Monitoring the Groningen gas reservoir by noise interferometry

Universiteit Utrecht

CREEP

Wen Zhou (w.zhou@uu.nl) & Hanneke Paulssen

Department of Earth Sciences, Utrecht University, The Netherlands

Since 2013, seismicity in the Groningen gas field in the Netherlands is monitored by geophone strings in two boreholes at reservoir level (3 km). Here we present ambient noise cross-correlation results for one month of data for one of the boreholes. The cross-correlations show that the noise comes mainly from above. The dominance of cultural noise from the surface is inferred from the asymmetry of the cross-correlations as well as from the observed diurnal and weekly variations. The P and S wave velocity structure of the reservoir is accurately determined from inter-geophone travel time data. The P velocity profile shows good agreement with well log data and has an uncertainty of less than 5%.

Groningen gas field and borehole data

The Groningen gas field in the Netherlands is one of the world's largest onshore gas fields and has been producing from 1963. As a result of gas extraction, subsidence and induced seismicity occur which cause damage and concern in the area.

Fig.1. *Left: The Groningen gas field in the Netherlands. Right: Two years of seismicity (M_L 0.1-3.5), subsidence (cm) and two borehole locations (NAM).*

Since 2013, the year with the highest level of induced seismicity, two geophone strings have been used to monitor the reservoir. For borehole SDM-1, 10 15-Hz geophones are positioned vertically from the top to the bottom of the reservoir with a geophone spacing of 30 m.

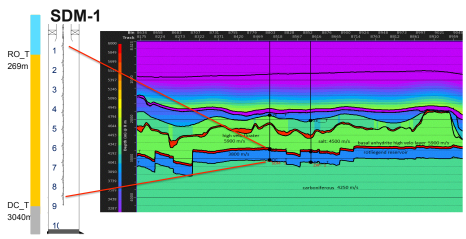

Fig.2. *P velocity model and borehole monitoring system (NAM).*

Data processing and cross-correlation functions

We used 1-bit normalization and spectral whitening, together with a bandpass filter from 3 to 400 Hz. After that, for each station pair, the cross-correlation function was calculated for 6 seconds segments with 2/3 overlap. These segmented cross-correlations were stacked over 1 hour.

1-bit Normalization
Spectral whitening
Filter 3-400Hz → Cross-correlation → Stacking over 1 hour data

Fig.3. *Processing schedule.*

Finally, 24(hours)*33(days) segments were obtained from each station pair. In total, for the 10 geophones, 55 independent cross-correlation pairs were calculated for each of the 3 components.

The vertical component cross-correlation functions (CCFs) for the top geophone show a clear downgoing P wave. The east component CCFs do not only show the downgoing S wave but also the downgoing P wave.

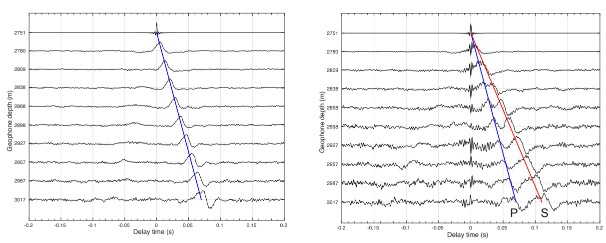

Fig.4. *Left: Vertical component cross-correlations with top geophone. Right: East component cross-correlations. Blue and red lines indicate P and S wave arrivals.*

Noise variations

Both diurnal and weekly variations of the CCFs are observed for the direct downgoing wave. This indicates that during the day the noise is dominated by cultural noise from the surface.

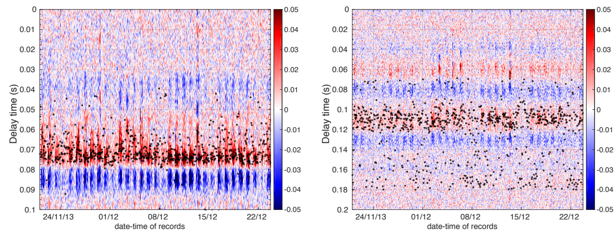

Fig.5. *Positive part of the CCFs between the top and bottom geophone for the vertical component (left) and the east component (right). Black dots indicate estimated travel times (maximum of CCFs).*

The amplitude as well as the timing of the direct wave varies. The apparent P wave travel time for each geophone pair is measured from the maximum of the vertical component cross-correlation for each of the hourly stacks. The apparent S wave travel time is measured from the east component CCFs.

P and S wave velocity estimation

Because the distributions of these (24*33) apparent travel times is skewed, we used kernel density estimations to obtain probability density functions (PDFs) of the travel times.

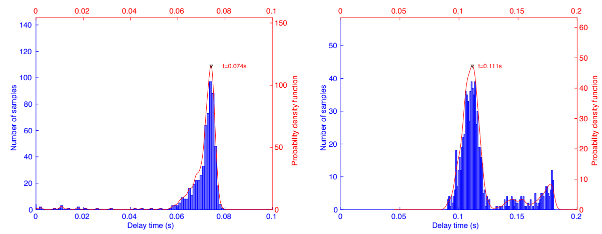

Fig.6. *Kernel density estimations for P wave (left) and S wave travel times (right) from the top to the bottom geophone. Histograms are shown in blue. The red curves represent the estimated PDFs.*

The maximum likelihood travel times of all geophone pairs were used to estimate the inter-geophone P wave and S wave velocities. The obtained P wave velocity profile has errors of less than 5% and shows good agreement with the P velocity profile obtained from well logging. The S wave velocity profile also agrees with the inferred average S wave velocity of the reservoir.

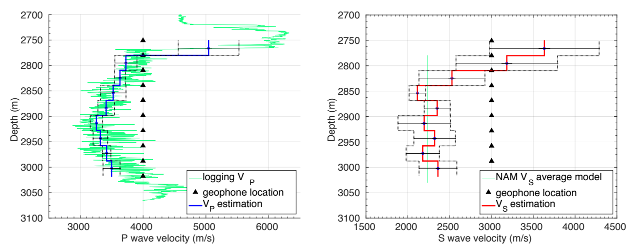

Fig.7. *Left: Estimated P wave velocity profile in reservoir (blue) together with well log data. Right: S wave velocity profile (red) with average shear velocity of reservoir. Well log data (green) were provided by the NAM.*

It is concluded that noise interferometry can be used to determine the seismic velocity structure from deep borehole data. In the future we will try to monitor seismic velocity variations in the reservoir.

Acknowledgements

We thank the NAM and Remco Romijn for providing us with the data. This project is funded from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642029 – ITN CREEP.