ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2006 (35 - 40)
VOLUME : 6
NUMBER : 1

AN APPLICATION OF KIRCHHOFF DEPTH IMAGING TECHNIQUE TO THE MULTI-CHANNAL SHALLOW SEISMIC REFLECTION DATA

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ABSTRACT

Applying Pre-satck Kirchhoff Depth Migration Technique to the multi-channel shallow seismic reflection data may be obtained successful results as well as obtained from the deep seismic reflection data. In order to test this approch, the technique converted the data, contains 40 seismic reflection records with 0.2 second record length and collected along straight profile, into the 120 meter depth section. The geometry of the layers and folding and faulting was revealed as depth as 120 meter in the image of the section. By comparing the fault plane emerged on the image with the corrupted parabola in seismic reflection records at the corresponding point, it is concluded that Pre-stack Kirchhoff Depth Migration Technique is capable not only imaging the layers at their correct places but also handling the parabola irregularity due to the fault structures and therefore it can be applied successfully to any shallow seismic reflection data too.

Keywords: *Seismic reflection, Pre-stack Kirchhoff Depth Migration, Shallow seismic reflection data*

1. INTRODUCTION

The seismic processing usually consists of three steps. These are pre-processing, stacking, and post-stacking processing. Pre-stacking processing generally consists of various filtering geometric correction applications to increase the signal/noise ratio and prepare the data for stacking processing. The data are converted into a seismic section in time by stacking processing that is a main processing in a seismic reflection procedure. Migration processing is applied to the section mainly for two reasons; first is to bring up the events to their correct location and second convert the data into a depth section. These processing steps have been standard application in seismic reflection studies [1].

A stacked section is processed under a number of assumptions. When these are violated, it may not be fully interpretable in some cases. NMO correction and the CMP stack ideally require laterally homogeneous and horizontally layered media. Even though small dips and mild lateral variations of velocities can be handled without significant extra effort, by increasing the degree

Received Date : 25.01.2005
Accepted Date: 10.12.2005

of lateral heterogeneity and the dips of layers, the two processes are performed very poorly [2]. If geologic structure is characterized by both strong lateral heterogeneity and steeply dipping layers, and as such cases the task of interpretation would be very difficult. Reflection points at depth deviate significantly from the midpoint locations and are not necessarily in the same vertical plane. These complexities caused reflections on the field records to have non-hyperbolic. Pre-stack migration is a process that can efficiently handle the geometric irregularities and lateral heterogeneities.

Pre-Stack Kirchhoff Depth Migration is the technique that is directly applied to the multi-channel reflection data records and inverts it to the migrated depth section. A number of studied have demonstrated that it is possibly to have advance interpretation from multi-channel seismic reflection data using Pre-Satck Kirchhoff Depth Migration Technique [3-7].

In this study, it is aimed to demonstrate that additional information may be obtained by applying Pre-Stack Kirchhoff Depth Imaging Technique to the shallow multi-channel seismic reflection data in addition to the results obtained by ordinary seismic stacking technique. For this purpose, the technique is applied to 40 multi-channal shallow seismic reflection records and all processing steps used are shown.

2. SEISMIC DATA AND PRE-PROCESSING

40 seismic reflection records are used in this study. The data acquisition parameters are as fallow: 24 channels with 2m shot and receiver arrays and 0.2 sampling and total record length is 0.25 s, were used. Survey has 2 and 48 m maximum and minimum offset respectively.

The pre-processing flows for the seismic reflection records included filtering, muting and stacking. In order to define frequency characteristics of the different events observed in the data, example three shot gathers were band-pass filtered through a range frequencies, from 1 to 600 Hz, at 50 Hz intervals. The results demonstrated that band-pass filtering the row shot gathers from 50-500 Hz yield the best signal to noise ratio for this study. Even though the band-pass filtering weakens the ground-roll but it still presents in the data. That makes it necessary to use velocity filtering to remove the ground-roll and other coherent noise from the shot records. (x,t)-domain technique of Hale and Claerbout [8] was used for this purpose. The average highest apparent velocity of ground roll and other coherent noise seen in the records was 1.0 km/s. A low-velocity-cut (high-dip-cut) filter also used to remove coherent noise having apparent velocities of 1.0 km/s in absolute value and lower. Figures 2a and 2b show 40 raw shot gathers before and after application of the frequency band-pass filter and the low-velocity-cut filter. The velocity filter obviously improved the signal-to-noise ratio but could not remove all of the noise from the data. A hand-picked mute are also applied to all data records to remove first arrival direct and refracted waves, enhancing the earlier reflections. The basic processing sequence was trace equalization gain, band-pass filtering, and velocity filtering, muting, normal move-out (NMO) velocity analysis, and common midpoint (CMP) gather and stack.

