Continuous wavefields method – Insights from a shallow water field trial

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Summary

In this paper we discuss the results from a shallow water 2D field test that PGS acquired in the autumn of 2019 offshore Malaysia using the continuous wavefields method. The primary purpose of this test was to demonstrate the continuous wavefields method in shallow water areas. In addition, different source configurations including tow depths, air pressures, gun volumes, number of air-guns per string, and time intervals between consecutive actuations of air-guns were tested. After a discussion of the different source configurations, we present preliminary results. The overall sound exposure levels (SEL) are very similar for the different source configurations. The small differences are mainly related to trigger time intervals of the individual air-guns, and to air-pressure. At lower frequencies the differences are mainly related to the volumes of the air guns used. Preliminary results achieved so far indicate that the continuous wavefields method works well in shallow water, and with relatively small differences between the different triggering schemes and source configurations.

Introduction

In autumn 2019, PGS successfully acquired a 2D test offshore Malaysia using the continuous wavefields method (Hegna et al., 2018; Klüver et al., 2018). The test was conducted in a shallow water area with water depths mainly ranging between 125 m and 200 m. This test primarily was conducted to verify the applicability of the continuous wavefields method in shallow water areas. In addition, various source configurations were tested including different time intervals between triggering individual air-guns. The test setup and results will be discussed in this paper.

The continuous wavefields method utilizes continuous wavefields on both the source and receiver side (Hegna et al., 2018; Klüver et al., 2018). A further description of the method is found in Hegna et al. (2019). The continuous source wavefield can be generated using existing hardware by triggering individual air-guns with dense, randomized time intervals.

The results from the 2019 shallow water 2D test complement conclusions drawn from a 3D pilot survey acquired in 2018 offshore Brazil which we reported on before (Klüver et al., 2019). That survey was acquired in a deep water setting (1,600 m to 2000, m water depth) and the results demonstrated the three main objectives of the continuous wavefields method, namely reduced environmental footprint of the seismic source by reduced sound pressure levels, improved source-side spatial sampling in both inline and crossline directions, and improved acquisition efficiency.

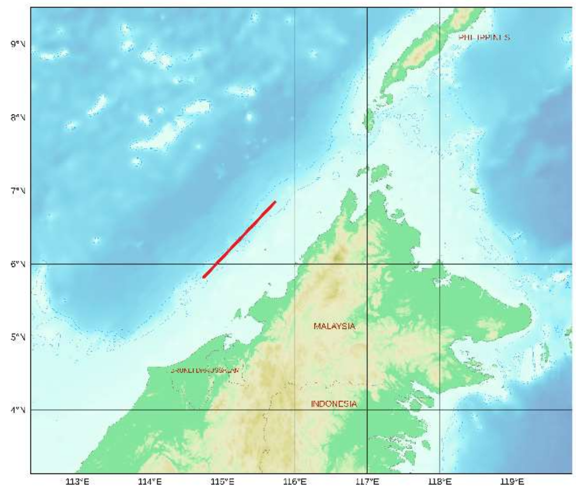

Figure 1: Location of the 2D shallow water field test offshore Malaysia.

Survey / Test	Air-guns per string (CUI)	Mean trigger interval (ms)
Deep water 3D pilot survey	2x45, 2x90, 2x150 (570)	290
Shallow water 2D Test 1	2x40, 2x90, 2x150 (560)	290
Shallow water 2D Test 2	2x40, 2x90, 2x150 (560)	200
Shallow water 2D Test 3	20, 40, 60, 90 (210)	208

Table 2: Source configurations used for the deep water 2018 Brazil survey, and for the shallow water 2019 2D tests.

Source configurations

In the 2D field test, a sailline was repeatedly acquired with different source configurations. The test location is shown in the map in Figure 1. Between the repetitions of the sailline, gun depth and firing pressure were varied from 5 m to 6 m, and between 1,500 PSI and 2000 PSI, respectively. A summary of the different source configurations, together with the setup from the 2018 deep water Brazil field trial, is

