Decomposition of ocean-bottom cable (OBC) data

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Summary

As a first step in the pre-processing scheme for multicomponent sea-bottom data, decomposition of the data into up- and downgoing P- and S-waves is proposed. This decomposition step improves the signal-to-noise ratio and optimally prepares the data for imaging/inversion. Eventually the aim is to make the decomposition work robustly on multicomponent datasets. Here, the performance of the decomposition operator is investigated with simulated data in different 'sea-bottom scenarios'. Furthermore decomposition results for field data acquired in the Vøring basin are presented.

Introduction

Recently, acquisition at the sea-bottom has been growing in popularity. In this type of aquisition (multicomponent) geophones and hydrophones are put on the sea-bottom, and a vessel with a source is moving over the sea-surface (see Figure 1). Recording data in this way has certain advantages over conventional marine aquisition, where streamers of hydrophones are towed behind a boat. To mention a few of these advantages:

- Certain marine areas have become so obstructed (i.e. with oil producing platforms) that conventional aquisition in these areas is no longer possible.
- Stationary detectors on the sea-bottom allow monitoring a reservoir during a longer period of time (4-D seismics).
- Sea-bottom recording is less sensitive to noise sources as sea wave motion in comparison with hydrophones positioned near the sea-surface.
- With the (converted) S-waves recorded by multicomponent geophones on the sea-bottom additional information about the sub-sea-bottom could be obtained (e.g. anisotropy).

The first three points mentioned above are related to the manner of aquisition. However, the realization of the last point depends on whether and how good the S-waves can be separated from the P-waves in the recorded field data. In the separation procedure proposed here, a choice can be made whether the up- and downgoing wave fields just above the sea-bottom (i.e. in the water) or just below the sea-bottom (i.e. in the solid) are calculated. In the first case the water layer parameters need be known, in the second case the parameters of the first sub-bottom layer. A decomposition in the water layer gives the up- and downgoing pressure wave fields, a decomposition in the solid results in the up- and downgoing P- and S-waves potentials.

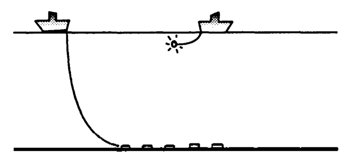

Fig. 1: Sea-bottom seismic aquisition.

First, the decomposition method used in this study will be reviewed [3]. A similar approach has been proposed by [1]. Then the performance of the decomposition method is tested on two different sea-bottom models. Finally, some results of the decomposition on a field data set will be shown.

Decomposition at the sea-bottom

The decomposition procedure outlined here is performed on the measured pressure and velocity data. The vectors $\vec{P}(z_1)$, $\vec{V}_x(z_1)$,$\vec{V}_y(z_1)$ and $\vec{V}_z(z_1)$ contain one angular frequency component of the recorded data (hence, each element in a vector corresponds to a lateral x and y position; z_1 denotes the depth of the sea-bottom). A two-way wave field vector $\vec{Q}(z_1)$, is defined according to

$$\vec{Q}(z_1) = \begin{pmatrix} -\vec{\tau}_z(z_1) \\ \vec{V}(z_1) \end{pmatrix}, \qquad (1)$$

where the traction vector $\vec{\tau}_z$ and the velocity vector $\vec{V}$ are defined as follows:

- for two-component data (acoustic approach)

$$\vec{\tau}_z(z_1) = -\vec{P}(z_1) \quad \text{and} \quad \vec{V}(z_1) = \vec{V}_z(z_1), \qquad (2)$$

- for four-component data (elastic approach)

$$\vec{\tau}_z(z_1) = \begin{pmatrix} \vec{0} \\ \vec{0} \\ -\vec{P}(z_1) \end{pmatrix} \quad \text{and} \quad \vec{V}(z_1) = \begin{pmatrix} \vec{V}_x(z_1) \\ \vec{V}_y(z_1) \\ \vec{V}_z(z_1) \end{pmatrix}, \qquad (3)$$

where the null-vectors (6) account for the absence of shear stresses at the sea-bottom.

