Offshore data processing by WCDP method

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Abstract

Practical realization of the Wave Analogue of the Common Depth Point (WCDP) Method is described. It is a seismic processing data based on the strong mathematical solution of inverse scattering problem in linear approximation by multiple overlapping data. The WCDP method is tested on field data from numerous oil reservoirs. The results show high quality of WCDP profiles and stability for a wave velocity choice.

Introduction

Presently the Common Depth Point (CDP) method (Mesbey, 1985) and different modifications of the wave migration method (Bleistein et al., 2001) are the basic ones for multichannel seismic data processing. The WCDP method is based on the strong mathematical solution of inverse scattering problem of acoustic waves in linear approximation by multichannel overlapping data. Such approach let us take into account all wave exceptions of reflection and diffraction of seismic waves. Using of input data overlapping increases in resulting profile the signal/noise ratio and allows, similar to CDP method, to do wave velocity analysis of medium. In our work we describe practical realization of WCDP method and show some results of its application to real data processing.

Statement of the problem and summation formula

Inverse scattering problem of acoustic waves in linear approximation consists in determination of function $a(r)$, describing heterogeneities of medium by wave field $u(x, x_0, t)$, recorded for different positions x_0 of source and x receiver situated on a free surface. This wave field satisfies the Cauchy problem (Bleistein, 2001)

$$\Delta u - \frac{1}{c_0^2}(1 + a(r))u_{tt} = d(r - r_0, t), \qquad (1)$$

$$u|_{t<0} \equiv 0,$$

where c_0 is background velocity of acoustic waves, $(r, r_0, t) \in R^2 \times R^2 \times R$, $r = (x, z)$, $r_0 = (x_0, z_0)$. The result of the problem solution is the following focusing operator (Kremlev, 1985; Kremlev et al., 2002)

$$b(r) = \frac{1}{(2p)^3}\int_{-\infty}^{\infty} dw \int_{-\infty}^{\infty} dk \int_{-\infty}^{\infty} dk_0 \, e^{i(k+k_0)x} f_c(z, k, k_0, w)\hat{u}(k, k_0, w), \qquad (2)$$

which allows us to calculate visualization function $b(r)$ being local average of required function $a(r)$ over domain with size of sounding signal wave length order. In formula (2) function $\hat{u}(k, k_0, w)$ is the spectrum of registered field,

$$f_v(z, k, k_0, w) = q\left(\left(\frac{w}{c}\right)^2 - k^2\right) q\left(\left(\frac{w}{c}\right)^2 - k_0^2\right) \cdot \left(\frac{c}{|w|}\right) \cdot$$
$$\cdot \sqrt{\left(\frac{w}{c}\right)^2 + kk_0 + \sqrt{\left(\frac{w}{c}\right)^2 - k^2} + \sqrt{\left(\frac{w}{c}\right)^2 - k_0^2}}$$
$$\exp\left\{-iz\left(\sqrt{\left(\frac{w}{c}\right)^2 - k^2} + \sqrt{\left(\frac{w}{c}\right)^2 - k_0^2}\right)\right\} \qquad (3)$$

is kernel of the focusing operator, $q(.)$ is Heaviside function and c is an *a priori* velocity of summation. Exponential factor in formula (3) describes shift under migration of wave field with respect to source and receiver coordinates, analogously to shift in migration by Gazdag (1978) and Stolt (1978), but at same time their multipliers are the result of exact problem solution. Focusing operator (2)-(3) is the basis of the WCDP method.

