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Ground Roll Repeatability Analysis - CO2CRC Otway Project Case Study

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SUMMARY

Time-lapse (TL) seismic is an essential tool for the monitoring of changes in reservoir conditions induced by reservoir production, reservoir stimulation and more recently CO2 sequestration. The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) is currently conducting a carbon dioxide geo-sequestration pilot study in the Otway Basin, onshore Victoria, Australia. An extensive TL seismic monitoring is a part of monitoring and verification program of the project. Being a well-developed methodology for offshore applications, time-lapse seismic is also gaining popularity as an onshore reservoir monitoring technique. However its onshore use is limited by issues of seismic repeatability. This is primarily attributed to the higher near-surface variability as compared to marine seismic. Analysis of several repeated Otway 2D surveys show that different frequency bands have different repeatability. Low frequencies (< 30 Hz), contaminated by the ground roll noise, are characterised by particularly poor repeatability. In this paper we analyse three repeated 2D surveys obtained with same geometry but different sources and near-surface conditions in order to investigate ground roll repeatability by evaluation of surface waves phase velocity spectra.

Introduction

Time-lapse (TL) seismic is an essential tool for the monitoring of changes in reservoir conditions induced by reservoir production, reservoir stimulation, and – more recently – CO_2 sequestration. The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) is currently conducting a CO_2 geo-sequestration pilot study in the Otway Basin, onshore Victoria, Australia. Extensive TL seismic monitoring is an essential part of the monitoring and verification program of the Otway Project (Dodds *et al.*, 2009). It includes several repeated 3D surface seismic surveys acquired from 2007-2010, and a large borehole seismic experiment (repeated zero-offset/offset VSP and 4D VSP). Seven repeated 2D surveys were also acquired to find the optimal parameters for the TL 3D surveys.

Being a well-developed methodology for offshore applications, time-lapse seismic is also gaining popularity as an onshore reservoir monitoring technique. However its onshore use is limited by issues of seismic repeatability. This is primarily attributed to the higher near-surface variability as compared to marine seismic. A study conducted by Al-Jabri and Urosevic (2010) confirms that significant seasonal variations of water table, which are typical for the survey area, should affect the Otway TL seismic surveys.

Analysis of several repeated Otway 2D surveys (Pevzner *et al.*, 2011) shows that different frequency bands have different repeatability. Low frequencies (< 30 Hz) are characterised by particularly poor repeatability in comparison to the middle frequency range (30-70 Hz). The obvious hypothesis is that this is the result of the changes in the ground roll, caused by variations in the near surface conditions, especially in the water saturation of the soil. These variations could affect both the source coupling (Meunier *et al.*, 2001) and near surface velocity profile for both P- and S-waves (West and Menke, 2001).

In this paper we analyse three repeated 2D surveys obtained with the same geometry but with different sources and near-surface conditions in order to investigate the ground roll repeatability by evaluation of the surface waves phase velocity spectra. In general, we follow the approach of Beaty and Schmitt (2003).

Seismic data acquisition parameters

Table 1: *2D test line acquisition parameters*

	Test1	**Test2**	**Test3**
Source type	Weight Drop	Weight Drop	Vibroseis
Receiver	Vertical 10 Hz single geophones		
Date	Jun, 2007	Nov, 2008	Nov, 2008
Weather condition	Wet	Dry	Dry
Total Number of Source positions	158	155	155
Total Number of Receivers	162	156	159
Source/Receiver Point Spacing, m	10/10	10/10	10/10
Number of Channels	162	156	159
Offset range, m	5-1605	5-1545	5-1545
Reference to Data Set	WD 2007	WD 2008	MB 2008

The data acquisition parameters are presented in Table 1. This is the same set of surveys as analysed by Pevzner *et al.* (2011).

In the survey area, winter (June, dataset WD2007) is a wet season with lots of rain and the water table being close to the surface. Summer months (November, datasets WD2008 and MB 2008) are relatively dry, and the water table can be several meters below the surface. The last two (2008) datasets were acquired within 2 consecutive days and constant weather conditions.

The weight-drop source used is a 720 kg weight free falling from a height of 1.2 m (4 stacks for each source position). The vibroseis source is an IVI minibuggy with a 12 s linear 10-150 Hz sweep.

