AAPG Search and Discovery Article #90173 CSPG/CSEG/CWLS GeoConvention 2011, Calgary, Alberta, Canada, May 9-11, 2011

Application of CSP Gather Modeling for Determination of Velocity Smoothing Operator for Prestack Kirchhoff Depth Migration

Hassan Khaniani *
CREWES, University of Calgary
khaniani@ucalgary.ca
and
John C. Bancroft
CREWES, University of Calgary

Summary

Optimum smoothing is required in the ray based prestack Kirchhoff depth migration to handle complex velocity models. It also ensures numerical consistency and validity of modeling of the finite difference data using ray tracing methods. In this paper, we studied the feasibility of performing the depth migration by Equivalent Offset Migration (EOM) that is a time migration method. In this direction, the techniques for CSP gathers modeling by ray tracing method are explained. Using the modeling of the CSP gathers we showed that it is possible to determine the optimum smoothing operator for ray tracing operation.

Introduction

The relationship between reflection and diffraction traveltime surfaces in the shot records is that the response of the scatter points (diffraction curves) is tangent to the reflection traveltime surface. In addition, the tangency between diffraction and reflection traveltime surface are a constructive interface. This is the basis for Kirchhoff migration algorithms (see e.g., Claerbout, 1985). In prestack Kirchhoff migration approach, it assumes the location of a scatter point within the model, and then gathers all appropriate energies from all available input traces and relocates it to the position of that scatter point (Bancroft, et al., 1998). Prediction of the diffractions traveltime response depends on waves propagating from sources location to the scatter points, and from the scatter points to the receivers. The CSP gather is an intermediate image gather in EOM. It is designed to collect all the possible diffraction energies based on a formulation that maps and sum the data with no time shifting (Bancroft et al, 1998).

In the complex structures, prediction of diffraction traveltime curves is a challenging problem that can be approximated by ray tracing methods. One of the concerns in ray based methods is that the foundation of ray tracing techniques is based on the high frequency assumption of wave equation. Therefore, to be able to model seismic signals by ray tracing, the spatial variations of velocity and its derivatives should be small with respect to the wavelength of the signal under consideration (Gray, 2000, Gajewski et. al., 2002). This requires smoothing of the model.

In a study by Gray (Gray, 2000), he pointed out that appropriate smoothing is determined by optimizing between scattering of the rays, distorting the structure of the earth model, losing of the accuracy in the velocities, creating a poorer image and causing a depth shift in the resulting image. As an empirical criteria, Kramps (Kramps , 2003) suggested a maximum vertical velocity derivative of less than 50, and a horizontal one of less than 20 for depth migrations. In both of the above approaches, optimum amount of velocity smoothing are found by the visual inspection of the final image after full prestack depth migration which are expensive and time consuming.

In this paper, we first present the possibility of modeling of the scatter points response in the CSP gathers using ray tracing methods, then by a numerical example, by comparing the constructed wavefront using the ray based method with finite difference method, we find the optimum smoothing operator. Finally, we show that optimum smoothing can be also obtained by comparing the modeled CSP gathers (computed by ray based traveltime) with the real data CSP gathers (computed by shot records). We implemented this approach on Marmousi 2-D synthetic dataset (Versteeg, 1994) and the results show that it is efficient and practical.

CSP modeling for depth migration

Scatter point response were modeled using the rays that depart from the scatter point into different directions (i.e., equally from -90 to +90 degrees with respect to the depth axis), then their traveltimes were recorded when the rays reach to the surface. Then the CSP gathers were simulated by converting the traveltimes of the scatter points to the equivalent offset domain.

About the accuracy of this simulation, for the case where the lateral velocity variation is negligible, all of equivalent offset domain data lie on the hyperbolic NMO path but in the case of strong lateral velocity variation, the definition of equivalent offset (i.e., the collocation of the sources and the receivers) is approximate and the events coherency reduces. In fact two reasons affect the accuracy of forward modeling. The first reason is the traveltime from scatter point to the receivers that determines the shape of diffraction curve as well as the effects of caustics. The second reason is the traveltime from scatter point to the sources. According to Kirchhoff theory, the shapes of diffraction energy are identical in all the shot records but they have different arrival times from the shot to the scatter point. Hence, the modeling process will be more accurate if the CSP data contained the information from adjacent shots.

