Separation and imaging of seismic diffractions using plane-wave decomposition

M. Turhan Taner, Rock Solid Images, Sergey Fomel, University of Texas at Austin, and Evgeny Landa, OPERA

Summary

We use the simulated plane wave section method to separate specular reflections and diffraction events. We show that plane wave sections naturally separate specular and diffracted events and allow us to use plane-wave distruction filters to suppress specular events resulting in plane-wave sections of diffractions. A synthetic example demonstrates the effectiveness of our method in imaging faults and small-scale discontinuities.

Introduction

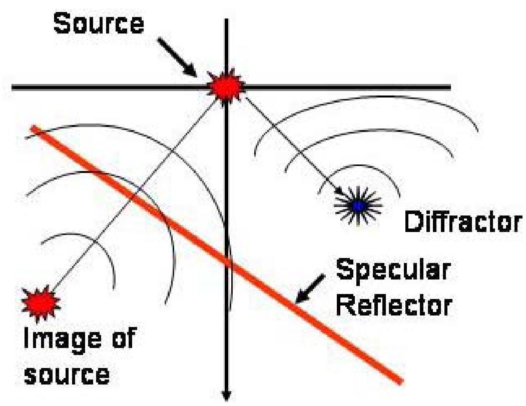
Seismic reflection data contain two types of coherent events generated from the subsurface discontinuities: specular reflections and diffractions. Specular reflections are the ones being used conventionally to interpret structural and stratigraphic features of the subsurface. Diffractions have been neglected by most researchers. Specular reflections are generated by interfaces with impedance contrasts. Diffractions are generated by local discontinuities when they act like point sources. These point sources become active as soon as the direct wave hits them. Presence of diffractions can indicate faults or fractures, which is important in carbonate environments, where locating fractures and their orientation is the objective of seismic interpretation.

The idea of using diffractions in seismic imaging is not new. Harlan et al. (1984) used forward modeling and local slant stacks for extracting velocity information from diffractions. Landa et al., (1987), Landa and Keydar (1998) used common-diffraction-point sections for imaging of diffraction energy and detecting local heterogeneities. In this paper, we take a different route by attempting to separate diffraction events before imaging. In a companion paper (Fomel et al, 2006), we discuss separation and imaging of diffractions appearing on post-stack sections. The separation is based on application of plane-wave destruction filters (Claerbout, 1992 ; Fomel, 2002). An analogous idea, but with an implementation based on multidimensional prediction-error filters, was previously discussed by Claerbout (1994).

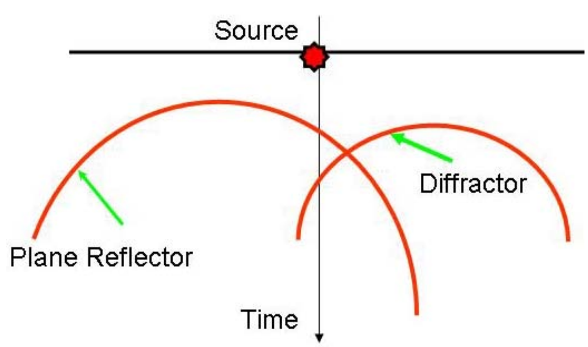
In this paper, we use the simulated plane wave section method (Taner, 1976; Shultz and Claerbout, 1978) to separate specular reflections and diffraction events. We show that the plane wave sections naturally separate specular and diffracted events and allow us to use the plane-wave distruction filter to suppress specular events resulting in plane-wave sections of diffractions. We use a synthetic example to confirm the proposed method.

Method

Let us consider behavior of a plane reflector and a point diffraction scatterer in case of a point source shot record. Specular reflection and diffraction from the point scatterer appear on the seismic record in the form of hyperbolas. That is both of them behave like a point source, as depicted schematically in Figure 1. While the specular interface acts like a mirror, we will see the point source in its mirror position, the diffractor is activated at the moment when the direct wave arrives and the scatterer point acts as a source in depth.