Analogous to equation (1) a one-way wave field vector $\vec{D}(z_1)$, is defined according to

$$\vec{D}(z_1) = \begin{pmatrix} \vec{D}^+(z_1) \\ \vec{D}^-(z_1) \end{pmatrix}, \qquad (4)$$

where the downgoing wave field vector $\vec{D}^+$ and the upgoing wave field vector $\vec{D}^-$ are defined as follows:

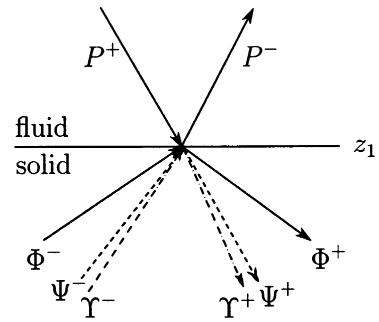

Fig. 2: One-way waves at the sea-bottom

- for two-component data (acoustic approach)

$$\vec{D}^+(z_1) = \vec{P}^+(z_1) \quad \text{and} \quad \vec{D}^-(z_1) = \vec{P}^-(z_1), \tag{5}$$

where vectors $\vec{P}^+$ and $\vec{P}^-$ contain the downgoing and upgoing acoustic waves, respectively,

- for four-component data (elastic approach)

$$\vec{D}^+(z_1) = \begin{pmatrix} \vec{\Phi}^+(z_1) \\ \vec{\Psi}^+(z_1) \\ \vec{\Upsilon}^+(z_1) \end{pmatrix} \text{ and } \vec{D}^-(z_1) = \begin{pmatrix} \vec{\Phi}^-(z_1) \\ \vec{\Psi}^-(z_1) \\ \vec{\Upsilon}^-(z_1) \end{pmatrix}, \tag{6}$$

where vector $\vec{\Phi}^{\pm}$ contains the down/upgoing P-waves, whereas $\vec{\Psi}^{\pm}$ and $\vec{\Upsilon}^{\pm}$ contain down/upgoing S-waves.

For arbitrary depth z the general relations between the two-way and one-way wave field vectors read:

- for composition

$$\vec{Q}(z) = \mathbf{L}(z)\vec{D}(z), \tag{7}$$

or

$$\begin{pmatrix} -\vec{\tau}_z(z) \\ \vec{V}(z) \end{pmatrix} = \begin{pmatrix} \mathbf{L}_1^+(z) & \mathbf{L}_1^-(z) \\ \mathbf{L}_2^+(z) & \mathbf{L}_2^-(z) \end{pmatrix} \begin{pmatrix} \vec{D}^+(z) \\ \vec{D}^-(z) \end{pmatrix}, \tag{8}$$

- for decomposition

$$\vec{D}(z) = \mathbf{L}^{-1}(z)\vec{Q}(z), \tag{9}$$

or

$$\begin{pmatrix} \vec{D}^+(z) \\ \vec{D}^-(z) \end{pmatrix} = \begin{pmatrix} \mathbf{N}_1^+(z) & \mathbf{N}_2^+(z) \\ \mathbf{N}_1^-(z) & \mathbf{N}_2^-(z) \end{pmatrix} \begin{pmatrix} -\vec{\tau}_z(z) \\ \vec{V}(z) \end{pmatrix}. \tag{10}$$

Expressions for the L and $\mathbf{L}^{-1}$ matrices can be found in [3]. The decomposition at the sea-bottom is obtained from equation (10) and consists of one decomposition just above and one just below the sea-bottom (see Figure 2):

- Decomposition just above the sea-bottom is based on the acoustic version of equation (10). Hence, upon substitution of equations (2) and (5) we obtain at $z = z_1^- = z_1 - \epsilon$ [1]

$$\vec{P}^{\pm}(z_1^-) = \mathbf{N}_1^{\pm}(z_1^-)\vec{P}(z_1) + \mathbf{N}_2^{\pm}(z_1^-)\vec{V}_z(z_1). \tag{11}$$

- Decomposition just below the sea-bottom at $z = z_1^+ = z_1 + \epsilon$ is accomplished by

$$\vec{D}^{\pm}(z_1^+) = -\mathbf{N}_1^{\pm}(z_1^+)\vec{\tau}_z(z_1) + \mathbf{N}_2^{\pm}(z_1^+)\vec{V}(z_1^+). \tag{12}$$

$\vec{D}^+$ represents the total downgoing wave field, including the transmitted downgoing source waves. In the elastic approach $\vec{\tau}_z$ and $\vec{V}$ are defined as in equation (3). Note that in equation (12) we have written $\vec{V}(z_1^+)$ rather than $\vec{V}(z_1)$, since the x- and y-components of the velocity may be discontinuous at the sea-bottom [bear in mind that since the geophones are planted in the sea-bottom they measure $\vec{V}(z_1^+)$].