Numerical example and results

Ideally, optimum smoothing operator should be found for several coordination of the model for the ray based depth migrations. However, for our analysis, we selected a scatter point located at (5500, 2450) m coordination of the Marmousi velocity model. This scatterpoint is located within a highly complex structure zone of the model. First, using finite difference algorithm, three propagating wavefronts initiated from the scatter point for times of 0.3s, 0.6s and 0.9s are computed. After applying a band pass filter by frequencies of 0 Hz, 10 Hz, 35 Hz and 55 Hz , for their illustration, we overlaid them on the velocity field in Figure 1. In the second step, we constructed the wavefront based on the traced rays initiated from the scatter point. The raytracing process was done by applying circular-shaped (Gaussian) smoothing operators with the lengths of 50 m, 150 m, 250 m and 500 m on the reciprocal of the velocity model (i.e., 1/v). The grid size of the velocity model was 12.5 m in both depth and lateral coordination. Constructed wavefront by ray tracing method (in different smoothed medium) and the finite difference method are compared in Figure 1a, 1b, 1c and 1d. They indicate that the traced rays in the medium with 250 m smoother length have optimum stability, accuracy and consistency. The blue dots in Figure 2 compares the one-way diffraction curve from the ray tracing method (250 m smoothed medium) and the finite difference method. From this smoother length the behaviour of traveltime scattering and the effects of the caustics as well as amplitude can be explained.

To demonstrate the feasibility of the CSP modeling, we used the ray tracing traveltime in 250 m smoothed medium. Figure 3a shows the modeled scatter point response in four different shot records. As expected (from the ray path and caustics) in Figure 3b, the mapped shots record data to equivalent offset domain experience fluctuations in the CSP gather. These fluctuations are less in left side of the gather. Hence, for observing the coherent event, we rely more on the left side of the CSP gather.

By this theory, to recover the diffraction curve of Figure 2, using only 50 shot records around the scatter point, we formed the corresponding CSP gather (see Figure 4). Comparing four smoothed medium ray based traveltime shows that by increasing the smoothing operator length to 250 m, optimum fit with CSP gather is obtained and fluctuations of modeled traveltime is less compared with 50 m and 150 m. Modeling with the smoother length of 500 m is not desirable since large smoothing length caused a losing of accuracy in the velocity model and consequently the resolution of modeled traveltime.

Conclusions

The CSP gathers are a side product of the Equivalent Offset Migration (EOM). It is defined based on constant migration velocity of the geological model. In the first part of this work we studied the accuracy of the modeling of the CSP gathers for the mediums that have lateral velocity variations. In the second part, using a numerical example, we compared the constructed wavefronts from ray based and finite difference method to determine the optimum length of smoothing operator for ray tracing. Finally, we showed that optimum smoothing can also be determined by comparing the CSP gathers modeled from the ray tracing data and the CSP gather formed from the shot records. This will lead to a more accurate algorithm for converting the EOM from time to depth migration.

Acknowledgements

The authors would like to thank all CREWES sponsors, staff and students for their supports. We also thank Gary F. Margrave, Hugh Geiger, Pat Daley, Faranak Mahmoudian and Mahdi Al-Mutlaq for their useful suggestions and comments.

References

Bancroft, J. C., Geiger, H. D., and Margrave, G. F., 1998, The equivalent offset method of prestack time migration: Geophysics, **63**, 2042-2053.

Claerbout, J. F., 1985, Imaging the earth interior: Blackwell scientific publications.

Gajewski, D., Coman R., and Vanelle C., 2002, Amplitude preserving Kirchhoff migration: a traveltime based strategy: Stud. geophys. geod., **46**, 193−211

Gray, S., 2000, Velocity smoothing for depth migration: How much is too much?, 70th Ann. Internat. Mtg: Soc. of Expl. Geophys., 1055-1058.

Kamps, B., Smoothing velocities for depth migration, unpublished report, Tsunami Development. http://www.tsunamidevelopment.com

Versteeg, R. J., 1994, The Marmousi experience: Velocity model determination on a synthetic complex data set, Rice University

Yilmaz, Ö., 1989, Velocity-stack processing: Geophys. Prosp., **37**, 357-382.