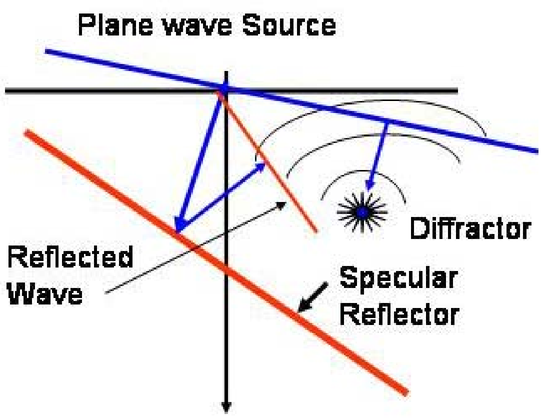
(a)



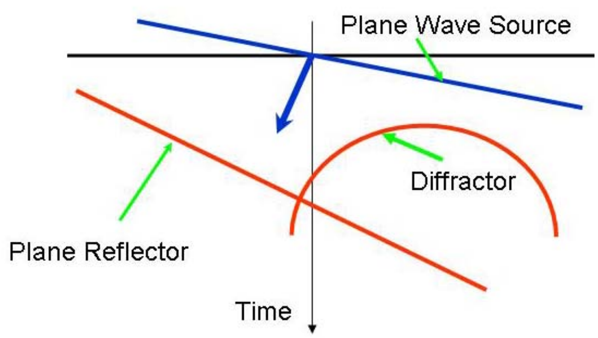
b)

Figure 1. Reflections from a plane reflector and a diffractor, illuminated by a point source. a) Depth section, b) Corresponding time section

If we activate a plane wave source, the reflected event from a plane specular reflector creates a plane wave, while the point diffractor behaves the same way as in the previous case and acts like a point source. (Figure 2)



(a)



(b)

Figure 2. Plane reflector and a diffractor reflections , as illuminated by a plane source wave: a) Depth section, b) Corresponding time section.

To generate plane wave sections from a point source seismic data we invoke two basic laws: superposition and reciprocity. Reciprocity helps us exchange receiver and source positions. By the superposition we can combine different seismic records together to simulate plane-wave records as if all the sources were exploded simultaneously.

Plane wave decomposition (Taner, 1976) can be schematically described as follows. Taking one common shot record and summing the traces horizontally without any time delay we simulate a trace which we would obtain if we exploded simultaneously many sources at the receiver locations and record the reflected data at the source position. Repeating this procedure for several shot records we can simulate plane-wave source record. When we deal with marine case (single end observation geometry) the cable end creates an edge effect: semi spherical wave field, we wish to attenuate. To do it, we can use the reciprocity principle and create an artificial split-spread shot record by sorting the data to CMP domain, replicating the CMP data to the opposite sign offsets, and sorting it back to the shot records.

When we sum a split spread shot record horizontally, we simulate a plane wave propagating vertically downward at the inception. If we shift the traces linearly before summation, we generate a dipping plane wave. By repeating summations with various dips, we actually generate a τ-p section corresponding to our shot record, or the Radon transform estimate. There are many procedures to compute the Radon transform (Gardner and Lu, 1991), and we do not discuss them here.

More details about plane-wave decomposition are described by Yilmaz and Taner (1994). A section of a constant plane-wave slope *p* illuminates the subsurface with a specific angle at the surface. On these constant *p* sections we will have specular reflections appear as quasi-linear continuous events and diffracted waves will appear in the quasi-hyperbolic shaped traveltimes (Green's functions). We can now use the plane-wave destruction filter (Fomel, 2002) to suppress the specular events and to obtain a section containing mainly diffracted events and residual specular reflection energy. Since the resulting traces are Radon transformed traces, their S/N ratio should be better than the original traces in the time domain. The scattering objects (faults, fractures etc.) will be imaged on the migrated (time or depth) common *p* sections.