Multi-channel analysis of surface waves dispersion

We implement a workflow that consists of a simple data conditioning step followed by the transformation of seismograms to the phase velocity spectra performed in a spatial window running along the test line.

Data conditioning

Only limited pre-processing was applied for the enhancement of the ground roll signal. As the majority of the wavefield energy is already dominated by surface waves at the near-surface, a simple top mute was deemed adequate. This effectively removed the refracted and reflected waves, hence enhancing the signal associated with the ground roll. A long-window AGC was applied to boost late time signal and equalise the traces and, finally, a bandpass filter was employed to remove high frequency random noise. The parameters utilized for the pre-processing are:

- AGC: 1500 ms time gate
- Bandpass Filter: 0 – 5 - 40 – 60 Hz

An example of raw data and the result of the pre-processing are presented in Figure 1.

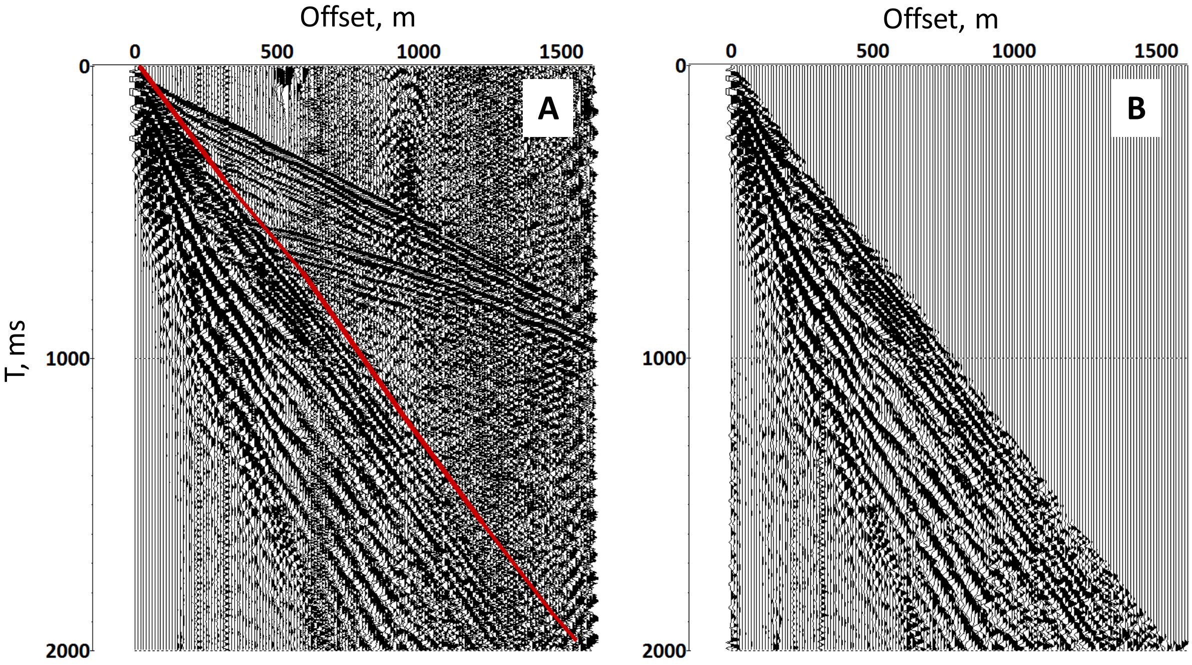

Figure 1: *Common shot gather, WD2007 (wet) dataset; A) raw data with top mute line (red); B) result of data conditioning*

Dispersion analysis and stacking of surface waves

The velocity (and dispersion) of surface waves characterises elastic properties in the vicinity of the receiver. Thus, for each individual shot, we compute the phase velocity spectra in a running window along the receiver coordinate.

Both a slowness-frequency transformation (McMechan and Yedlin, 1981) and a frequency domain slant-stack (Park *et al.*, 1998) were evaluated. The latter produced better results in terms of the resolution of the spectra. Following Neducza (2007), we stack the phase velocity spectra computed for a given receiver window over all shot points to improve signal to noise ratio. The optimal receiver window size was found to be 400 m, and we use a 50 m window step along the line. The same processing parameters are used for all three datasets.