For practical realization of the WCDP method, we pass the summation formula (2)-(3) from "source - receiver" coordinates to "Common Middle Point - offset" ones:

$$m = \frac{1}{2}(x + x_0), \qquad (4)$$
$$l = x - x_0.$$

Let us mark as m and n the frequency variables corresponding to m and l. Because of invariance of wave phase we have $kx + k_0 x_0 = mm + nl$. Using (4) one obtains

$$k = \frac{m}{2} + n, \qquad k_0 = \frac{m}{2} - n. \tag{5}$$

Let $U(m,l,t)$ be wave field in (m,l)-coordinates and $\hat{U}(m,n,w)$ be its spectrum. One obtains from obvious equality $u(x,x_0,t) = U(m,l,t)$ and formulae (4)

$$u(x,x_0,t) = U(\frac{x+x_0}{2}, x-x_0,t), \qquad U(m,l,t) = u(m+\frac{l}{2}, m-\frac{l}{2}, t). \tag{6}$$

It is easy to establish by using formulae (6) the following connection between spectrums of reflected field

$$\hat{u}(k,k_0,w) = \hat{U}(k+k_0, \frac{1}{2}(k-k_0), w), \qquad \hat{U}(m,n,w) = \hat{u}(\frac{m}{2}+n, \frac{m}{2}-n, w). \tag{7}$$

By introducing a new variable

$$q = c\left(\sqrt{\left(\frac{w}{c}\right)^2 - k^2} + \sqrt{\left(\frac{w}{c}\right)^2 - k_0^2}\right) \tag{8}$$

and using formulae (7) it is possible to obtain the final variant of the summation formula (2)-(3)

$$b_v(m,t) = \frac{1}{(2p)^3}\int_{-\infty}^{\infty} dq e^{iqt} \int_{-\infty}^{\infty} dm\, e^{imm} \times \int_{-\infty}^{\infty} dn\, f_c(t,m,n,q)\,\hat{U}(m,n,q), \tag{9}$$

Here kernel $f_c(.)$ is defined by formula

$$\hat{f}_c(t,m,n,q) = \hat{f}_c(ct,k,k_0,w), \tag{10}$$

where $w = w(q)$ is a solution of equation (8). For numerical construction of WCDP profile by formulae (2)-(3) or (9)-(10) the corresponding integrals are changed by integral sums with finite summation limits both with respect to time variable and with respect to spatial coordinates too. There are two important advantages of formulae (9)-(10).

First, the summations with respect to time frequency q and spatial frequency m have the forms of Fourier sums and for their calculations we can use effective fast Fourier transform (FFT). The second reason is connected with choice of aperture summation. Consider general seismic plane giving on fig.1. Each seismic trace of 2D profile is characterized by coordinates (x, x_0) or (m, l) and can be represented as point on the plane. And more, all traces are situated in band $l < l_{\max}$, where $l_{\max}$ is the largest distance between source and receiver. The square *ABCD* (pink) on Figure 1 corresponds to the aperture in (x, x_0)-coordinates, its diagonal *AC* forms summation base. Choice of the summation base is determined by depth of disposition and inclination of reconstructed boundaries. Its size is bounded by volume of RAM of computer too, that is connected with possibility of effective reconstruction of spatial spectrum of wave field with help of FFT algorithm. Increasing of summation base in (x, x_0)-coordinates leads to appearance of the domains (the green triangles *BB₂K* and *DLD₂*) in aperture having no real seismic traces. For using of FFT algorithm we need to fill in by zero traces. It increases the volume of calculations but does not increase derivable profile comprehension. In "CMP-offset"-coordinates the aperture of summation is a blue rectangle, in which the summation base is parallel to m-axes. The rectangle *A'B'C'D'* corresponds to the same base of summation, see fig.1. Such rectangle has only real recorded seismic trace or traces that can be reconstructed from them by reciprocity theorem.

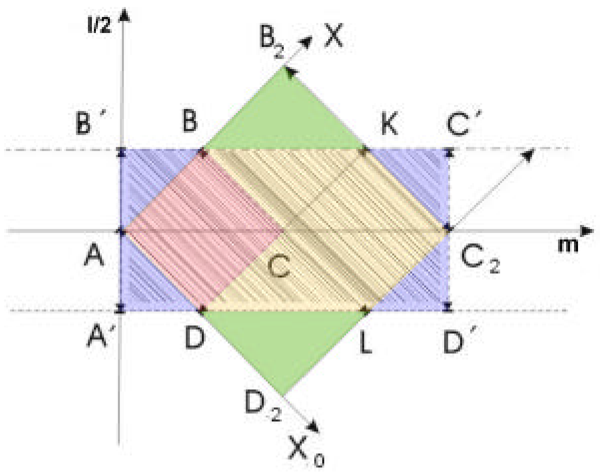

Fig.1- Aperture summation WCDP in (x, x_0) and (m, l)-coordinates.

