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Kirchhoff's Depth Migration over Heterogeneous Velocity Models with Ray Tracing Modeling Approach

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***Abstract*—**Complex seismic signatures are generated due to the complexity of the subsurface which is difficult to interpret. In the present study, an attempt has been made to model the complex subsurface using the Ray tracing modeling technique. Add to this, for the imaging of these geological features, Kirchhoff's prestack depth migration is applied over the synthetic common shot gather dataset. It is found that the Kirchhoff's migration technique in addition with the Ray tracing modeling concept has the flexibility towards the imaging of various complex geology which gives satisfactory results with proper delineation of the reflectors at their respective true depth position. The entire work has been carried out under the MATLAB environment.

***Keywords*—**Kirchhoff's migration, Prestack depth migration, Ray tracing modeling, Velocity model.

I. Introduction

SEISMIC numerical modeling is a technique used to produce a seismic section from the desired geological model. Different types of seismic modeling techniques are performed, basically of, Wave equation solved by direct methods, Ray tracing methods and Integral methods based on integral representation of wave fields using Huygens' principle. Among all these techniques, Ray tracing methods are very frequently used in seismic modeling and imaging [3]. This Ray tracing theory used energy in the form of rays, which travels along minimum time paths in the desired model. The computing time is also significant in this method. The model building approaches become equally as important as seismic forward realization methods [1].

Migration is a mathematical process that reconstructs the seismic sections so that reflectors are repositioned to their true subsurface location. It also improves the resolution of the seismic section. In practical applications, two types of migration are performed i.e. time migration and depth migration. In time migration, the vertical dimension of the migrated section is observed in terms of time, whereas in depth migration by using appropriate velocity information, the vertical dimension of migrated reflection times are converted into reflector depth: which improves the quality of migration. Except from this, migration can also be applied before or after stacking of the seismic gathers.

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Kirchhoff's prestack depth migration is performed by using ray parameter information, which is measured either from common shot or common receiver gathered data. However, many researchers have discovered that Kirchhoff algorithms using first-arrival travel times do a poor job of imaging complex structures [6], [5]; although, Kirchhoff's migration is more accurate when it is applied to prestack seismic data. This migration is based on the diffraction summation approach, which can efficiently handle irregularities in the data in comparison to other wave equation based migrations [7]. Due to this characteristic, an improved result is obtained by the presented technique.

II. Theory and Methodology

In seismic migration, the reflectivity of geological boundaries is estimated, resulting in a structural image of the subsurface [4], [2]. In this present study, various geological velocity depth models such as fault, anticline, and syncline structures are developed by detecting model dimension and is followed by selecting horizons and dipping interfaces. For these velocity depth models, a code has been developed by the help of MATLAB.

The inhomogeneous velocity model is generally the sum of the background velocity model and the scattered one. The background velocity model is deviated slowly and the scattered one is deviated rapidly. Mathematically given as:

$$(x) = v_0(x) + \delta v_1(x) = v_0[1 + \epsilon(x)] \quad (1)$$

where; $\epsilon > 0$ is a dimensionless parameter. In Ray theory, Green's function is performed as a background function which is basically a high frequency approximation. So that, now consider the wave equation of the velocity model in the frequency domain:

$$s(x,\omega) = \omega^2 c^{-2}(x) u(x,\omega) + \nabla u(x,\omega) \quad (2)$$

where; $s(x,\omega)$ is the source function at a trial point x and ∇ is the Laplace operator. After this, the reflectivity series of the corresponding velocity model is computed. Then, the common shot gather data is generated aided by the reflectivity series. At this stage, the wave equation of the velocity model, which is in the frequency domain and works by starting from a point source and up to the total source area. Later, the prestack depth migration is applied over the common shot gather data.

During this step, also, the first migrated image is obtained at the trial point x. Mathematically given as:

$$m(x) = \sum_w \sum_r \propto (\omega, x, r, s)[G(x,s)^* \, G(r,x)^*] \, D(r,s) \quad (3)$$

where, $m(x)$ is the migrated image at the trial point x, $\propto (\omega, x, r, s)$ is the geometric spreading of the survey, $G(x,s)^*$ is the back-ground Greens function at the source s observed at the point x. Likewise, $D(r,s)^*$ is the common shot gather data at the source s and receiver r in terms of the frequency domain. This accounts only for the single scattering events. After obtaining this, then the energy is summing along the hyperbolic events throughout the common shot gather section, which results in the migrated image for total shot gathers. In the current implementation, MATLAB code is used to generate a reflectivity model, common shot gather data and also to perform the Kirchhoff's prestack depth migration.