Ground roll repeatability analysis

An example of the phase velocity spectra computed using one of the receiver windows (and all the sources) is presented in Figure 2. Two modes are clearly seen in the displays. We interpret them as the fundamental and the first higher Rayleigh wave mode.

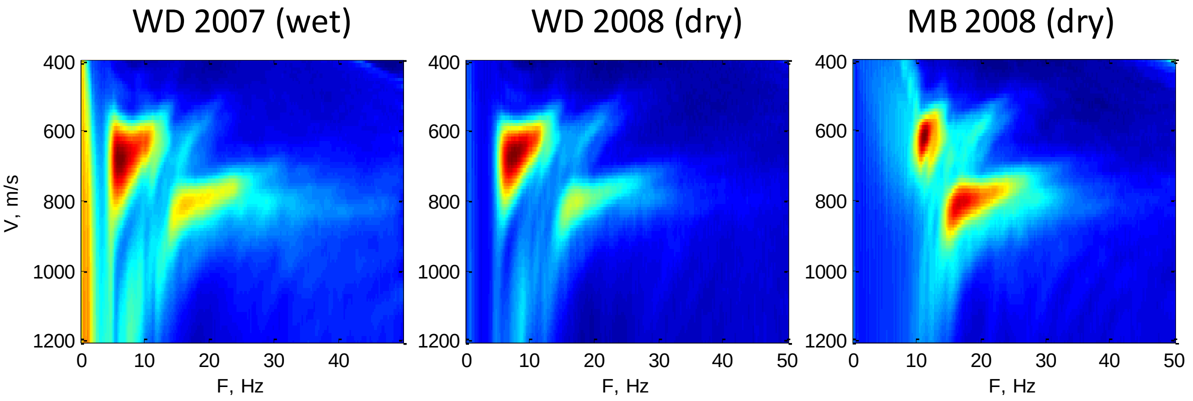

Figure 2: *Phase velocity spectra computed for spatial window 800-1200 m.*

Velocities of both of these modes were picked for every position of the spatial receiver window (Figure 3).