Decomposition results on simulated data

The decomposition method was first applied to simulated data. In this section examples are shown for two different sea-bottom models. One model has a high velocity contrast at the sea-bottom (at 500 m in Figure 3) expected in the case of a 'hard' sea-bottom, the other model represents an unconsolidated sea-bottom with a low-velocity contrast and a linearly increasing velocity in the topmost sediments (see Figure 3).

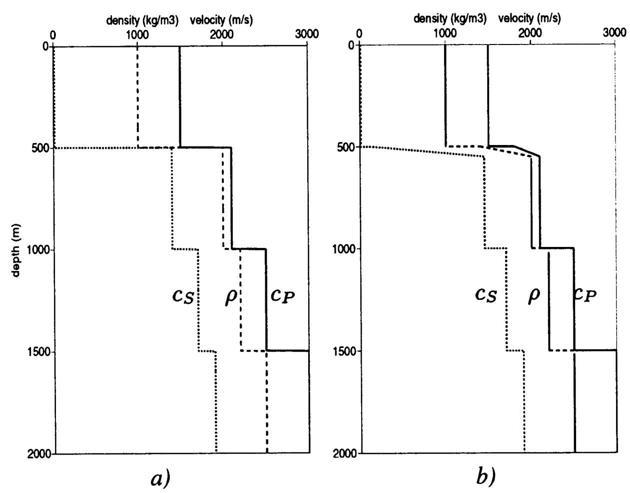

Fig. 3: a) Model with hard sea-bottom (at 500 m depth). b) Low velocity sea-bottom with velocity gradient.

The decomposition results below the sea-bottom on the simulated data from the above mentioned models are shown in Fig-

[1] The notation $z_1^{\pm}$ is used for quantities that are discontinuous at the sea-bottom. For continuous quantities simply z_1 is used.

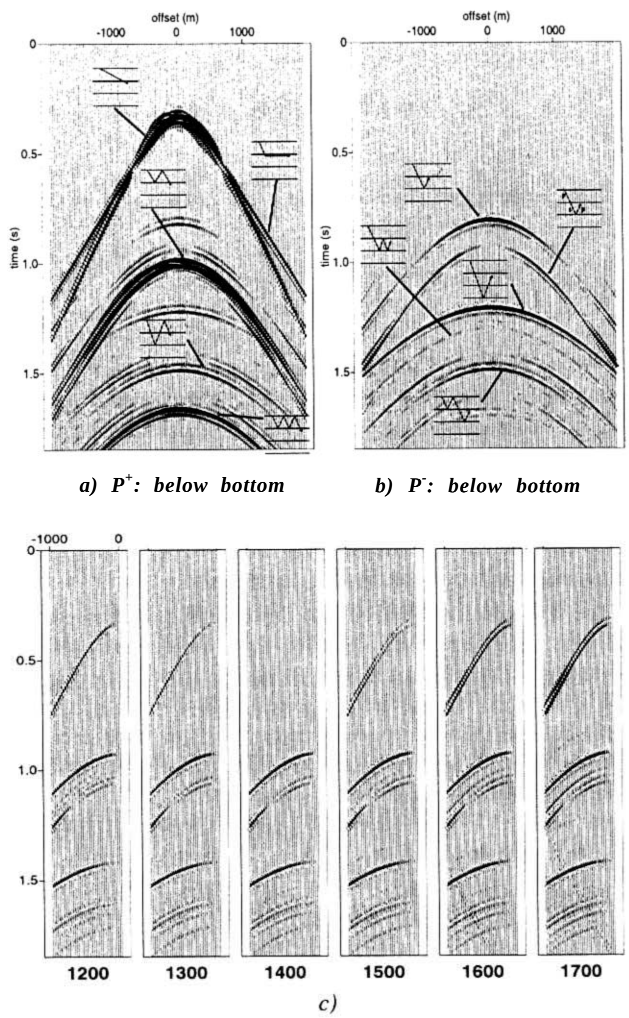

Fig. 4: a) Elastic decomposition result for downgoing P-waves below the sea-bottom; b) for upgoing P-waves below the sea-bottom, c) Decomposition into upgoing S-waves just below the sea-bottom using different sub-sea-bottom S-velocities. The S-velocity used in the decomposition is written beneath each picture. The true medium S-velocity is 1400 m/s.