In summary, our flow for wavefield separation is:

1) Generate split spread common source records;
2) Plane-wave decompose each common source record;
3) Sort into constant *p* sections;
4) Plane-wave destruction filter on constant *p* sections;
5) Velocity analysis for migration;
6) Migrate individual *p* sections and then sum to produce a prestack migration image.

Example

Figure 3a shows a synthetic single end shot gather for a model containing numerous sharp structural discontinuities producing numerous diffraction events. To perform plane-wave decomposition for shot records we constructed a split spread observation geometry using the reciprocity as it is described above (Figure 3b). Figure 4a shows plane-wave decomposed shot gather and Figure 4b illustrates the same shot gather reconstructed by an inverse Radon transform.

Repeating plane-wave decomposition for all shot records we obtain common p section for entire line. Figure 5 and 6 show two common p sections for different p parameter: 0, 0.5. Applying the plane-wave distruction filter to each of the total wavefield sections (left) we obtain the corresponding sections containing mostly diffraction energy (right). It is interesting to observe that some of the separated events in the deeper part of the sections are actually not diffractions but triplications of the propagating plane wave caused by lateral velocity variations.

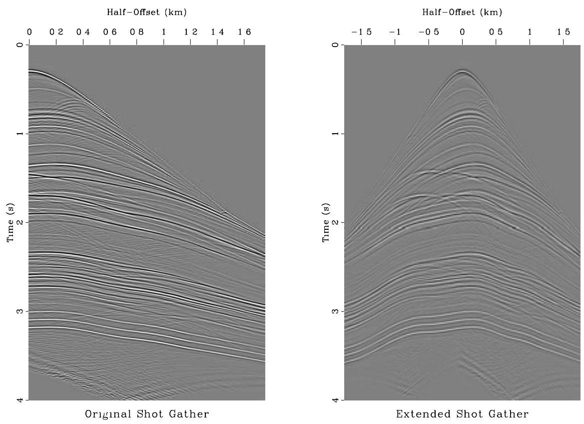


Figure 3. Single ended (left) and split-spread (right) shot gather.

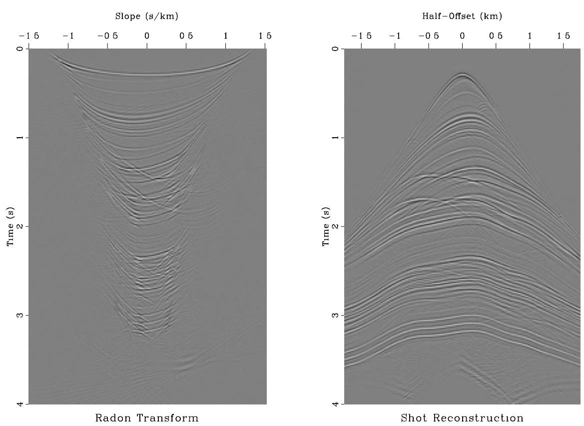


Figure 4. Radon transformed (left) and reconstructed by inverse Radon transform shot gather

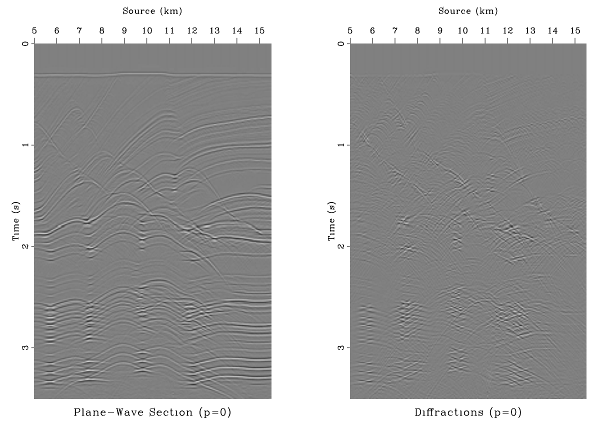


Figure 5. Common p (p=0) section of the total wavefield (left) and after wavefield separation (right).