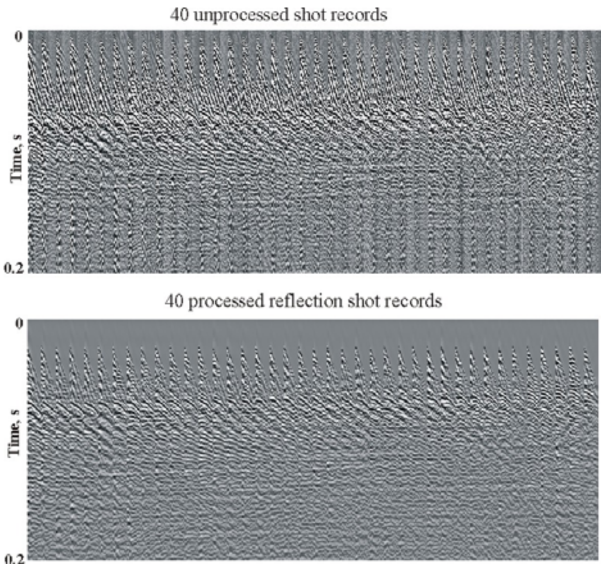


Figure 1. (a) 40 unprocessed data records on top and data records, (b) after applying band-pass and velocity filter and mute shown below.

In order to obtain the velocity information for Pre-stack Kirchhoff Depth Migration, CMP-Stacking technique was used and stacking section was obtained. To identify the best stacking velocity model by performing NMO velocity analysis, velocities picked from constant velocity test stacks made at 100 m/s increments ranged from 800 to 2400 m/s. After choosing the best stacking velocities as a function of time at several different shot locations, CMP-stacked sections were obtained (not shown). Table 1 shows the computed interval velocities that are used to check the picked velocities.

Table 1. Interval velocities obtained from the velocity analysis by seismic stacking processing.

Times (twt, s)	**Velocities (km)**	
	Stacking	**Interval**
0.034	1.2	1.2
0.067	1.5	1.67
0.096	1.7	2.14
0.12	2.0	2.23

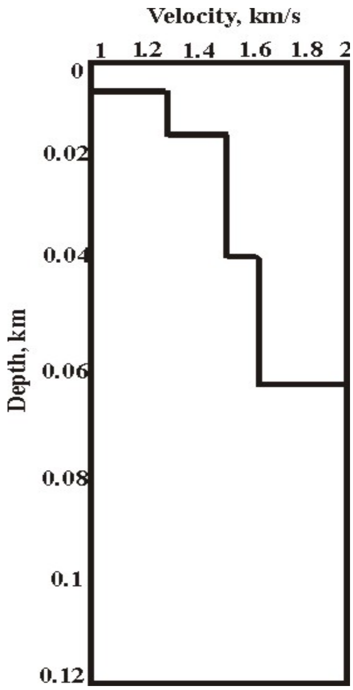


Figure 2. Interval velocities calculated from stacking velocities using Dix equation.

3. KIRCHHOFF DEPTH MIGRATION

The pre-stack migration algorithm used in this paper is Kirchhoff summation method. Based mainly on three assumptions, the method simplifies the task of inverting an elastic wave field for an image of the earth through which it has propagated [9]. The first one is the Born assumption that considers the scattered wave field to result from small, rapid variations in material properties which are superimposed on larger, slowly varying properties that effect only the propagation of the wave [3]. The second assumption is that the medium parameters vary slowly along the propagation through the medium to be regarded as a high frequency ray. This assumption is related the third assumption that the source and receiver have to be in far field relative to the reflector [3].

These assumptions reduce the inversion of reflection data to a process very similar to the Kirchhoff sum migration of Jain and Wren [2]. The method requires travel time curves computed from a velocity model. We used interval velocities obtained from the stacking velocity picks (Table 1) as the velocity model to calculate travel times using Vidale's [10] finite-difference solution of the Eikonal equation. The Kirchhoff pre-stack imaging is done by mapping unsorted seismogram traces into a depth section by computing the travel time from the source to the depth point and back to the receiver, through the velocity model. The travel time calculation includes turning rays, which allows for imaging reflections of the down-facing sides of structures. Within the travel times down to and up from every point in the data volume, the value of the seismogram is summed into the section at the depth point. Coherent and continuous events will indicate structure in the depth section. Figure 4 shows the results of Kirchhoff pre-stack migration.