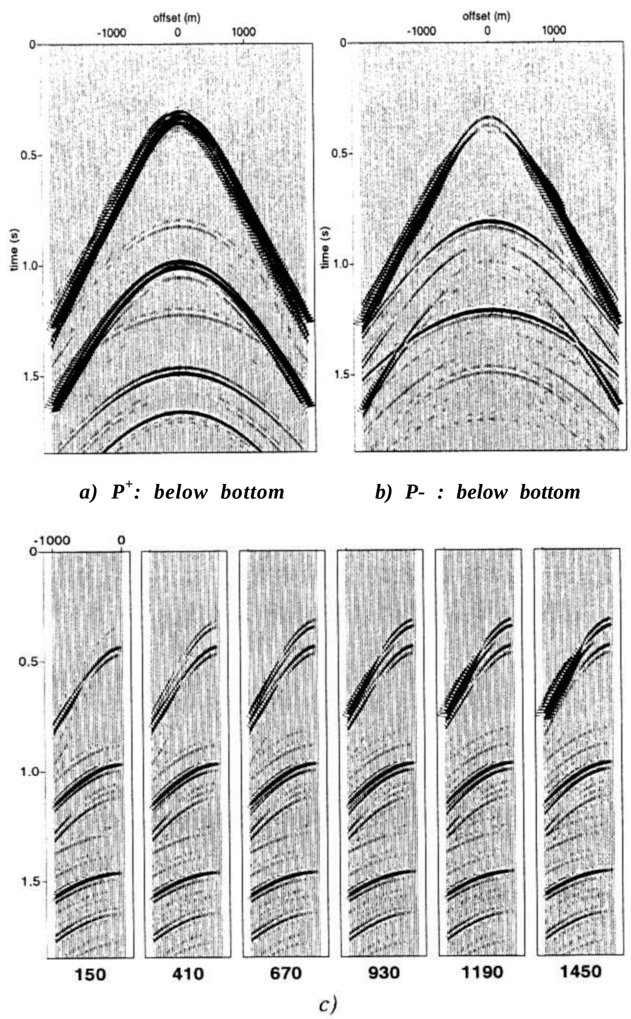

Fig. 5: a) Elastic decomposition result for downgoing P-waves below the sea-bottom; b) for upgoing P-waves below the sea-bottom, c) Decomposition into upgoing S-waves just below the sea-bottom using different sub-sea-bottom S-velocities. The S-velocity used in the decomposition is written beneath each picture. The true medium S-velocity is 150 m/s.

ures 4 and 5. In both figures a and b represent the up- and downgoing P-waves just below the sea-bottom. For the S-waves six decompositions with different S-velocities were done (Figures 4 c and 5 c). The velocity value used in the decomposition is written beneath each picture.

Figures 4 c and 5 c give an impression of the sensitivity of the decomposition to errors in the sub-sea-bottom velocities. In order to select the correct decomposition result when the medium parameters are not known. there are a few markers that can be used as "quality control":

- The upgoing waves below the sea-bottom should not contain the direct (transmitted) source wave, no water bottom reflections. and no water bottom multiples.

This criterion is met for an S-velocity of 1400 m/s and 150 m/s in respectively Figure 4 c and 5 c.

Decomposition results on field data

Next the decomposition was applied to an experimental three-component ocean-bottom cable dataset, obtained in the Voring area. From the dataset a common receiver gather of 401 shot positions at the surface was selected for this example. The shot spacing was 25 m. At the receiver location both multi-component velocity and pressure measurements were available. A more detailed description of the dataset is given in [2].

Assuming that the sub-sea-bottom is more or less one-dimensional. the common receiver gather was considered acornmon shot gather. This assumption is quite correct for the shallower reflectors. First, a decomposition was done just above the sea-bottom. The water parameters are known. but there was the practical problem that the pressure and velocities were measured with different devices causing a different receiver "wavelet" and a different magnitude. By matching the wavelets and setting the scaling factor so that the quality factors mentioned in the previous section were best met, these problems were overcome. The decomposition result just above the sea-bottom is shown in Fig-***ure 6.*** Clearly, all the primary reflection energy has been moved to the upgoing wavefield (Figure 6). Further results on the decomposition below the sea-bottom will be shown in the presentation.