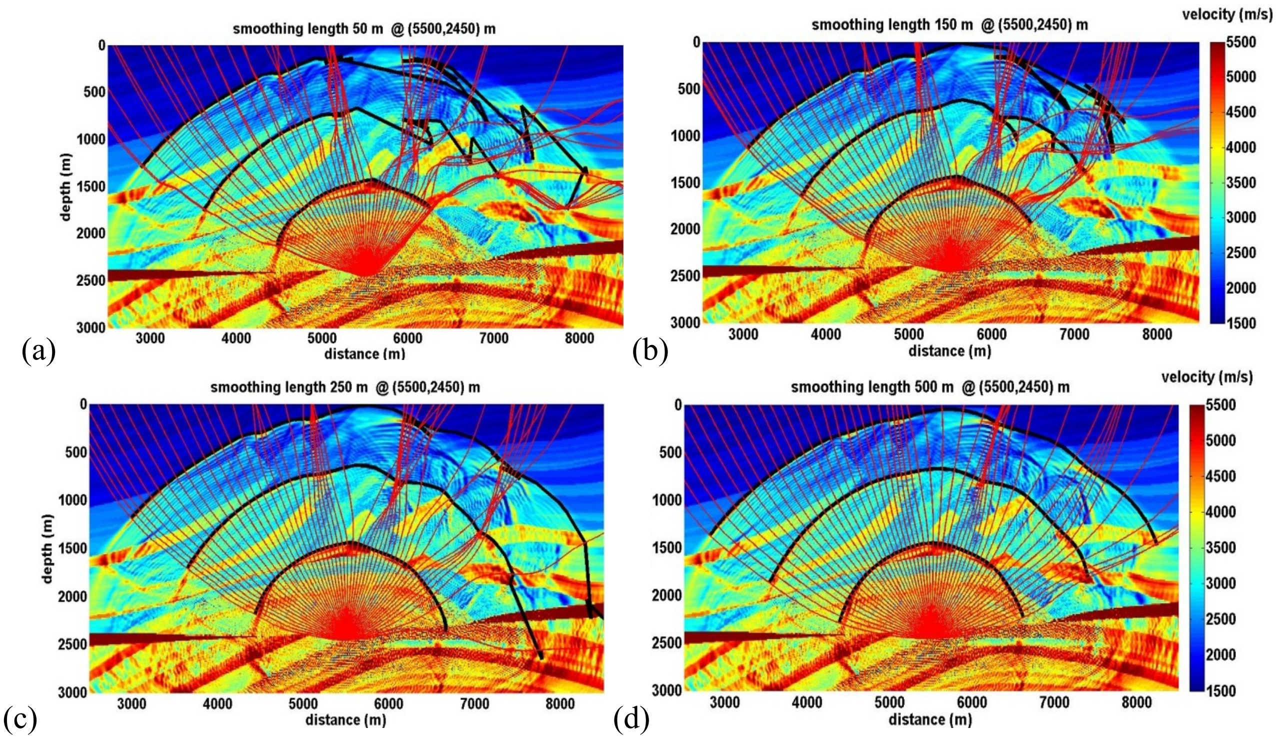

Figure 1: Effects of smoothness on accuracy and behaviour of the rays for the traveltime computations in the mediums smoothed with operator length of (a) 50 m (b) 150 m (c) 250 m and (d) 500 m.

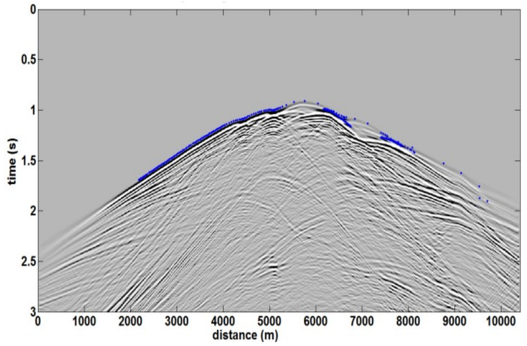

Figure 2: Comparison of one-way diffraction time from ray tracing and the finite differences. The blue dots are the ray tracing traveltime versus the receiver positions.

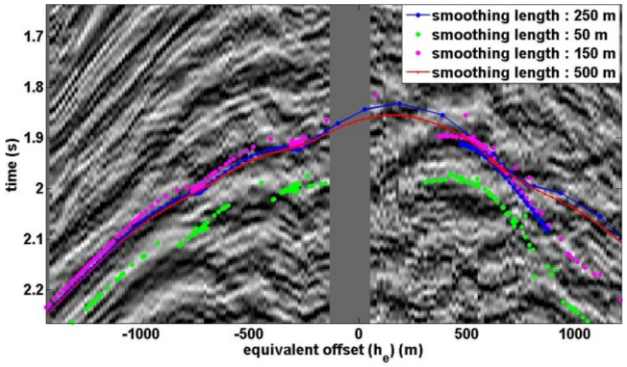

Figure 4: Comparison of Simulated CSP gather formed from the ray tracing and the real CSP gather formed from the shot records. The blue curve has the most optimum fit.

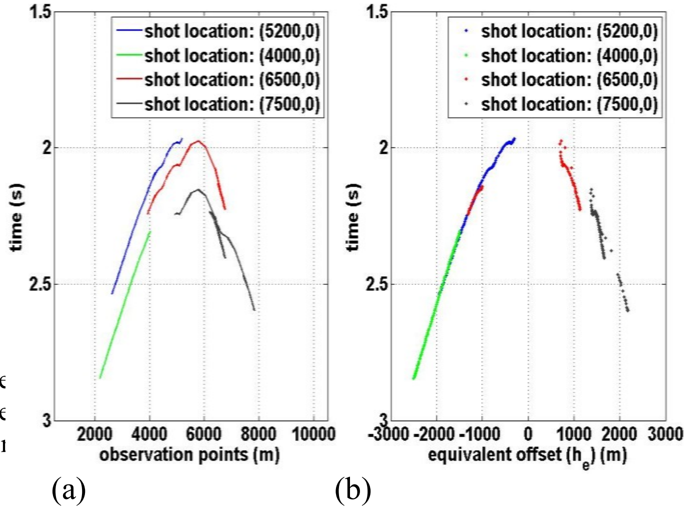

Figure 3: Feasibility of CSP gathers modeling. One scatterpoint response of the model in four shot records by (a) location of involved receivers converted to (b) equivalent domain.