III. Numerical Results

A. Numerical Modeling and Kirchhoff's Migration of Anticline

Fig. 1 (a) represents an anticline structure having a 100 by 100 grid points with a grid interval of 10 meters. This structure consists of three layers from which, the first one is a horizontal layer of a velocity of 811 meter/sec. In between the second and third layer, an anticline structure is observed, where the velocities are 1246 meter/sec and1752 meter/sec. The reflectivity series of the velocity model is shown in Fig. 1 (b). In this figure, all the reflectors appear at its true position. The common shot gather data for the current shot location number at 100 of the model is represented in Fig. 1 (c). A number of hyperbolic events appeared in the CSG data. At this processing step, a Ricker wavelet with central frequency of 50 Hz is used. The total number of traces calculated for this model is 389. The migrated section is illustrated in Fig. 1 (d). At the central region of the shallow horizontal reflector i.e. at a depth of 200 meters, some noises are seen. The noises that are present in the section could be due to the effect of numerical artifacts. With the exception of these, all the reflectors are repositioned at its true depth position and the amplitude is restored properly throughout the total structure which can be interpreted from the migrated section.

B. Numerical Modeling and Kirchhoff's Migration of Syncline

Fig. 2 (a) is the characteristics of a syncline structure having a 100 by 100 grid points with a grid interval of 10 meters. This structure also builds up three layers, from which, the first one is a horizontal one with a velocity of 811 meter/sec. The second and third ones are separated by a syncline structure where the velocities are 1246 meter/sec and 1752 meter/sec, respectively. Fig. 2 (b) represents the reflectivity series of the corresponding velocity model through which it is clearly visible that all the reflectors are reflected at its actual depth without any obstacle. After modeling, Fig. 2 (c) illustrates the common shot gather data for the current shot location at the distance of 3000 meters, in which a number of hyperbolic events are observed. The total number of traces generated is 389 and the model is operated with a Ricker wavelet with a central frequency of 50 Hz. The prestack depth migration algorithm is applied over this result is represented in Fig. 2 (d). From this migrated section, the anticline structure could be easily interpreted, in which all the reflectors are delineated at its actual depth position, as in the velocity model. Somehow, at a depth of near to 200 meters some noises appear, which are basically due to the impact of numerical artifacts. Except from these, at the point where the two dipping interfaces of the syncline structure meet each other, some noises also appeared. Overall, the amplitude restored properly throughout the migrated section.

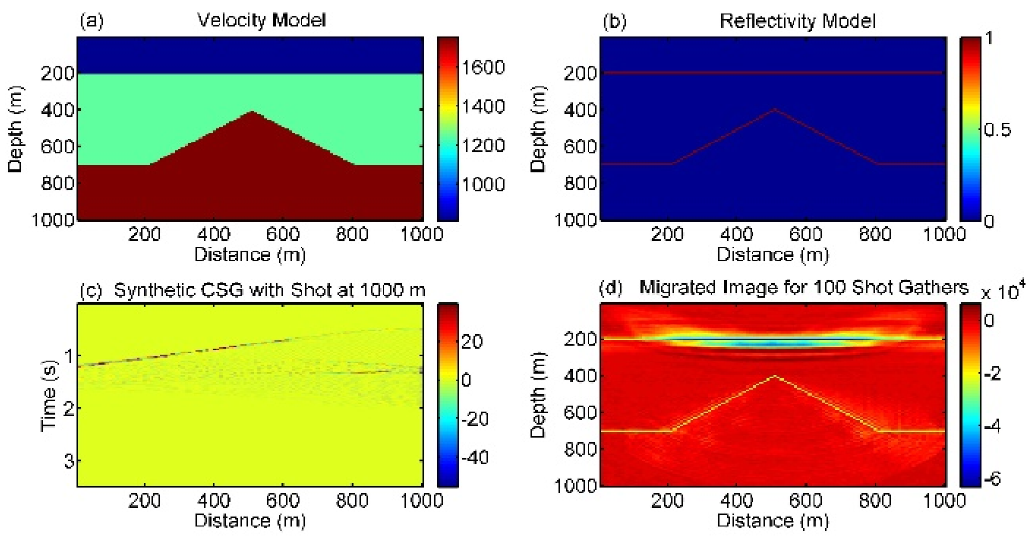

Fig. 1 Schematic diagram for modeling and migration of anticline

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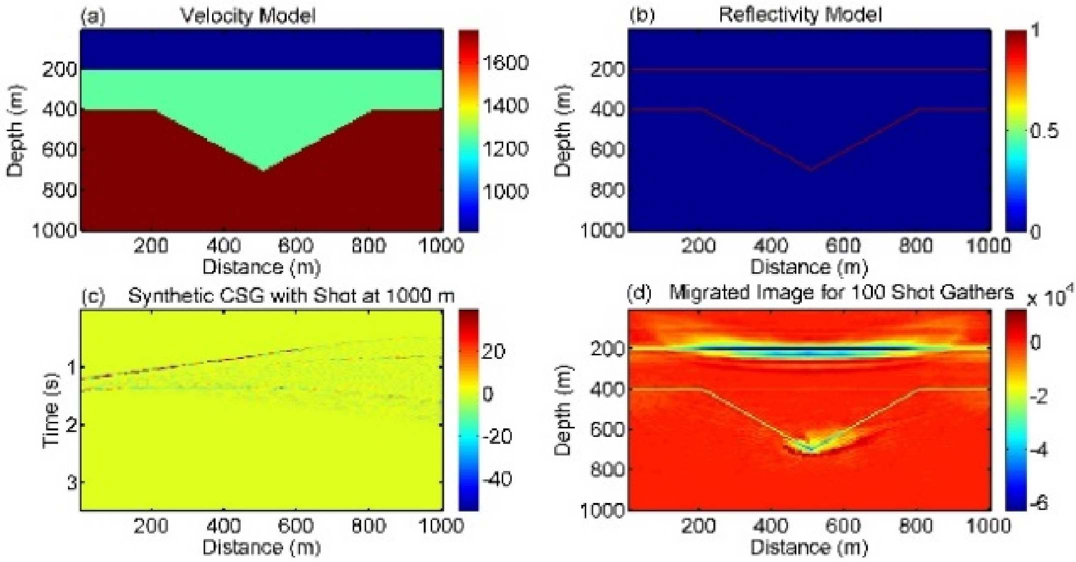

