Indonesian Journal of Physics
Vol 19 No. 4, October 2008

Marine Seismic Tomography for Detecting Fracture and Void of Subsurface Seabed : a Theoretical Framework Development and Application of Wide-Band Fresnel Tomography

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Abstract

Fracture as well as void can generate unstable structure in offshore building. We use seismic tomography based on scattering wave instead of conventional raypath seismic tomography. Conventional raypath tomography usually needs dense source-receiver configuration as well as wide-angle measurement. Therefore, it will be high cost in field data acquisition.

We propose scattering wavepath tomography by means of Fresnel interpolated wavepath (FIW) wide-band inversion. FIW is an interpolation between imaginary part of Rhytov scattering wavepath and raypath. Then, FIW is combined with wide band inversion procedure to handle sparseness configuration of measurement. By this method, smooth constraint is implemented more naturally by based on wave's spectrum. In this paper, we showed some applications of Wide-band inversion of FIW tomography in imaging fracture and void in marine carbonate sea bed.

***Keyword**: Marine Seismic Tomography, Fresnel Interpolated Wavepath, Rhytov scattering, Fracture and void imaging, Wide-band inversion, Carbonate*

1. Introduction

In recent years, tomography has become an important tool for mapping unknown objects. Tomography is often used in medical engineering for finding tumors in the brain as well as in applied seismology for mapping the earth's interior, and in exploration geophysics for unraveling complex geological structure. Geotomography appears to be very serviceable since it can provide accurate estimates of seismic velocities regardless of their complexities.

This paper describes the identification of void and fracture in submarine area.

We have developed a new technology that can image clearly fracture, void, and intrusion using our own algorithm. The algorithm is based on Fresnel interpolated wave-path (FIW) wide-band inversion tomography. FIW is then combined with wide band inversion to produce a stable inversion procedure. Wide-band inversion of FIW tomography has been tested into various difficult and challenge seismic field data in order to image intrusion, void, fault and even fracture. The results shown that tomography based on FIW could handle the limitation of configuration angle, sparseness configuration and resulting good image. We have used this method in many difficult cases of field data such as: subsurface tunnel imaging and also void-fracture imaging in volcanic rock[1-3].

2. Theory

Seismic tomography is an inverse problem. The objective is to solve for seismic velocities as a function of position using measured travel times (arrival times if earthquake sources are used). If we measure M travel times (t_i, i = 1, 2, . , M) and assume ray theory is valid, each time can be related to some unknown function u(**r**), which characterizes the slowness (l/velocity) as a function of position through the relation

$$t_i = \int_{\Gamma_i} u(\mathbf{r})\, ds \qquad (1)$$

Γ_i is the ray path joining source and receiver and equation (1) is a line integral along that path. These equations are nonlinear because Γ_i depends on u(**r**).

To solve these equations, the standard approach is to linearize them. The linearization yields

$$d_i = t_i - \int_{\Gamma_i} u_o(\mathbf{r})\, ds = \int_{\Gamma_i} \delta u(\mathbf{r})\, ds \qquad (2)$$

That is, d_i is the travel time residual based on some initial guess $u_o(\mathbf{r})$ of slowness. In equation (2), $\delta u = u - u_o$, so d_i is related to a slowness perturbation relative to the background u_o.

3. Fresnel Interpolated Wavepath Tomography

Fresnel interpolated wavepath (FIW) is a interpolation approach of raypath and the imaginary part of Rhytov approximation wavepath. Eventhough this wavepath contains scattering wavepath, by following formulation we can simplify of calculation procedure of FIW by means travel times from source to any points, receiver to any points and source to receiver.

Let phase perturbation can be expressed by Rhytov approximation.

$$\Delta\phi(g \mid s) = \sum_r \left(2.\omega_0^{\,2}\, p_0 G(r \mid s, g)\right)\Delta p.d \qquad (3)$$

Where $\Delta\Phi$ indicates wave field phase perturbation. d is a raypath length in a cell and G is Green function. We would like to minimize the slowness difference Δp by minimizing phase misfit $\Delta\phi$ of equation (4). By Lagrange multiplier, let the error function (E) of Δp prediction is expressed as follows:

$$E = \sum_r \left((\Delta p)^2 - L_\lambda A(k)\left(2\omega_0^{\,2} p_0 G(r \mid g,s)\Delta p.d - \Delta\phi\right)\right) \quad (4)$$