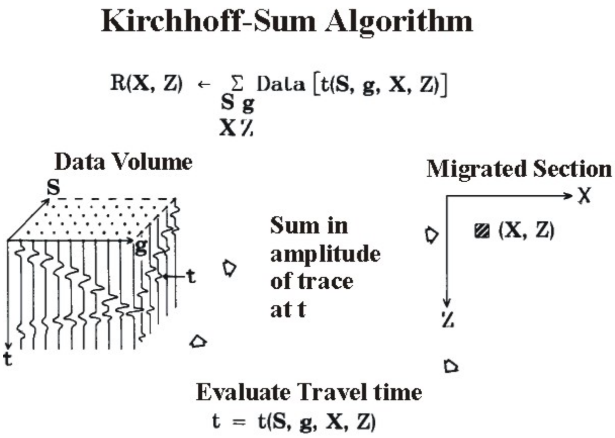


Figure 3. The figure sammurizes the processing of Pre-satck Kirchhoff Depth Migration Technique. The velocity model shown in Figure 2. was obtained from stacking velocities that are converted to interval velocities using Dix equation [11]. Once obtained best model the travel times are

calculated down to and up from each depth point. The value of the seismogram at that time than summed into the section at the depth point: This is done as each recorded reciever pair (S,g) over each point (X,Z) in some depth section, a traveltime is calculated. The amplitude of the recorded trace at that time is than summed into the point of the depth section. Figure modified from [3].

Figure 3 summarizes the Kirchhoff pre-stack imaging procedure. The data traces are mapped into a depth section by computing the travel time from the source to the depth point and back to the receiver, through the velocity model. The travel time calculation includes turning rays, which allows for the imaging of structures with dips. To allow for wave propagation through a model with laterally heterogeneous medium, the travel time calculation could take the form of ray-tracing through a variable-velocity medium [4]. Once the travel time down and up from every point in the data volume has been obtained, the value of the seismogram at that time is summed into the section at that depth point (Figure 3). Coherent and continuous events at that time will constructively interfere, which will indicate the presence of earth structure in the depth section. The tomographic sum, or the summation of arrival times, may be made in any order, since the Kirchhoff summation methods contains the geometrical configuration of the source, receiver, and the reflector as a function of time (Figure 3).

The travel time calculation for each individual trace should include many points of reflection along a three-dimensional projection of an ellipse. When Kirchhoff summation of all traces is calculated at a particular time, it will allow for the definition of a unique point in the earth for all ellipses calculated for each individual source-receiver pair. Figure 4a displays the travel time matrix calculations for source-receiver pairs. Kirchhoff summations, applying to only one and multi records are displayed in Figure 4b and 4c respectively. The amplitudes of each ellipse at each particular time have been summed. Kirchhoff summation method does not require a particular interest for which one section at a time can be migrated, as shown in Figure 4b, and 4c. On the base of tomographic summations of source-receiver pairs within the data volume, constructive interference of amplitudes will define vertical structure. The Kirchhoff migration does not require definition of ray path [3]. The ability to calculate travel times for laterally heterogeneous structures avoids the limitations of straight ray approximations. The summation of the value of each seismogram, or the amplitudes, at specified times will produce images of structures which vary laterally in velocity. A complete Kirchhoff pre-stack migration image is displayed in Figure 5.

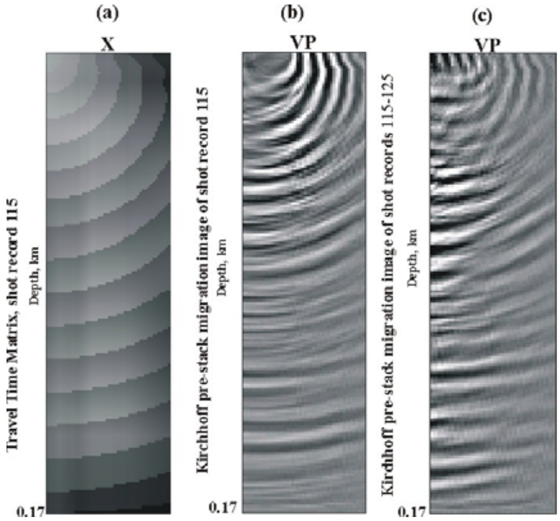
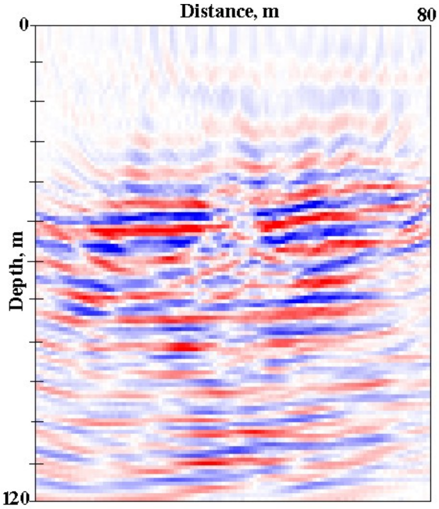