Real data examples

The WCDP method was applied for two different seismic maritime surveys and comparative analysis with Kirchhoff and NMO-CDP-stack was done (Soares Filho et al., 2002; Misságia, 2003). The first example treats 2D line of Baikal Lake, Russia. The second one represents a 2D line extracted from 3D maritime survey denominated here as line A.

Results

Figure 2 shows the results and expanded view of the Baikal line reconstruction by WCDP and NMO-CDP-stack methods. Comparison of the two sections shows that WCDP method positions right the summation of both diffracted waves and reflected waves. Therefore, WCDP section is able to image small details of structures. CDP-NMO-stack section exhibits fault zone image distortions. In contrast, the WCDP image displays the structure clearly and offers superior imaging of the fault plane. It is possible by WCDP method to decrease the uncertainty and obtain new information about geological structures of offshore sediments, exhibit the nature of anomaly of wave field. According to details of Figure 2, by NMO-CDP-stack method the diffractions of seismic waves were scattered giving a section with noise and low contents of information.

Figure 3 represents two seismic sections and their windows of migration by Kirchhoff and WCDP methods of offshore line A. Comparison of these results shows that the WCDP section gives us a better signal/noise ratio, continuity and position of reflection, definition of fault plane; and its possibility to improve details of some events in comparison with another section, kind of normal-slip fault, the sigmoid, the salt base and reflection under the salt. Although the Kirchhoff section has shown this reflection, the diffractions of seismic wave were scattered, see domain about time 3.0s and trace 600 (above salt line), which means the section with low information level. In the WCDP section we observe that diffractions were well collapsed, because its integral formulation, by Born approximation include the diffracted term not present on the Kirchhoff procedure based on theory of rays, but yet significant to solve great lateral variations of disturbances of velocities. Another aggravation is this necessity of knowing well the input of velocity field. This stage dispensable in WCDP processing, as this part the uniform field velocity, which does not require velocity analysis a priori, and encounters internally an excellent value for the focalization velocity of reflection from each point of observation in seismic plane. Thus, we can say that WCDP does not neglect the forms of surfaces of reflections attributed to lateral variations and/or verticals media velocity. So displays an image that damages the distortions related to these variations that cause the pull-up and pull-down effect. Therefore by analysis of Figure 3 it is evident that the method is effective, able to evidence the fault of region, which are absent or badly focalized in the respective Kirchhoff profile.

The reason of superior quality of the WCDP method is due to migrating the seismic wave to the local of origin of secondary sources describing the diffractions and reflections of these waves. As a result diffracted and reflected waves will be focalized and positioned in the local of its generation, then the method visualized as the elements of diffraction just as smooth boundaries of great extension.

Conclusions

Investigation of exact solution of inverse acoustical problem in linear approximation with overlap data allows:

(1*) to take into account all wave singularities of seismic waves reflections and diffractions the most useful;*

(2) *to ensure useful signal accumulation*.

Practical realization of the WCDP method and its approbation on field data show high quality of reconstructed time profiles and good stability of the method for the choice of a priory velocity model. Reservation of real amplitudes and undistorted wave packages on time profiles makes promising using of WCDP for investigation of dissipative properties of geological media.

Acknowledgments

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References

Bleistein N.C.J., Cohen K.J., Stockwell-Jr. J.W., 2001, Mathematics of multidimensional seismic imaging, migration and inversion, Springer-Verlag, New York.

Gazdag J. and Sguazzero P., Migration of seismic data by phase-shift plus interpolation. Geophysics, n.49,124-131.

Kremlev A.N., 1985, Wave analog of CDP method, Geology and Geophysics, n.10, p.77-86 (in Russian).