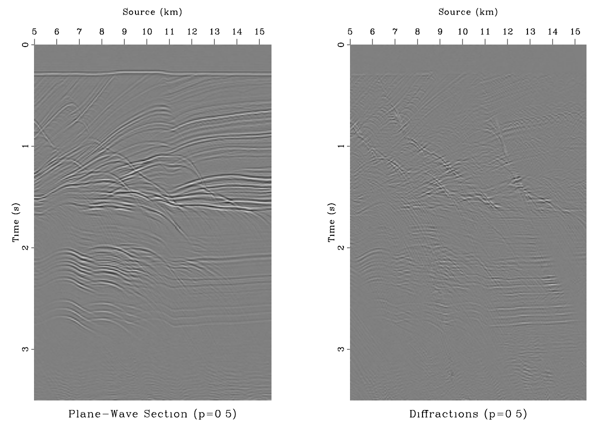
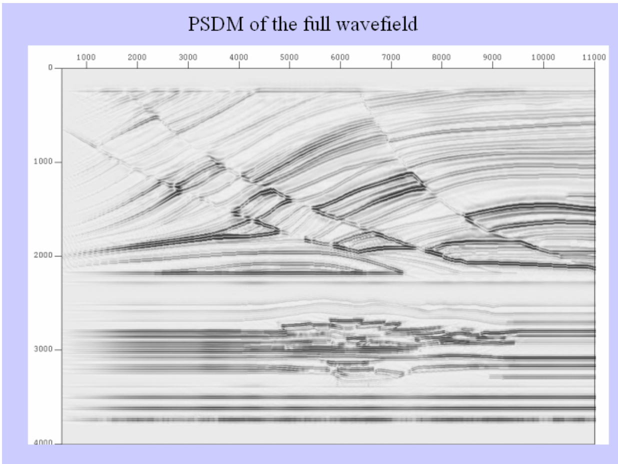
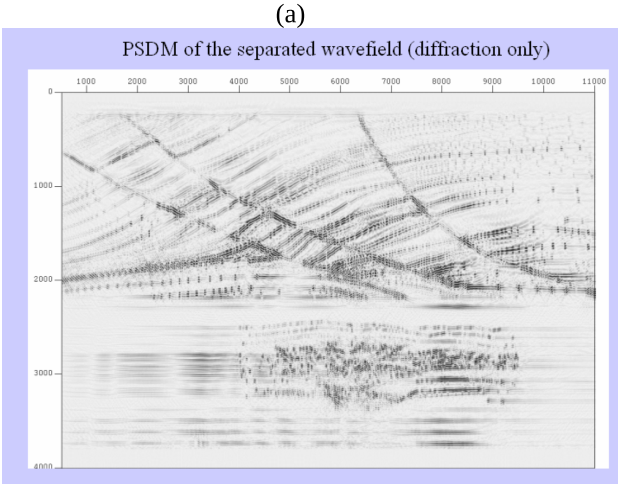


Figure 6. Common p (p=0.5) section of the total wavefield (left) and after wavefield separation (right)

Sorting back to shot domain and applying inverse Radon transform we obtain seismic records containing diffraction events and residual specular reflection energy. These records now can be used for velocity model estimating, time or depth imaging and should emphasize sharp discontinuities of the subsurface. Figure 7 shows prestack depth migrated image of the total wavefield (a) and “diffractions only” components (b). Most of the scattering objects which are masked on the conventional section (a) can be observed on the “diffractions only” section (b).



(a)



(b)

Figure 7. Prestack depth migration of the full wave-field (a) and the separated diffractions (b).

Conclusions

The objective of this paper is to show that plane-wave constant *p* sections contain diffraction patterns that directly obey the wave equation together with specular reflectors. In contrast to point source sections, plane-wave sections contain specular events that appear as simply shaped laterally continuous events. Diffracted events appear in the form of focusing operators with a delay equal to the travel time from the source wave origin to the point scatterer.

This observation allowed us to develop a method for diffraction separation and imaging based on applying plane-wave destruction filtering on plane-wave sections. Separated and imaged diffractions can provide valuable information about small-scale subsurface features such as faults, fractures, rough salt boundaries, channels, etc.

