique of VSP data includes CDP/LOG-VSP tie with the use of primary reflections trace (PR) and acoustic impedance obtained from zero-offset VSP data processing. Resolution and reliability of these data depend on signal-to-noise ratio of raw data.

At the same time, geological objective is to study the medium from offset VSP data. Wavefields contain information about acoustic impedance near the borehole, which can be used to increasing the quality of CPD/LOG-VSP tie.

Primary reflections stacking

It is clear that PR can be obtained from offset VSP (PR_O) data processing in the same way as for zero-offset VSP (PR_Z). To increase signal-to-noise ratio, it is offered to stack with weights PRs derived by using VSP data from several shot points. The weights are calculated using cross-correlation function between all combinations of PR. Also, analysis of cross-correlation functions and results of CPD/LOG-VSP tie allows to control and correct cable depth errors at each shot point.

To compensate the dependence of true reflection coefficients on incidence angle it is offered to stack PRs both for P- (PR_P) and S-waves (PR_S). Denote this sum as PR_{PS}. It has been shown for synthetic data that such approach essentially decreases dependence on incidence angle *(fig. 1)*, and allows to increase signal-to-noise ratio.

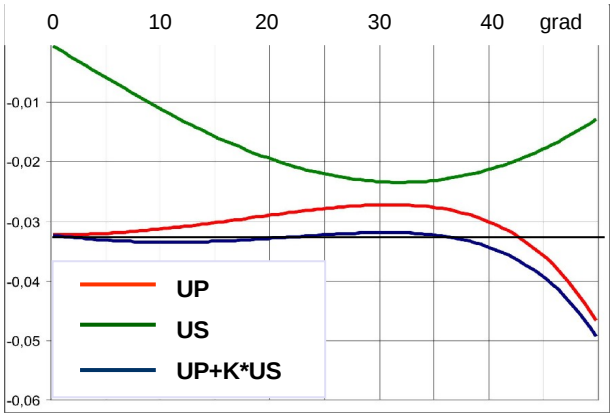

Fig. 1. Reflection coefficients for P- and S-waves (red line, green line), sum of reflection coefficients for P- and S-waves (blue line)

The method of using of reflectivity characteristic from several shot points can be represented as the following chain of procedures:

- obtaining primary reflections traces for P- and S-waves from VSP data for all shot points in the depth scale (PR_P and PR_S);
- stacking of primary reflections traces derived by processing P- and S-waves for each shot point (PR_{PS}) – correction of reflectivity coefficients on incidence angle;
- calculation of cross-correlation functions between PR_{PS} traces;
- determination of weights and cross-shifts of PRs;
- cable depths correction for each shot point (if necessary);
- stacking of all PR_{PS} traces from all shot points;
- CDP/LOG-VSP tie.

Synthetic experiment

The velocity model, derived by processing of the real VSP data, has been used for the synthetic experiment.

Wavefields for the first and second shot points (SP1 – 300 and SP2 – 1000 meters) were calculated using this model.

Then VSP processing for fields of P- and S-waves was applied. Processing includes following stages: deconvolution for downgoing wave, moveout correction, corridor stacking and transformation to depth scale.

For efficiency estimation of the presented method optimal primary reflections trace (PR_1) was calculated by means of convolution of perfect reflectivity function (constructed by the model of the media) with given signal.

Correlation coefficient of PR_1 with PR_Z (obtained from zero-offset shot point – SP1 with the use of field of P-waves) is 0.88; after stacking of PR_P and PR_S – 0.98. For the offset shot point (SP2) correlation coefficient have changed from 0.73 to 0.93. Thus, stacking of P- and S-waves allows to compensate the dependence of true reflection coefficients on incidence angle.

At the same time, correlation coefficient of PR_1 with PR_Z obtained from SP1 with the use of field of P-waves was 0.82, but correlation coefficient of PR_1 with PR_{PS} obtained from both (SP1 and SP2) shot points was 0.93 (*fig. 2*).