Figure 4. (a) travel times matrix that was calculated from the interval velocities shown in Figure 3. The matrix was calculated using Vidale's (1988) finite difference solution of the eikonal equation in two dimensions, (b) is the Pre-stack Kirchhoff depth migrated section for shot gather 115, relative to the entire study area. In this case, only gather 115 have been migrated. Not how the artifacts produced in the migration match the shape of the points of equal travel time shown in (a), and (c) is the Pre-stack Kirchhoff depth migrated section for shot gathers 115-120. The amplitudes of each trace at any particular time, as calculated in the travel time matrix, have been summed regardless of any particular ordering of the data.

4. RESULTS AND DISCUSSING

The pre-processing steps are same for stacking and Pre-Satck Kirchhoff Depth Migration techniques. In order to obtain velocity model, stacking technique is applied to the data to drive stacking velocities. Kirchhoff Migration technique requires a reliable velocity model that it was obtained by performing stacking analysis for this study (Figure 2). Travel times curves are calculated from the velocity model using Vidale's [10] finite difference equation method. The calculated travel time model was used as a velocity input for the technique. In Figure 4, (a) shows travel times matrix that was calculated from interval velocities, (b) the result that Kirchhoff technique is applied only one shot records and (c) Kirchhoff technique is applied five shot records. As it is seen from the figure, the amplitudes of the coherent event are summed in the section depending input velocity model reliability as adding more records for processing. The section obtained from 5 records is better result relatively to the section obtained from only one record.



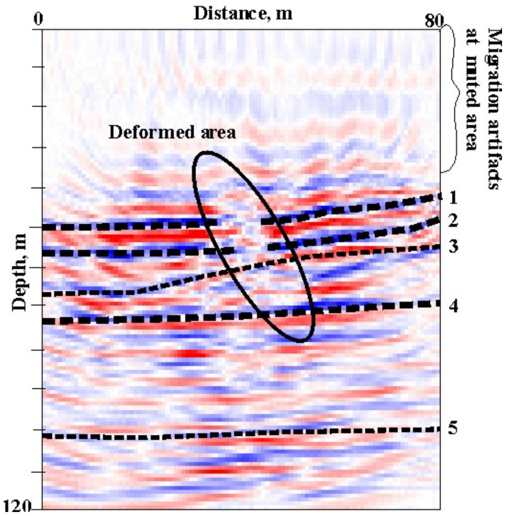


Figure 5. Pre-stack Kirchhoff depth migrated imaging section. A indicate migration artifacts polluting upper side of the section.

In Figure 5 interpreted and un-interpreted Pre-stack Kirchhoff Depth Migration section are shown. This section was obtained by applied the technique to the pre-processed 40 seismic reflection records. In the interpreted image, subsurface of the Earth layer are marked by given numbers. The data are imaged in 120 m depth and 5 layers are identified. The first and second layer having mild sloping toward left appears between about 43-57 m. The third layer emerged deformed has more sloping and at the end of the section starting the level of second layer riches 67 depth. This layer appear on the section weakly relatively to the upper layers. The fourth and fifth layer appears at 75 m and 100 m depth respectively.

As it is seen in Figure 6 another remarkable event in the image the strong deformation on the first and second layers that are separated each other by a fault plane. Three shot records corresponded the deformed area are shown in Figure 7. In the records the parabolas emerged about at 0.135 s (two way travel time) beginning from 18th receiver the arrival times make a sudden jump and being shorter. This indicates a fault plane that makes an offset as much as the length corresponding shorten time. The fault may be interpreted as trust fault since the arrival times are shorter at that point.