By minimizing the error, we can find Δp prediction as following:

$$\Delta p = L_\lambda A(k)\omega_0^{\,2} p_0 G(r \mid g,s) d \quad (5)$$

Where,

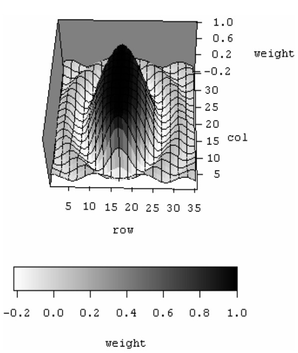
$$L_\lambda = \frac{\Delta\phi(g \mid s)}{\sum_r \left(2\omega_0 4 p_0^{\,2} \Delta p G(r \mid g,s)^2 d^2 A(k)^2\right)} \quad (6)$$

To normalized the equation, the weight factor A(k) is assumed to be $A(k) = \left(2\omega_0^{\,2} p_0^{\,2}\right)^{-1}$

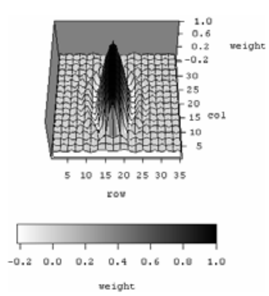
If phase can be expressed by product of frequency and time, then, Rhytov scattering wavepath can be extracted from following equation:

$$\Delta p = \frac{d.L_{wavepath}.\Delta T}{\sum_r d^2.L_{wavepath}^2}. \quad (7)$$

Then, we interpolate $L_{wavepath}$ of equation (7) with raypath and normalized it to produce Fresnel zone interpolated wavepath [1,2]. While the frequency is higher, the Fresnel zone wavepath oscillates spatially more frequent than when the frequency is lower (see Fig.1). In the high frequency, Fresnel Interpolated wavepath becomes similar to the ray path. If we consider on first Fresnel zone only, the character of FIW is quite similar with Fresnel wavepath which has been proposed by other authors [4-7]. In the application of Fresnel zone wavepath to the inversion tomography.



(a)



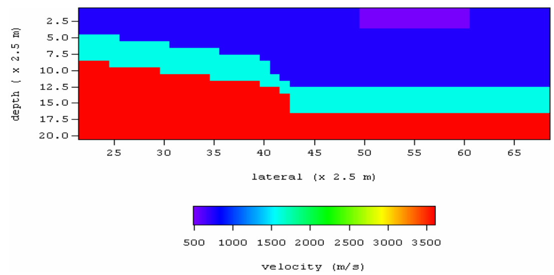
(a)

Figure 1. Fresnel interpolated wavepath in homogeneous medium, (a) 10 Hz wavepath, (b) 30 Hz wavepath.

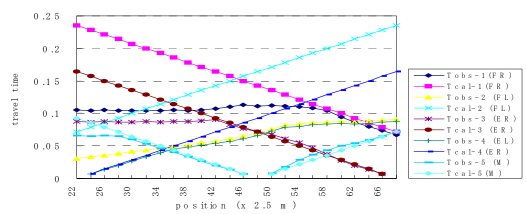
4. Benchmarking

Before applying inversion formula based on FIW (a scattering interpolated wavepath), an inversion process is done for imaging the subsurface model. This is for benchmarking of this method.

Figure 2(a) shows a model of subsurface. Figure 2(b) shows differences among travel times of initial model and true model. Figure 3 (a) shows the result of inversion which is quite similar with the result of true model and Figure 3(d) shows the differences between true travel time and model which is quite similar (fit).

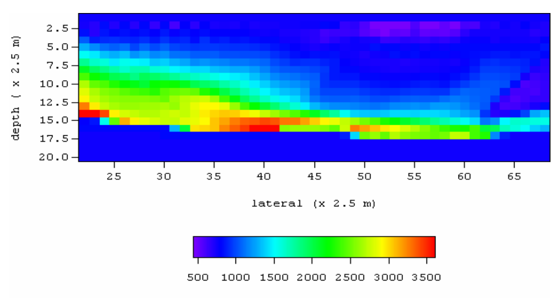


(a)

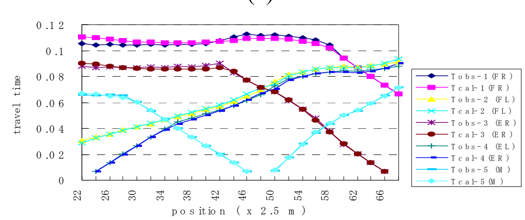


(b)

Figure 2. Benchmarking with synthetic data. (a)model of subsurface, (b) the differences among travel times of initial and true model.



