3D Interferometric Refraction Statics. No More First-Break Picking.

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Summary

A 3D data-driven statistical interferometric approach has been developed to eliminate first-break picking from the land seismic data processing sequence and to overcome the limitation of ideal 2D geometry, inherent to the reciprocal methods. The reliability of the proposed static solution is based on utilization of the stacked first-arrival signal.

Introduction

The complexity of near-surface weathered layers represents a major problem for imaging deep reflectors of land seismic data.

Most refraction methods rely on first-break pick times to derive a near-surface model and obtain corrections for the thickness and velocity variations.

Data-driven methods, such as the refraction convolution section (Palmer, 2001) and refraction velocity analysis (de Franco, 2011) as well as commonly used reciprocal methods (Cox, 1999) are based on the 2D geometry assumption, that a seismic survey is acquired along straight lines with a regular receiver spacing, which presents a challenge for the application of these techniques on 3D land data, crooked lines and sparse surveys.

We propose a 3D data-driven statistical approach with 3D geometry corrections to obtain a multilayered shallow subsurface model and compute refraction statics corrections.

Theory and Method

In the 2D interferometric refraction statics (IRS) solution to build a near-surface model, we generate a common-receiver-time image of several shallow seismic refractors and a time image of the spatial variations of seismic refraction velocity for the same refractors.

The refraction interferometry (de Franco, 2011) is used to obtain the shallow refraction velocity. Traces from each shot for a fixed receiver distance are cross-correlated (Figure 1). The resulting traces are stacked over all available shots for each receiver pair to produce one refraction velocity stack (RVS) trace. The resulting trace will have an amplitude peak corresponding to a time $t_v$ equal to the receiver distance, divided by the refraction velocity.

To obtain delay times at each receiver position we generate the refraction convolution stack (RCS) (Palmer, 2001), by convolving trace S1-R1 with trace S2-R1 and cross-correlating the result with trace S1-S2, assuming there is a receiver at the position of shot S2. The resulting trace will have an amplitude peak corresponding to the delay time at receiver R1 (Figure 2), where the delay time is given by:

$$t_d = t_{B-R1} + t_{C-R1} - t_{C-B}$$

Offset discrimination is used to generate separate sections for refractors at different depths.
After picking the events in a manner similar to horizon picking (Figure 3), the near-surface depth model is obtained, and static corrections are computed to replace the velocity in the weathered layers with the replacement velocity.

As previously formulated (Khatchatrian and Galbraith, 2013) after obtaining the depth model, we compute theoretical refracted first-arrival times for all refractors by ray-tracing for every shot-receiver pair through the model.

These model first breaks (MFBs) are then applied as static time shifts, and the data are stacked in the common receiver and common shot domains for the same offset ranges as for the initial model calculation. If the model correctly describes the subsurface then flattening to the MFBs and stacking creates a flat horizon at time zero.

Any deviation from time zero represents an average difference between the model and subsurface. To compensate for the geometry imperfections in the case of crooked lines, buried shots or geometry errors shot- and receiver-consistent time corrections are applied to the pre-stack data in addition to the IRS corrections.

Nevertheless, these corrections won’t be enough to compensate for the errors in the case of 3D and sparse surveys or severely crooked lines because the geometry does not satisfy the ideal 2D geometry assumptions the method is based on. As the method does not rely on scalar first break picks, we cannot expect that averaging errors will produce a stable solution. On the contrary, stacking incoherent events may lead to unreliable velocity and delay time stacks.

To successfully apply the principles of the 2D IRS solution on 3D data, as well as crooked lines and sparse surveys, we developed an approach to overcome the limitations of “ideal” geometry assumptions:

- For both refraction velocity and delay time stacks, each trace is corrected for the real offset before stacking.
- Traces that are off the straight line are used and adjusted for the exact difference in offsets.
- Missing traces are replaced with traces within defined constant velocity area and adjusted for the required offset.

To limit allowed deviation from the straight line we define tolerance for inclusion as an area of constant velocity, where the diameter of the area depends on interferometry offset, defined as a constant distance over which refraction velocity is estimated.

2D ideal straight line RVS trace (Figure 4, top):

$$T_v^0(t) = (S^0 R1^0) \otimes (S^0 R2^0)$$

3D or 2D crooked line RVS trace (Figure 4, bottom):

$$T_v(t) = (S R1) \otimes (S R2) = T_v^0(t - t_s)$$

where:

- time shift: $$t_s = (X_{s-r2} - X_{s-r1} - X_{r1-r2}^0)/V_{ref}$$
- interferometry offset: $$X_{r1-r2}^0 = X_{s-r2}^0 - X_{s-r1}^0$$

We can prove that within the tolerance for inclusion, time shift $$t_s$$ can be substituted with a time stretch, which does not depend on refraction velocity and which will force the refraction signal to the travel time $$(R1^0 R2^0)$$ for coherent stacking of refraction events only:

$$T_v^{00}(t) = T_v(t/c_s)$$

Thus, input RVS traces are calculated over the range of offsets and corrected for the defined output interferometry offset prior to...
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stacking. Figure 5 shows the comparison of the 3D RVS in-line obtained with traces which satisfied the 2D ideal geometry assumption and with tolerance for inclusion equal to 40 m.

For the RCS the difference between the ideal and the real trace depends on the offsets difference and refraction velocity.

After obtaining velocity, 3D geometry corrections can be applied to generate RCS. Figure 6 shows the 3D RCS time slice, calculated with traces which satisfied the 2D ideal geometry assumption and with tolerance for inclusion equal to 50 m.

Notwithstanding the advantage of RCS being independent of refraction velocity, the impossibility of generating an RCS stack arises in the special case of thin refraction layers or acquisition with limited offsets. Cross-correlation can also introduce noise and artefacts.

We now formulate an alternative way of generating the delay time stack – namely the offset reduction stack (ORS). Each trace is shifted by the time of the source-receiver path and traces are stacked in shot or receiver domain (Figure 7).

The resulting trace will have an amplitude peak corresponding not at the double delay time as in RCS, but at delay time plus average for the ensemble. \( t'_i = t_{di} + \frac{1}{M} \sum_{j=1}^{M} t_{dij} = t_{di} + \bar{t}_{di} \).

An iterative process has to be applied to estimate the average and extract the delay time.

Figure 8 compares the RCS and ORS.

examples

Figures 9 and 10 compare conventional and IRS statics application on two 3D datasets.

Examples show a more reliable long wavelength solution obtained with interferometric refraction statics.

figure 7: ORS generation

figure 8: 3D RCS (top) and 3D ORS (bottom)

figure 9: 3D CMP stack cross-line. Elevation statics (left), conventional refraction statics (middle), interferometric statics (right)
Conclusions

A 3D Interferometric refraction statics approach has been developed to build a multilayered shallow depth model, compute long and short wavelength refraction statics, and accurately predict first-arrival times for 3D land data, crooked lines and sparse surveys.

A new method – offset reduction stack to produce delay times was introduced. The statics solution is obtained by data processing techniques and horizon picking without the need to pick first breaks.

Several examples show

- increased coherence of events
- a more reliable long wavelength solution

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References

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