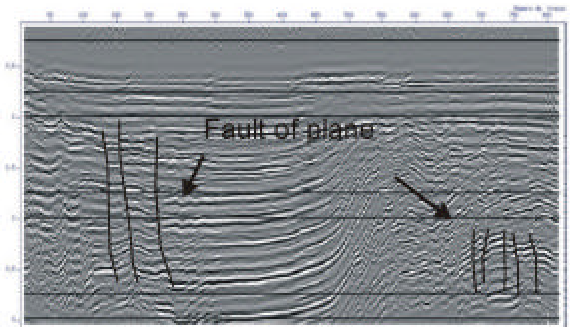
Kremlev A.N., Priimenko V.I., Oliveira S.A.M, Misságia R.M., 2002, Practical realization and testing of the wave analog of common depth point method on synthetic and real data, Bull. of the Novosibirsk Computing Center, Russian Academy of Sciences, Ser.: Math. Modelling in Geophysics, 7, pp.59-67 (in Russian).

Mesbey V.I., 1985, Methods of multiple overlappings in seismic exploration, M., Nedra (in Russian).

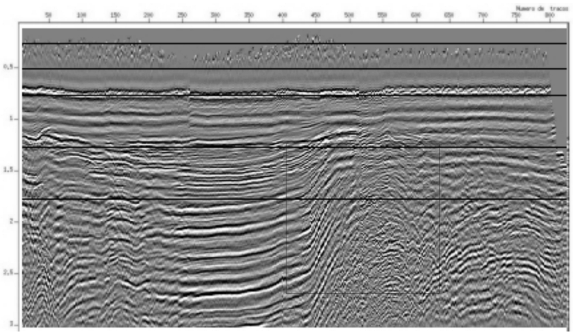
Misságia R.M., 2003, Improvement, practical implementation and test of WCDP imaging method application to synthetic on real data. PhD thesis. LENEP/UENF, Brasil, 104pp.

Soares Filho D. M, Priimenko V.I., Oliveira S.A.M., Roseane M. Misságia, Gomes E.C., et al., 2002, Processamento de dado sísmico com técnica de filtragem Proni e imageamento WCDP. Programa LENEP/CCT/UENF - CENPES/PETROBRAS. Contrato: 6502178017. Relatório Final, 159pp.

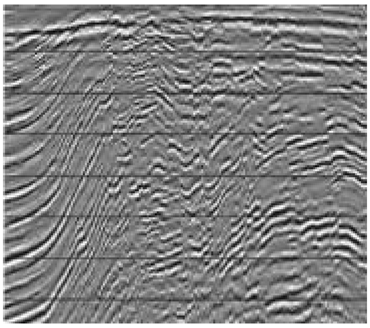
Stolt R.H., Migration by fourier transform. Geophysics, n.43, 23-48.



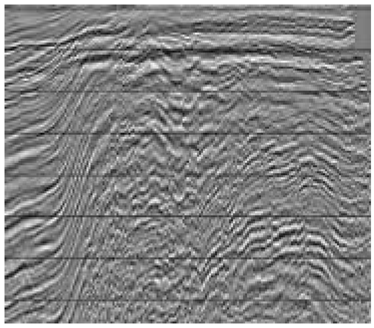
2D time WCDP section.



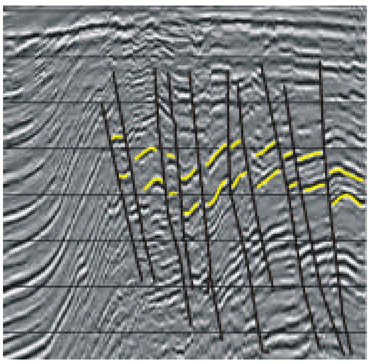
2D NMO – CDP-stack.



Expanded view of an area of fault zone in the WCDP section.