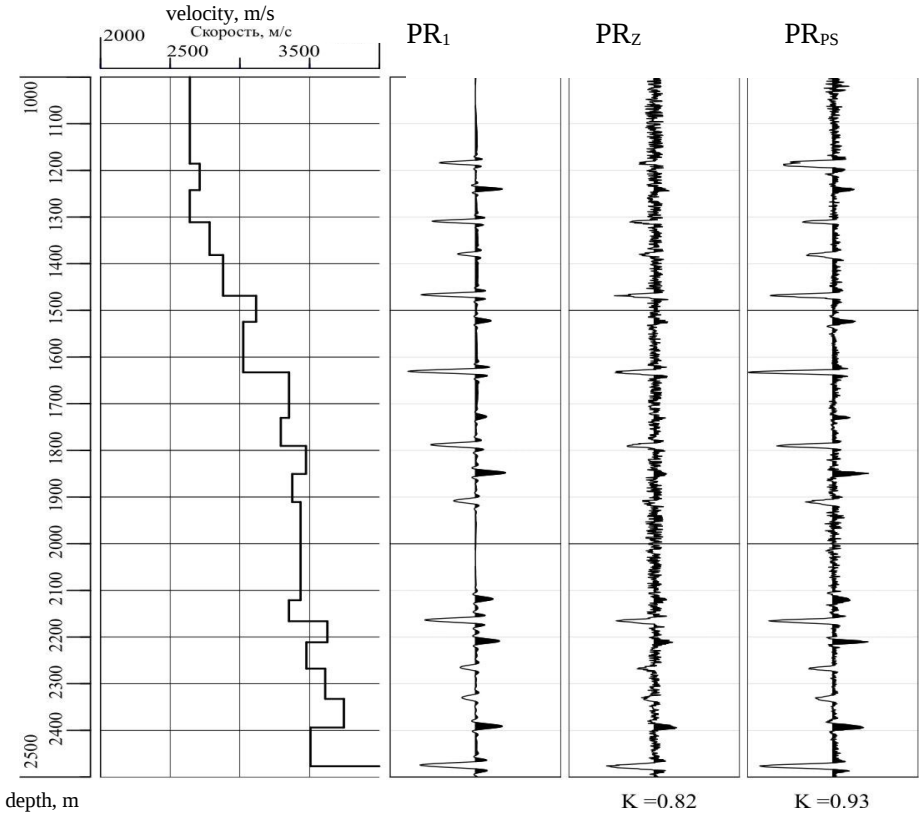

Fig. 2. Accordance of velocity model (1st graph) to PR_1 (2nd graph), PR_P obtained from SP1 with the use of field of P-waves (3rd graph) and PR_{PS} obtained from SP1 and SP2 (4th graph); K – correlation coefficient.

This experiment shows that proposed technique allows to increase signal-to-noise ratio in primary reflections traces and consequently CDP/LOG-VSP tie quality.

Real data

Proposed method was successfully tested on the real VSP data. Correlation coefficient of trace of CDP section with PR_{PS} obtained from both zero-offset (SP1) and offset (SP2) shot points is 0.57. This value is greater then correlation coefficient derived by using only one PR from SP1 – PR_Z (0.44).

After deconvolution of CDP section with the use of only one PR_Z CDP section became noisier and some of thin phases lost their correlation. But after using PR_{PS} obtained from both shot points correlation coefficient rises from 0.51 to 0.69 and CDP signal shape became zero-phase and CDP section resolution increases without significant rising of noise level (*fig. 4*).