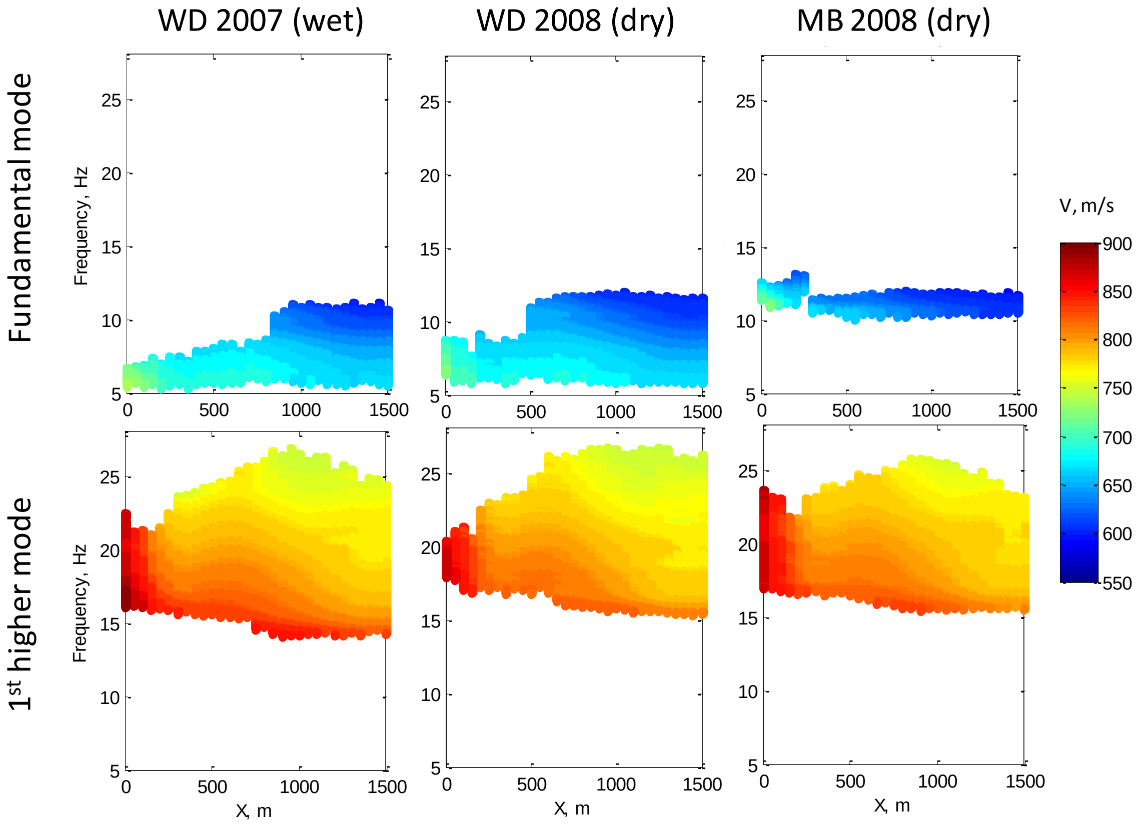

Figure 3: *Phase velocities of fundamental and first higher order Rayleigh waves*

Having a very limited number of frequency points for (especially) the fundamental and the 1st higher mode dispersion curve for each surface location, we were unable to obtain robust results for the inversion of the Rayleigh wave dispersion to the S-wave velocity profile.

Figure 3 shows that changes of the Rayleigh wave velocity dispersion along the line are much more pronounced than the temporal changes. Two of the surveys were acquired virtually at the same time (MB2008 and WD2008) and the difference in the observed velocities between them is as big as the differences between WD2008 and WD2007. This means that we cannot robustly detect temporal variations in the near surface conditions from this surface wave analysis. Differences in the frequency content and the intensity of the ground roll are significant for any pair of surveys used for the analysis. The vibroseis source, due to the sweep parameters, doesn't have any ground roll energy below 10 Hz. Also, the intensity of the ground roll is higher for the wet conditions. This can be explained by better source coupling for that case.

Conclusions

Phase velocity spectra were obtained through a multi-channel analysis of surface waves using a frequency domain slant-stack transformation. The effect the source type and the near-surface saturation will have on the level of the ground roll repeatability in the case of the Otway Basin pilot project was evaluated. Based on the conducted research, following main observations were made:

1. Ground roll velocity dispersion varies insignificantly in the presence of changing source type and seasonal variation.
2. Frequency content and signal intensity are affected by both the source type and the seasonal variation (increased source-ground coupling in the wet season).
3. Lateral variation in the ground roll velocity along the survey line is significant.

The principal conclusion is that the ground roll can be non-repeatable even if temporal variation of the Rayleigh wave velocity (and its dispersion) is small. The source type and the ground coupling are the main controlling factors in the ground roll repeatability, with seasonal variation of the near-surface velocity profile playing a secondary role. Acquiring the seismic data using the same source and during similar seasons from year to year will further reduce variations in the frequency content and provide a higher level of repeatability.

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References

Al-Jabri, Y. & Urosevic, M. [2010] Assessing the repeatability of reflection seismic data in the presence of complex near-surface conditions CO2CRC Otway Project, Victoria, Australia. Exploration Geophysics, **41**, 24-30.

Beaty, K.S. & Schmitt, D.R. [2003] Repeatability of multimode Rayleigh-wave dispersion studies. Geophysics, **68**, 782-790.

Dodds, K., Daley, T., Freifeld, B., Urosevic, M., Kepic, A. & Sharma, S. [2009] Developing a monitoring and verification plan with reference to the Australian Otway CO_2 pilot project. The Leading Edge, **28**, 812-818.

Mcmechan, G.A. & Yedlin, M.J. [1981] Analysis of Dispersive Waves by Wave Field Transformation. Geophysics, **46**, 869-874.

Meunier, J., Huguet, F. & Meynier, P. [2001] Reservoir monitoring using permanent sources and vertical receiver antennae: The Cere-la-Ronde case study. The Leading Edge, **20**, 622-629.

Neducza, B. [2007] Stacking of surface waves. Geophysics, **72**, V51-V58.

Park, C.B., Miller, R.D. & Xia, J. [1999] Multichannel analysis of surface waves. Geophysics, **64**, 800-808.

Pevzner, R., Shulakova, V., Kepic, A. & Urosevic, M. [2011] Repeatability analysis of land time-lapse seismic data: CO2CRC Otway pilot project case study. Geophysical Prospecting, **59**, 66-77.

West, M. & Menke, W. [2001] Fluid-induced changes in shear velocity from surface waves. Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), 21-28.