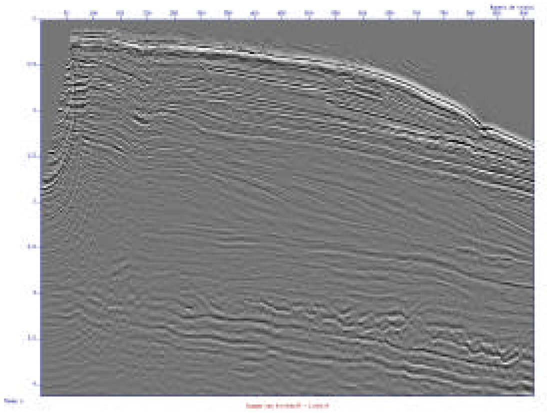


Expanded view of an area of fault zone in the NMO – CDP- stack.

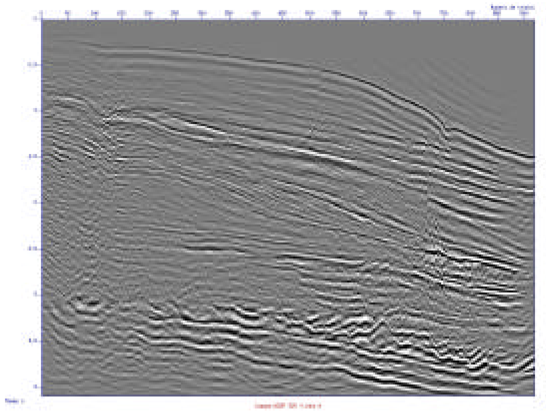


Expanded view interpretation of an area of fault zone in the WCDP section.

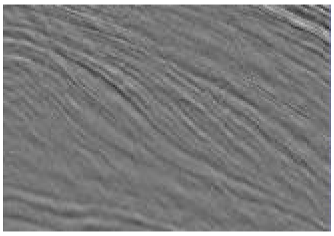
Figure 2 – A comparison of the two sections of Baikal Lake, Russia. NMO – CDP-stack exhibits distortions of fault zone image. In contrast, WCDP image displays the structure clearly and offers superior imaging of the fault plane as well.



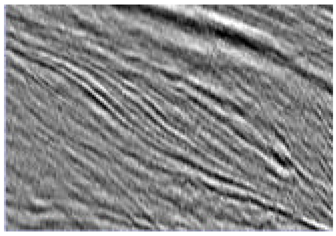
2D time Kirchhoff section.



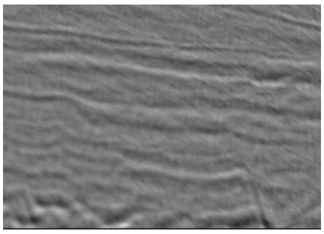
2D time WCDP section.



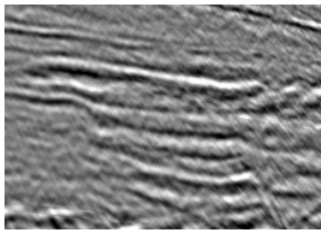
Expanded view of an area of sigmoid in Kirchhoff section.



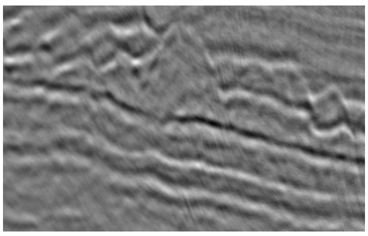
Expanded view of an area of sigmoid in WCDP section.



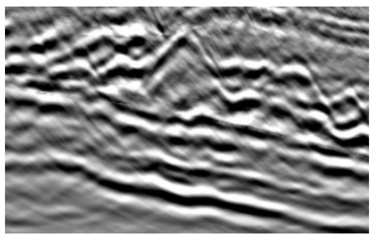
Expanded vi ew of an area of fault zone in the Kirchhoff section.



Expanded view of an area of fault zone in the WCDP section.



Expanded view of an area of salt line and reflection under salt in the Kirchhoff section.



Expanded view of an area of salt line, and reflection under salt in the WCDP section.

Fig.3 – A comparison of the two sections from a line A, Brazil. The Kirchhoff section exhibits distortions of fault zone image. In contrast, the WCDP section displays the structure clearly and offers superior imaging of the fault plane as well.