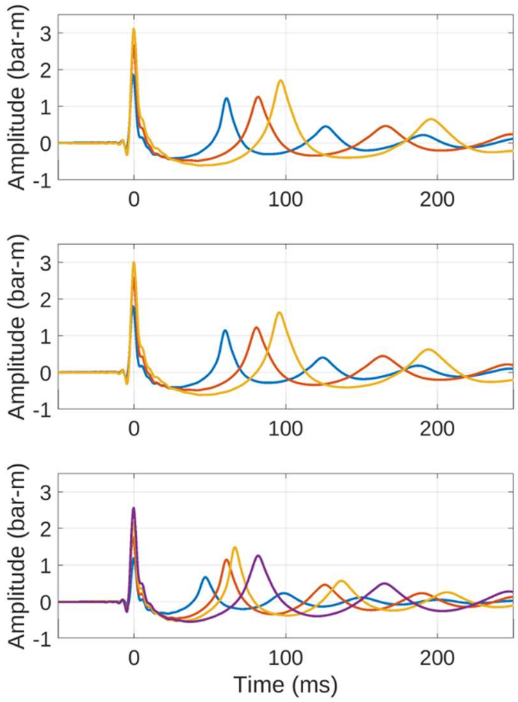

Figure 2: Average notional source signatures for each air-gun volume (left). Volumes in Test 1 (top) and Test 2 (middle) are 40 (blue), 90 (red) and 150 (yellow) CUI, and volumes in Test 3 (bottom) are 20 (blue), 40 (red), 60 (yellow) and 90 (magenta) CUI.

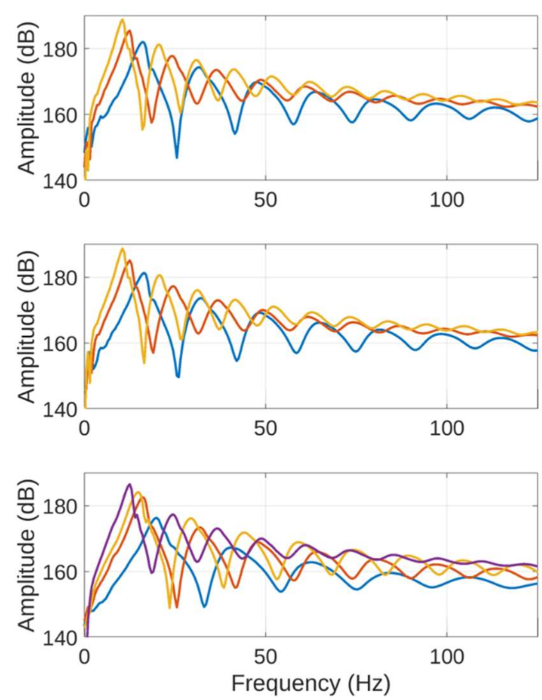

Figure 3: Average amplitude spectra for each air-gun volume (left). Volumes in Test 1 (top) and Test 2 (middle) are 40 (blue), 90 (red) and 150 (yellow) CUI, and volumes in Test 3 (bottom) are 20 (blue), 40 (red), 60 (yellow) and 90 (magenta) CUI.

given in Table 1. The randomization window for the individual air-gun actuations is much larger in Test 3 compared to Test 1 and Test 2.

Multisensor streamers of 8,100 m length with pressure and particle motion sensors were deployed in the 2019 shallow water 2D field test as well as the 2018 deep water 3D pilot.

The continuous source wavefield was generated by triggering individual air-guns with dense, randomized time intervals. The average notional source signatures for each air-gun volume triggered in the different tests are shown in Figure 2.
The air-gun volumes are chosen such that their bubble periods and the related notches in their amplitude spectra are complementary. Figure 3 shows the amplitude spectra for the notional signatures shown in Figure 2. The signatures have been derived from the recorded near-field hydrophone data. The air-gun volumes used in Test 3 are smaller than the ones used in Test 1 and Test 2. Therefore, the maximum amplitude levels of the notional source signatures for Test 3 are slightly lower compared to the other tests.

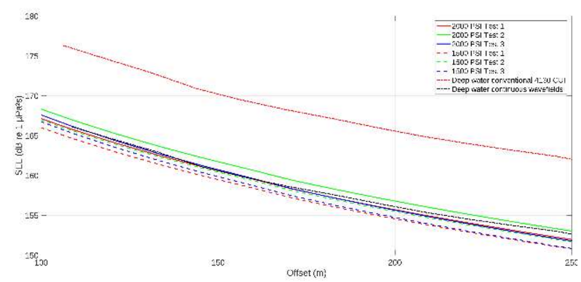

Figure 4: Sound exposure levels derived from extracted direct waves for Tests 1 (red), 2 (green), 3 (blue), 2000 (solid) and 1500 (dashed) PSI. For comparison, SEL from the 2018 deep water surveys are shown. The red dash-dot line shows the SEL for a conventional 4130 CUI source array triggered with a 25m shot-point interval (flip-flop), and the black dash-dot line shows the SEL for the deep water 3D pilot acquired with the continuous wavefields method.