Although we show only a 2-D example in this paper, our method is applicable to 3-D plane-wave decompositions such as those recently described by Zhang et al (2005).

References

Claerbout, J. F., 1992, Earth sounding analysis: Processing versus inversion: Blackwell.

Claerbout, J. F., 1994, Applications of two- and three-dimensional filtering: 64th Ann. Internat. Mtg, Soc. of Expl. Geophys., 1572–1575.

Fomel, S., 2002, Applications of plane-wave destruction filters: Geophysics, **67**, 1946–1960.

Fomel, S., E. Landa, and M. T. Taner, 2006, Post-stack velocity analysis by separation and imaging of seismic diffractions: 76th Ann. Internat. Mtg, Soc. of Expl. Geophys., submitted.

Gardner, G. F. and L. Lu, eds., 1991, Slant-stack processing: Soc. Of Expl. Geophys.

Harlan, W. S., J. F. Claerbout, and F. Rocca, 1984, Signal/noise separation and velocity estimation: Geophysics, **49,** 1869-1880.

Landa, E., V. Shtivelman, and B. Gelchinsky, 1987, A method for detection of diffracted waves on common-offset sections: Geophysical Prospecting, **35,** 359-373.

Landa, E. and S. Keydar, 1998, Seismic monitoring of diffracted images for detection of local heterogeneities: Geophysics, **63**, pp 1093

Schultz, P. S. and J.F. Claerbout, J. F., 1978, Velocity estimation and downward continuation by wavefront synthesis: Geophysics, **43**, 691-714.

Taner, M. T., 1976, Simplan: similated plane-wave exploration, 46th Ann. Internat. Mtg., Soc. Expl. Geophys., 186-187.

Yilmaz, O. and M. T. Taner, 1994, Discrete plane-wave decomposition by least-mean-square-error method: Geophysics, **59**, 973-982.

Zhang, Y., J. Sun, C. Notfors, S. H. Gray, L. Chernis, and J. Young, 2005, Delayed-shot 3D depth migration: Geophysics, **70,** E21-E28.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2006 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Claerbout, J. F., 1992, Earth sounding analysis: Processing versus inversion: Blackwell Scientific Publications, Inc.

———, 1994, Applications of two- and three-dimensional filtering: 64th Annual International Meeting, SEG, Expanded Abstracts, 1572–1575.

Fomel, S., 2002, Applications of plane-wave destruction filters: Geophysics, **67**, 1946–1960.

Fomel, S., E. Landa, and M. T. Taner, 2006, Post-stack velocity analysis by separation and imaging of seismic diffractions: Presented at the 76th Annual International Meeting, SEG.

Gardner, G. F., and L. Lu, eds., 1991, Slant-stack processing: SEG.

Harlan, W. S., J. F. Claerbout, and F. Rocca, 1984, Signal/noise separation and velocity estimation: Geophysics, **49**, 1869–1880.

Landa, E., and S. Keydar, 1998, Seismic monitoring of diffracted images for detection of local heterogeneities: Geophysics, **63**, 1093.

Landa, E., V. Shtivelman, and B. Gelchinsky, 1987, A method for detection of diffracted waves on common-offset sections: Geophysical Prospecting, **35**, 359-373.

Schultz, P. S., and J. F. Claerbout, 1978, Velocity estimation and downward continuation by wavefront synthesis: Geophysics, **43**, 691–714.

Taner, M. T., 1976, Simplan: Similated plane-wave exploration: 46th Annual International Meeting, SEG, Expanded Abstracts, 186–187.

Yilmaz, O., and M. T. Taner, 1994, Discrete plane-wave decomposition by least-mean-square-error method: Geophysics, **59**, 973–982.

Zhang, Y., J. Sun, C. Notfors, S. H. Gray, L. Chernis, and J. Young, 2005, Delayed-shot 3D depth migration: Geophysics, **70**, E21–E28.