Direct stacking along corridors of hyperbolic trajectories for shallow seismic data

Ki Young Kim, Kangwon National University, Chunchon, South Korea;*
Choon B. Park, Richard D. Miller, and Jianghai Xia, Kansas Geological Survey

Summary

Large velocity gradients are one of the most troublesome phenomena frequently encountered with shallow seismic reflection data. To minimize both direct and indirect stretch effects during normal moveout correction, we introduce a method for direct stacking along corridors of hyperbolic trajectories. In the stacking regime, all data points in a particular corridor have the same amount of moveout for a given offset. Directly stacked traces along hyperbolic corridors show excellent agreement with reflection times and remarkably well preserved waveforms. Compared with conventional stacking methods using synthetic experiments, it is evident that the technique described here can be effective in minimizing distortion effects result from the NMO correction.

Introduction

One of the most serious problems with shallow seismic reflection data is introduced by the large velocity gradient commonly found at bedrock surface and/or groundwater table (Birkelo et al., 1987). Due to these large velocity contrast, undesirable artifacts are produced by wavelet stretching necessary during the NMO correction. Miller (1992) suggested a very aggressive mute to decrease such artifacts. However, far-offset data are always valuable both to increase signal-to-noise ratio and to extract precise velocity functions of subsurface. Indirect stretch effects including sample reversion, sample compression, and duplication of reflection wavelets are discussed by Miller and Xia (1998). They suggest segregation of shallow reflections with lower velocities from deeper ones with higher velocities.

Jou et al. (1996) introduced a new type of generalized Radon transform, called the τ-g transform. This new slant-stack technique follows hyperbolic traveltime trajectories and, in theory, has the advantage of minimizing indirect stretch effects due to large velocity gradients in near-surface materials. A CMP stacked trace is simply the trace at g=0 in the τ-g domain. This idea is similar to the semblance calculation commonly used for velocity analysis. The difference between the two is that the τ-g transform is conducted through sample-by-sample operations whereas the semblance is generally computed in certain windows along hyperbolic trajectories. Due to the difference in computation method, the former yields more stretch effects than the latter.

Introduced here is a direct stacking method along corridors of hyperbolic trajectories. Synthetic experiments show that both direct and indirect stretch effects can be significantly alleviated with this new stacking method.

Hyperbolic Corridor with a Constant Width

While waveform of signals is generally considered to be unchanged in a CMP gather, variation of correction amount with time changes frequency contents of a wavelet during NMO correction. In Figure 1, hyperbolae H_1 and H_2 depict travel time curves at zero-offset time T_1 and T_2, respectively. Normal moveout (ΔT_1) for hyperbolic event H_1 at offset x is

$$\Delta T_1 = P_1 - T_1 .$$

Assuming $T_1 >> (x/v)$, the NMO term is approximated to

$$\frac{1}{2T_0}(\frac{x}{v})^2 ,$$

where v is the stacking velocity.

Hence, assuming a constant velocity, the difference in NMO between time samples P_1 and P_2 in Figure 1 can be expressed in the form of

$$\Delta\Delta T = \frac{1}{2}(\frac{x}{v})^2(\frac{1}{T_1} - \frac{1}{T_2})$$

The above equation clearly shows that normal moveout correction is a function of time at a given offset.

During conventional processing, the moveout difference $\Delta\Delta T$ at offset x stretches to T_2-T_1 at zero offset.

The key objective of this new stacking method is keeping the waveform constant. For a given offset, therefore, all data points in the hyperbolic corridor are assumed to have the same amount of moveout. The width of corridor ΔP coincides with duration time of the wavelet. Since stacking along the hyperbolic corridor performs both NMO correction and stacking simultaneously, indirect stretch effects such as sample reversion and compression are also greatly reduced.

Data Synthesis

Our synthetic model is based on the shallow reflection data acquired in an alluvial/fluvial valley immediately adjacent to the Mississippi River in eastern Minnesota, USA, possessing several distinct reflection events. The most significant variation in velocity is at 35-40 ms and due to the groundwater table near 6-7 m (Miller and Xia, 1998). The parameters used for the velocity model are described in Table 1.

Table 1. Velocity model used for the synthetic CMP gather.