Results and data examples

One main objective with the continuous wavefields method is the reduction of emitted sound levels in the field. Figure 4 shows a comparison of the sound exposure levels (SEL) derived from the acquired data for the different tests listed in Table 1. Curves are shown for both 2,000 and 1,500 PSI. Included in the figure are, for comparison purposes, the levels from the deep water 3D pilot survey and a 3D survey acquired in the same deep water area with conventional 4130 cubic inch dual source arrays. The sound exposure levels were calculated by integrating the recorded pressure sensor data over 10 seconds. The amplitude levels in the shallow water data are highly affected by local geology whereas the amplitude levels in the near offsets of the deep water data are dominated by the direct waves. The sound exposure level for the shallow water data are therefore computed from the extracted direct waves only, excluding reflected energy, to make the SEL comparable between the different data sets. The SEL of the data acquired with the continuous wavefields method show a good agreement between the curves for shallow and for deep water. Due to denser trigger time intervals, the sound exposure levels are slightly higher for Test 2 compared to Test 1. Test 3 shows lower SEL than Test 2 due to the smaller air-gun volumes deployed in Test 3. Lowering the firing pressure from 2000 psi to 1500 psi yields a slight reduction of the SEL. The SEL for all tested source configurations is significantly lower for the continuous wavefields method than with conventional 4130 cubic inch dual source arrays.

The pre-processing of the data follows the methodology outlined by Hegna et al. (2018). It consists of direct arrival attenuation, noise attenuation, and receiver motion correction, followed by receiver side wavefield separation and source deconvolution. A comparison of common receiver gathers, output by the source deconvolution applied to raw data with no noise attenuation for the different tests is shown in Figure 5.

For a preliminary comparison at image level, the data have been taken further through source and receiver domain time dependent f-k filtering (dip limitation) followed by source side deghosting. Using a RMS velocity model, estimated on a 2 km by 2 km grid onboard for QC purposes, the data have been normal-moveout corrected, stacked, and finally post-stack Kirchhoff time migrated. The migrated sections for the three source configurations with 5 m source depth and a firing pressure of 2000 PSI are shown in Figure 6. Geological variations prevent a detailed comparison of the configurations since they were acquired in different locations along the same sailline. The overall difference between the source configurations are limited. The migrated image of Test 3 shows a slightly increased low frequency noise level in the deeper part of the section.

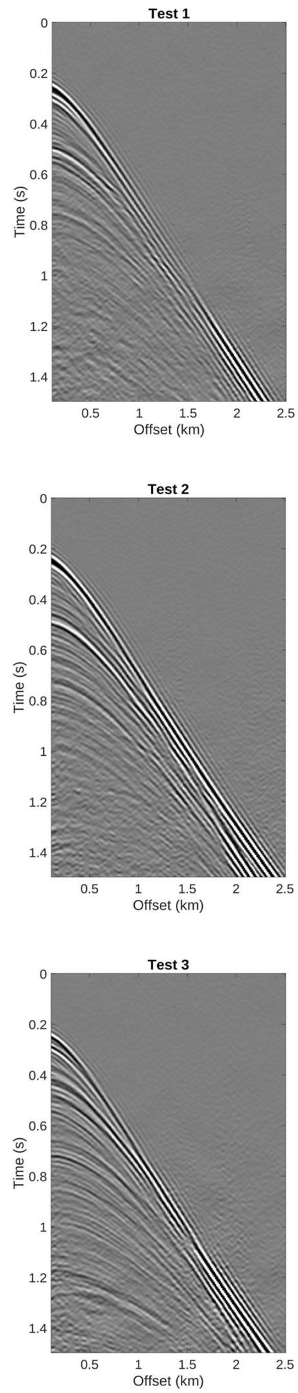

Figure 5: Common receiver gathers for Test 1 (top), Test2 (middle) and Test 3 (bottom). The source deconvolution has been applied to raw recorded data with no noise attenuation, and after receiver motion correction. A T^2 time variant gain, 2-4 – 50-60 Hz band-pass filter, and filtering of the evanescent region have been applied for display purposes. The gathers are in different locations.