Conclusions

On a simulated dataset the decomposition procedure works correctly. Good results are also obtained with field data. The decomposition is not excessively sensitive to errors in the velocity estimations. Velocity errors up to 50 m/s will give a more or less correct result. However, when using an average velocity to approximate the top-part of an unconsolidated sea-bottom. the direct (transmitted) source wave is not correctly removed from the upgoing P- and S-waves below the sea-bottom. Events arriving at later times seem less sensitive to errors in the velocity estimation.

The decomposition on real field data gives promising results. The performance of the decomposition is for a large part dependent on how the geophones are coupled with the sea-bottom for a specific dataset. In the field dataset used in these examples the top part of the sea-bottom had low velocities.

Acknowledgement

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References

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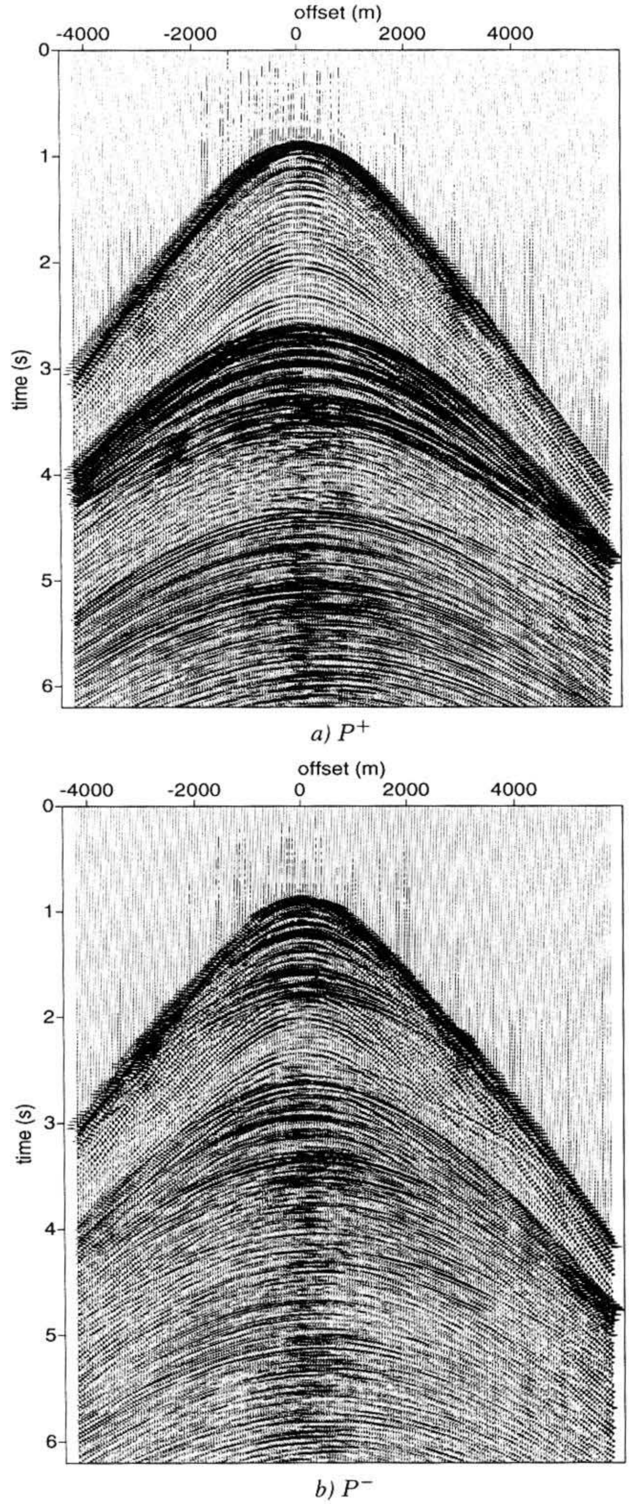

Fig. 6: *Sea-bottom measurements after decomposition just above the sea-bottom a) Downgoing pressure wavefield. b) Upgoing pressure wavefield.*