	RMS velocity (m/s)	Zero-offset time (ms)
Layer 1	243	14
Layer 2	344	38
Layer 3	820	50
Layer 4	1148	70

The synthetic CMP gather includes 48 traces, each separated by 0.61 m. Record length and sampling interval are chosen to be 200 ms and 500 μs, respectively. Ricker wavelets with a dominant frequency of 200 Hz were convolved with spikes at four reflection times for each geophone location. Since we are only concerned with arrival time for this discussion, attenuation of signal amplitudes is not considered. Figure 2 shows the synthetic CMP gather depicting shallow events crossing with deeper events. The shallowest three events merge together near trace 18.

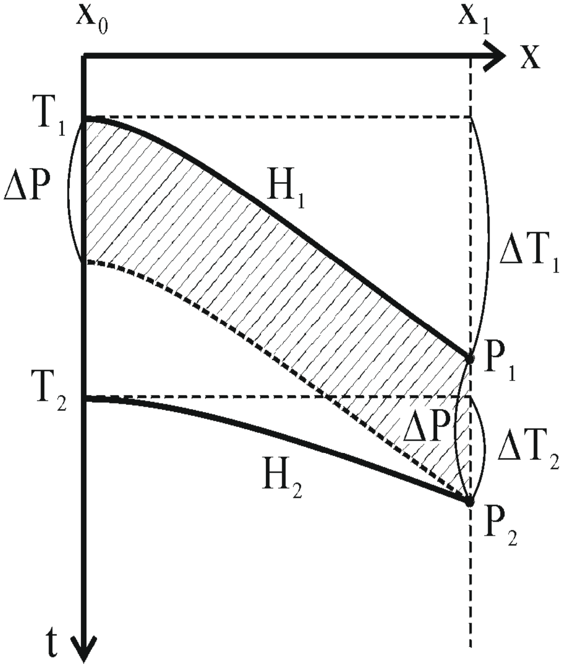

Figure 1. Schematic illustration showing the moveout difference between two data points at a given source-receiver offset. A hyperbolic corridor is also indicated with hatch.

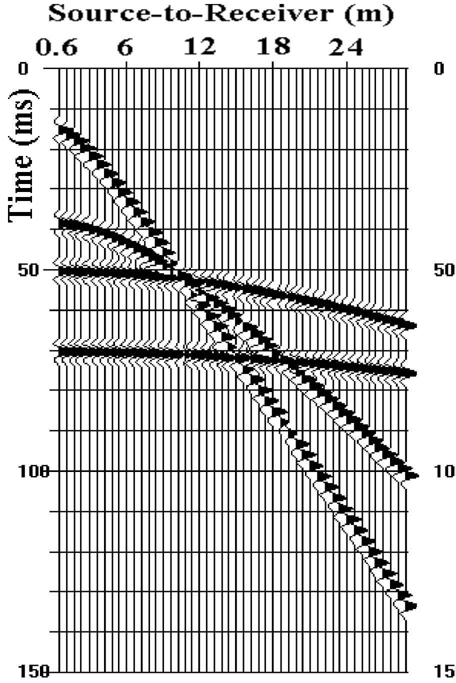

Figure 2. Synthetic CMP gather showing a large velocity gradient for shallow reflection events.

Analysis

The synthetic data in Figure 2 are NMO corrected to yield Figure 3 with a stretch mute of 100% allowance. Even with such a generous stretch mute, only the first several traces of the shallowest two events are left after NMO correction. Also waveforms are severely distorted and low frequencies introduced in shallow events.

Figure 4 shows an ideal zero-offset trace (A) and two stacked traces (B and C). The first trace (A) is simply obtained by convolving a Ricker wavelet of 200 Hz with the reflection model described earlier. The second trace (B) is the result of stacking along the hyperbolic trajectories, and the last one (C) is obtained through direct stacking along hyperbolic corridors. Zero-offset reflection times agreed for all three traces. Yet, waveform characteristics of the shallow events on the second trace are severely distorted. In contrast, the trace resulting from direct stacking along hyperbolic corridors shows remarkably well preserved waveforms. This comparison strongly suggests that direct and indirect stretch effects can be minimized using this stacking technique on real data.