(a)



(b)

Figure 3. Inversion result of Figure 2. (a) inversion image (b) differences between true travel time and inversion model travel time.

5. Acquisition of marine seismic tomography

A acquisition of this marine seismic data has been done in Nipah island, it is near the border of Indonesia and Singapore Fig.4.

Figure 4. Nipah island

A set of hydrophones (streamer) have been used in this survey as seen in Figure 5. This streamer is then configured as Figure 6.

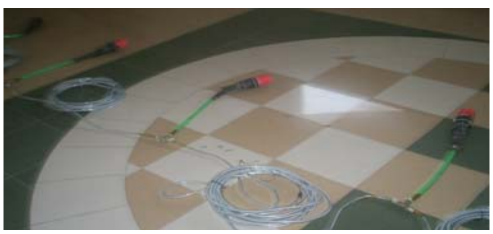


Figure 5. Streamer or hydrophone in this survey

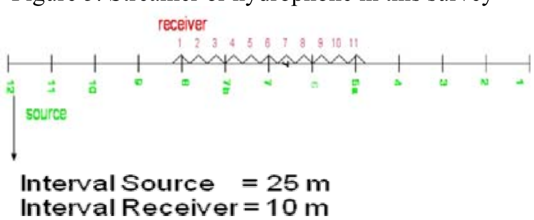
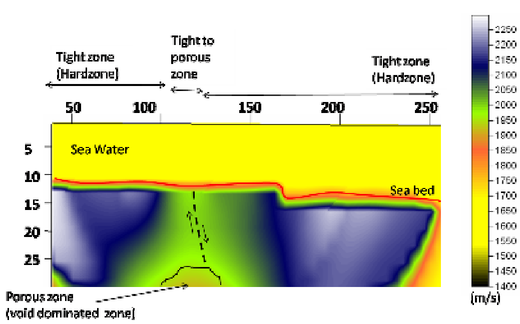
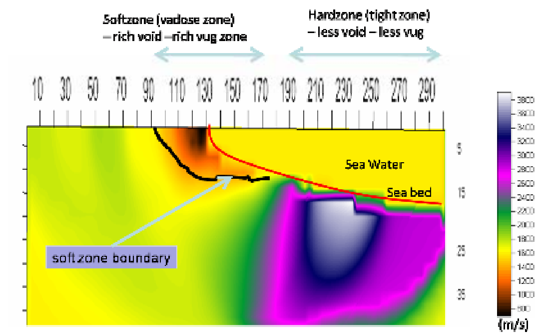


Figure 6. Measurement configuration



(a)



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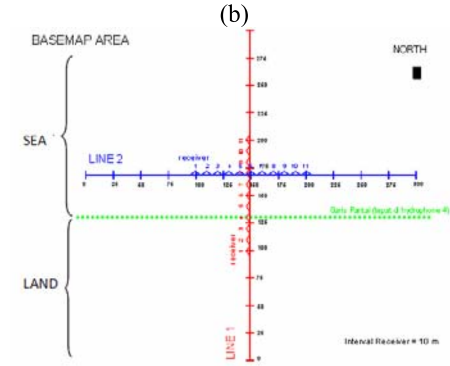

(c)

Figure 7. Tomography image (a) tomography of line 2, (b) tomography of line 1, (c) position of line 1 and 2.

6. Result of FIW Seismic Tomography

After preprocessing to filter noise, all of wave signals were picked to produce travel times of first break and frequencies spectra. Then, Wide-band FIW was run. The result of Wide-band FIW tomography is shown in Fig 7. It is clearly seen that position of void is clearly detected and identified (Figure 7.a). In addition, fracture zone can be also detected by comparing velocity of two images (7.a and 7.b.) at cross-line position. Line of 7.a and 7.b are traversed each others as seen in Fig.7c. It is clearly seen that velocity of both tomography image are different at cross-line position. At cross-line position, the velocity of line 2 is lower than one of line 1, therefore, it is clearly predicted that fracture's axis of at cross-line's subsurface is perpendicular with line 2 or inline with line 1.

7. Conclusion

It is clearly seen that void and fractured zone can be detected in subsurface of seabed using marine seismic Wide-band FIW tomography.

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