Conclusions

A field test of the continuous wavefields method in shallow water was successfully conducted offshore Malaysia in the autumn of 2019. The results so far demonstrate the applicability of the method in shallow water areas. Different source configurations with different schemes for triggering individual air-guns were tested. When estimating the sound exposure levels from the direct waves, they are very similar to data acquired in a deep water area offshore Brazil. The differences in SEL between the different source configurations and triggering schemes tested are related to differences in air-pressure and mean trigger time intervals. The differences between 1500 PSI and 2000 PSI air pressures is 1.5 – 2 dB, whereas Test 2 with a 200 ms mean trigger time interval shows ~ 1 dB higher SEL compared to Test 1 with the same source set-up but 290 ms mean trigger time interval. The reduction in total volume per string from 560 cubic inch to 210 cubic inch with about the same mean trigger time interval leads to a reduction in SEL of 1.5-2 dB. The SEL for all tested source configurations is significantly lower than for conventional 4130 cubic inch dual-source arrays triggered with 25 m shot point interval. Preliminary imaging results achieved so far show that the continuous wavefields method works well in shallow water. The different source configurations and triggering schemes lead to relatively small differences.

Acknowledgments

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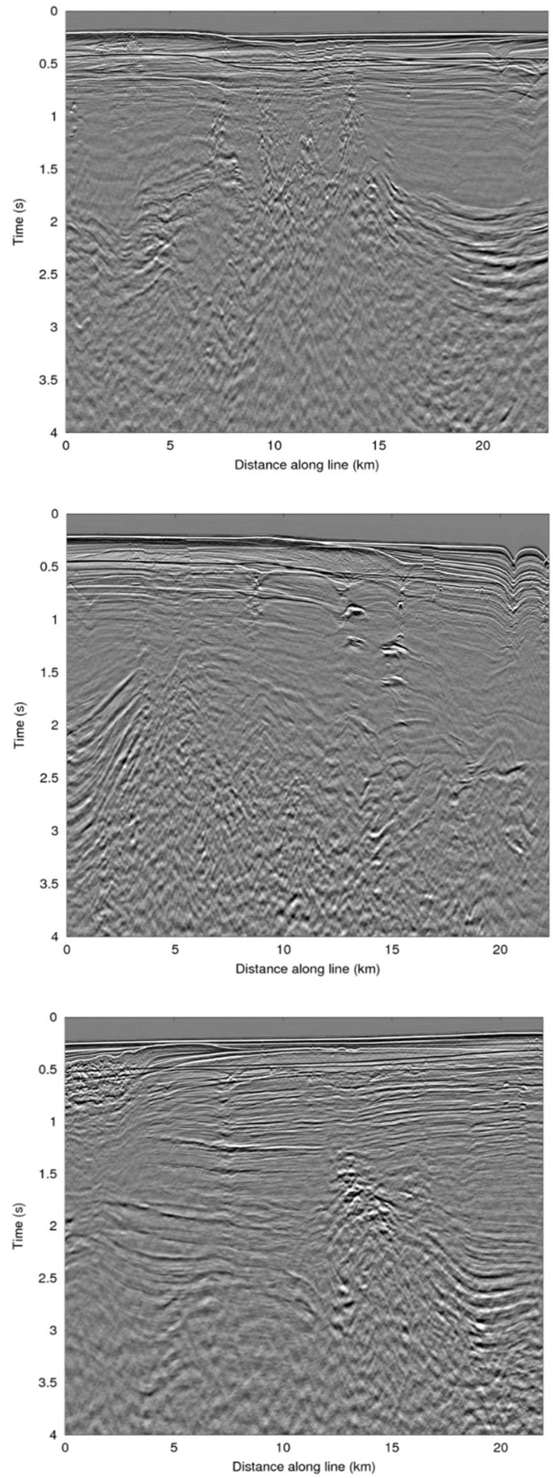

Figure 6: Post-stack time migrated sectiones for Test 1 (top), Test2 (middle), and Test 3 (bottom):

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