Discussions and Conclusions

As part of our ongoing research, we introduced a direct stacking method along corridors of hyperbolic trajectories to minimize both direct and indirect stretch effects during NMO correction. The stacking method was tested with synthetic CMP data and compared with conventionally processed results. The stacking along corridors may turn out to be an effective method of minimizing the undesirable effects of stretching produced during NMO correction. Ultimately, once protected, this method provides good agreement between calculated and actual reflection times and preserves the waveforms.

Spiking deconvolution before NMO correction can be considered as an alternative to reduce stretch effects. However, with the small number of reflectors targeted by most shallow seismic data statistical assurances are not met. The direct stacking method along hyperbolic corridors is presently being tested with real data, with very promising initial indications. Some refinements need to be made in association with several practical issues of data processing.

One purpose of this paper is to demonstrate various difficulties and unique methods of addressing problems related to the NMO correction with shallow reflections from the data-processing perspectives. Previous testing included several concepts (e.g., τ-g and τ-p transformation) that seemed viable from the theoretical standpoint to solve the problem. However, we found that there are many practical (and also theoretical) issues involved that are not obvious, but affected the results in a somewhat unpredictable and undesirable manner. Future discussions will include approaches taken, the results of those approaches, and the issues that are not obvious when investigating methods to overcome the adverse effects of NMO stretch.

Acknowledgments

We would like to thank Mary Brohammer for her kind editorial review of this paper. One author (Kim) would like to give sincere thanks to all the staff at the Kansas Geological Survey for the hospitality showed during his visit to KGS.

References

Birkelo, B.A., Steeples, D.W., Miller, R.D., and Sophocleous, M.A., 1987, Seismic reflection study of a shallow aquifer during a pumping test: Ground Water, 25, 703-709.

Jou, H.T., Kim, H.J., Suh, J.H., and Youn, O.K., 1996, A new slant-stack technique based on hyperbolic statistics: J. Seis. Explor., 5, 203-212.

Miller, R.D., 1992, Normal moveout stretch mute on shallow-reflection data: Geophysics, 57, 1502-1507.

Miller, R.D. and Xia, J., 1998, Large near-surface velocity gradient on shallow seismic reflection data: Geophysics, 63, 1348-1356.

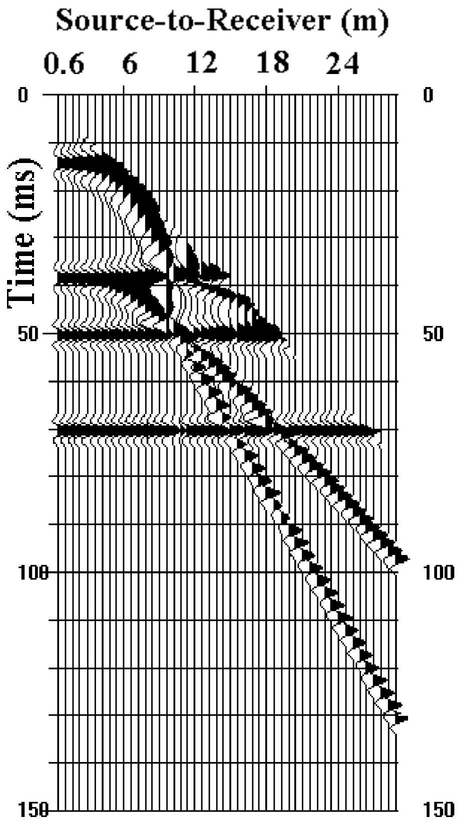

Figure 3. NMO corrected data with 100% stretch allowance.

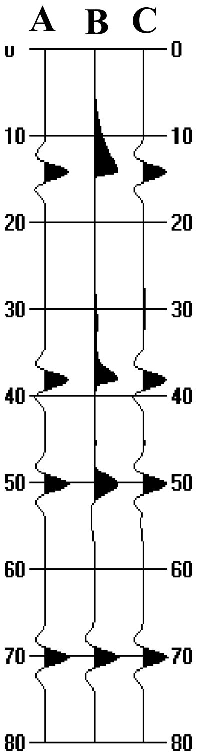

Figure 4. Comparison of stacked traces with an ideal zero-offset trace.