Fig. 2 Schematic diagram for modeling and migration of syncline

C. Numerical Modeling and Kirchhoff's Migration of Fault

In this study, a fault model with five horizontal and three dipping interfaces is presented, as shown in Fig. 3 (a), to demonstrate the effects of numerical modeling and Kirchhoff's migration. The velocity depth model is developed by 100 by 100 grid points with a grid interval of 10 meters. The velocity of each of the different layers is 1500 m/sec, 2400 m/sec, 3300 m/sec and 4000 m/sec, respectively. Fig. 3 (b) represents the reflectivity model of the corresponding velocity depth model. It is noticed that all the reflectors are seen clearly at its true depth position. Fig. 3 (c) is the common shot gather data at the current shot position at 3000 meters. In this modeling section, a Ricker wavelet with a high central frequency of 50 Hz is used. The total number of traces generated for this model is 1887 in number. It is noticed that various reflectors are showing a hyperbolic nature. The migrated image for the fault model is shown in Fig. 3 (d). A noticeable change is observed over the migrated section that the structure of the real model is restored properly with amplitude preservation; however, in some parts at the shallow smoothed horizontal reflector, i.e. at the depth position of 400 meters, noise can be seen. The noise appearing in the migrated section may be due to the abnormal behavior of some numerical artifacts.

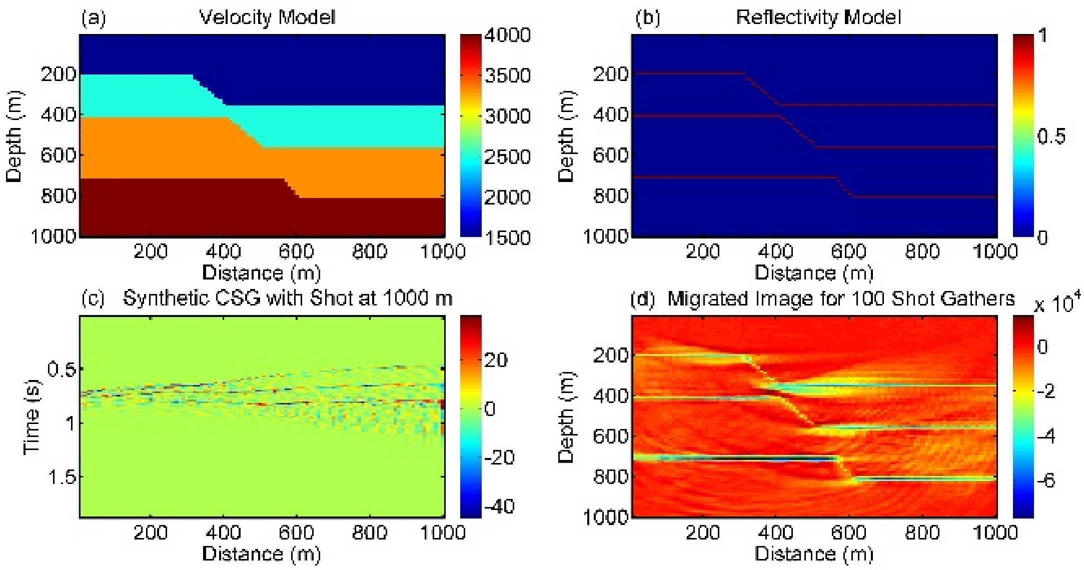

Fig. 3 Schematic diagram for modeling and migration of fault

IV. Conclusions

In this work, an attempt has been made to perform Kirchhoff's depth migration aid using the Ray tracing method. The efficiency to perform prestack depth migration is satisfactory. From the above numerical application, it observed that the seismic signatures over three geological models brings out geological interfaces with their true depth location, which has been seen in their corresponding reflectivity series. From a modeling point of view, in the common shot gather of each synthetic structure, a number of hyperbolic events are originated. With regard to the imaging section, all the reflectors are repositioned at their actual depth position with true amplitude restoration throughout each structure without any diffraction. The numerical results elaborated above have a smaller extent of error that some numerical artifacts are generated at the shallow depth of the migrated section. Future works could apply this process over 3D complex geological structures. In general, because of the coherence and respective effectiveness with computational efficiency, Kirchhoff's migration technique aid combined with Ray tracing modeling is termed as a consequential technique towards seismic modeling and imaging.

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