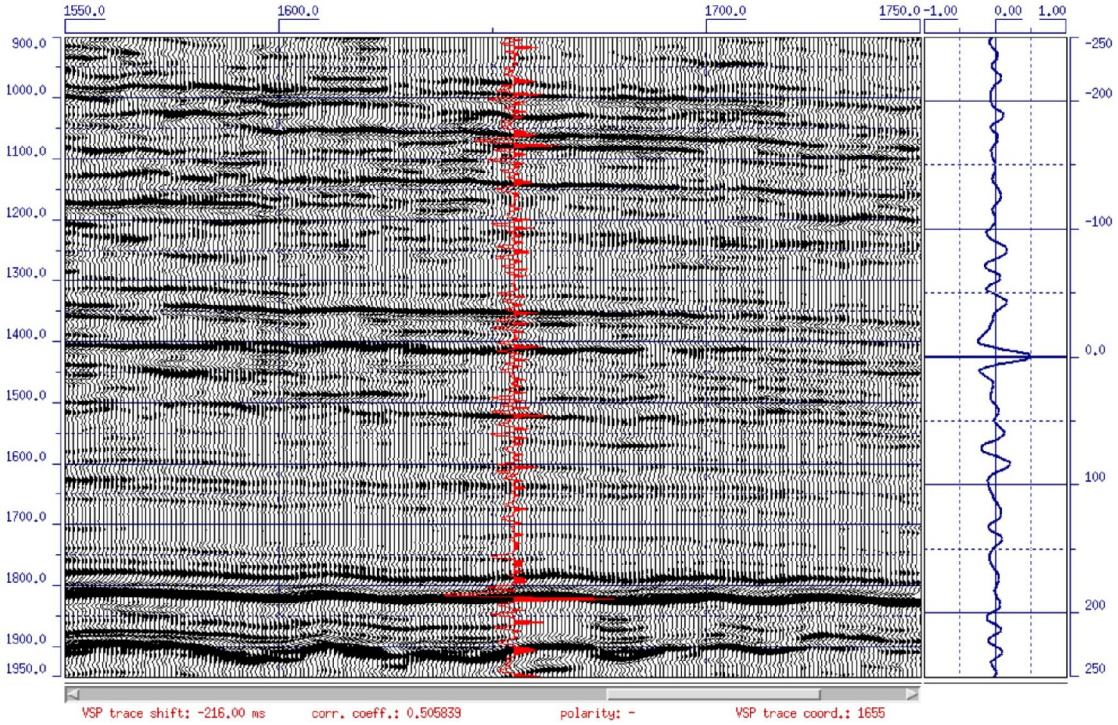

Fig. 3. Cross-correlation function (blue line, right) of CDP section after deconvolution with PR_Z (red trace).

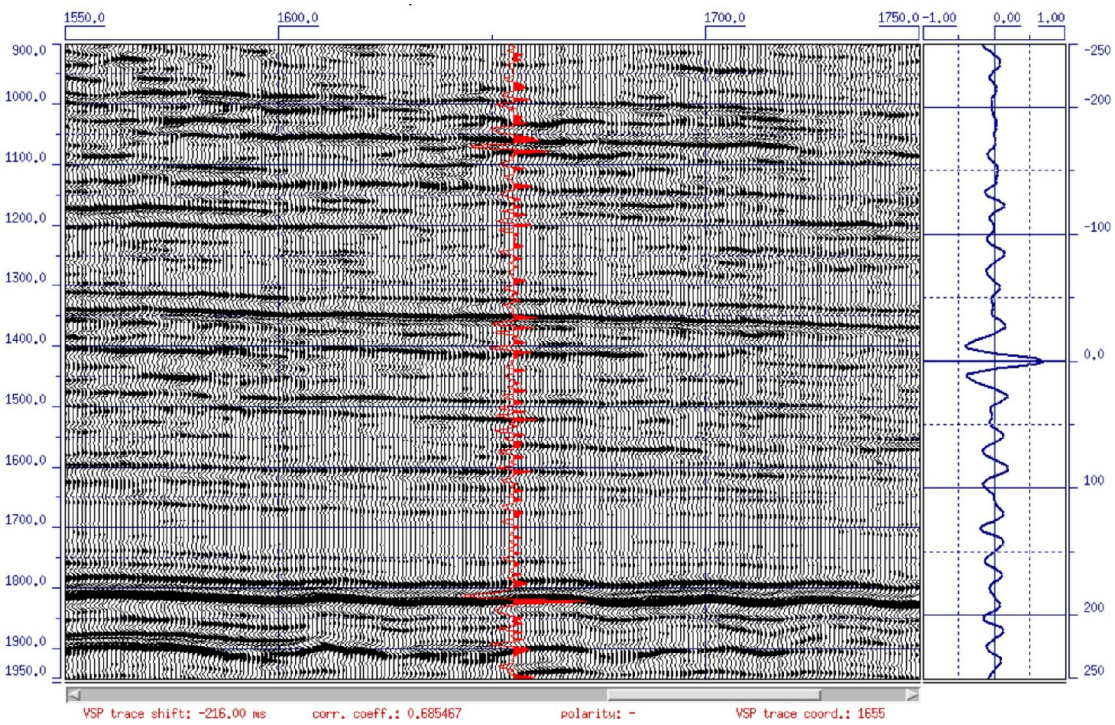

Fig. 4. Cross-correlation function (blue line, right) of CDP section after deconvolution with PR_{PS} obtained from both shot points (red trace).

Conclusion

Increasing quality of CDP/LOG-VSP tie by stacking primary reflections traces can be attained by stacking of PP- and PS-waves from several shot points. The efficiency of this method was illustrated on synthetic and real data experiments.