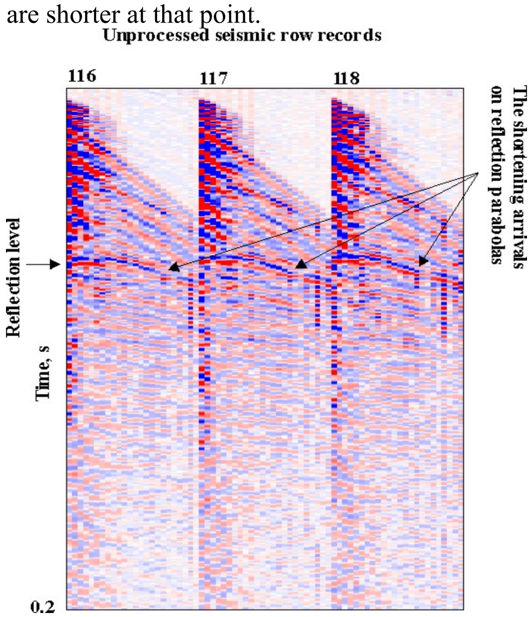


Figure 6. Seismic reflection shot records 116, 117, 118 showing the irregularities emerged on the first parabola. Starting from 16th receiver based on shot record 118 arrival times becomes much shorter.

5. CONCLUSION

In this study Pre-satck Kirchhoff Depth Migration technique was applied to 40 shallow seismic reflection data collected along a linear survey profile and this data set were converted to seismic section and imagined in depth domain. In order to obtain the result the all steps of a standard seismic reflection technique were applied to the seismic data but some of them are not presented here. Even though the stacking section is not presented here but it was used to deduce the stacking velocities.

In the image of Pre-stack Kirchhoff depth migrated section the layers and destructive structure and also their corresponding depth are very well defined. The first and second layers that appear in 45-55m depth range are corrupted a mild sloping fault structure that can be traced until 60 m depth. This shows Pre-stack Kirchhof depth migration technique is capable to image the irregularities of the parabola that are originated from a thrust fault. The corresponding records were shown in Figure 6. Figure 6 shows a suit of reflection records that indicate the reflection parabolas. The regularity of the reflection are destructed at Previous studies showed that relatively better results can be obtained from multi-channel seismic reflection data using this technique [3-7]. This study demonstrated that the technique also can be applied successfully to multi-channel shallow seismic reflection data and obtained additional interpretation.

REFERENCES

[1] Yılmaz, Ö., "*Seismic data processing: Society of Exploration Geophysicists*", 1987.

[2] Jain, S., Wren, A.E., "*Migration before stack – procedureand significance:*" *Geophysics*, 45, 204-212, 1980.

[3] Louie, J. N., Clayton, R.W., Le Bras, R. J., "*Three-dimensional imaging of steeply dipping structure near the San Andreas fault, Parkfield, California*", *Geophysics*, 53, 176-185, 1988.

[4] Louie, J.N., Qin, J., "*Subsurface imaging of the Garlock fault, Cantil Valley, California*", *J. Geophys. Res*., 96, 14, 461-14,479, 1991.

[5] Honjas, W., Louie, J.N., "*Results of post pre-stack Migrations imaging the Hosgri fault, offshore Santa Maria Basin*, *CA.*", *MSc Thesis*, Seismo lab., Univ. of Nevada, Reno, 1995.

[6] Kanbur, Z., Louie, J. N., Chavez-Perez, Plank, G., Morey, D., *Seismic Reflection Study of Upheaval Dome, National Park, Canyonlands, Utah*, *J. Geophys. Res.-Planet*. 105: (E4), 9489-9505, 2000.

[7] Kanbur, Z., "*Yığma öncesi migrasyon tekniği ile Marmara Denizi Tekirdağ Havzası yansıma verilerinin yorumlanması*", Doktora Tezi, İstanbul Üniveristesi, Fen Bilimleri Enstitüsü, 2002.

[8] Claerbout, J.F., "*Introduction to Imaging in Imaging the Earth's Interior"*, Blackwell Scientific Publication Inc. 238 Main Street Cambridge, MA 02142, USA, 1985.

[9] Le Bras, R., Clayton, R.W., "*An iterative inversion of back-scattered acoustic waves*", *Geophysics*, 53, 501-508, 1988.

[10] Vidale, J. E., "*Finite-difference calculation of travel times*:" *Bull., Seis. Soc. Am*., 78, 2062-2076, 1988.

[11] Dix, C.H., *Reflection seismic crustal studies: Geophysics*, 30, 1068-1084, (1965).