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Research Advances

# Long-Term Geophysical Observations and Analysis of the World's Deepest Borehole

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## Objective

In order to reduce the interfering noise from the earth surface, scientists have carried out multi-geophysical borehole observations and the related study. This study aims at improving signal-to-noise ratio obtained from the observation data to obtain zero noise data, which will be of great help to improve geophysical studies. Insights from this study will be significant for the earthquake disaster reduction, resource exploration and environmental protection. The Donghai borehole multi-geophysical long-term observatory was constructed in Donghai County, Jiangsu Province, China, and is now the deepest long-term borehole observatory in the world. This is a world-leading project titled as "Analyses of seismic data and studies of the non-linear properties of seismic waves recorded at different depths of the Donghai 5000 m borehole and the dynamics of seismo-tectonic motion in the Tan–Lu fault", and has guided China's comprehensive borehole geophysical study. The Donghai borehole observatory is located in the Sulu ultrahigh pressure metamorphic belt near the Tan–Lu fault, and the research results will therefore provide important geophysical constraints on the tectonics and dynamics studies in this area.

## Methods

Two sets of three-component seismometers with different frequency bands and one geothermal instrument were installed at four different depths of 544.5 m (L1), 1559.5 m (L2), 2545.5 m (L3) and 4050 m (L4) in the borehole, respectively. As shown in Fig.1(a) the borehole seismographs of L1, L2, L3 and L4 are all airproofed in the steel tubes. In each borehole seismograph mentioned above two sets of three-component seismographs with different frequency 4.5 Hz and 15 Hz are installed. The seismographs and steel tubes can resist to high temperature and high pressure so that borehole observation instruments are able to work continuously long term at high temperature and high pressure in borehole. A fluid pressure meter was located at the 3500 meter deep. In addition, a broadband three-component seismograph was placed on the ground (L0). These above instruments are all high-precision digital ones. The temperature can be up to 142.4°C and the pressure reaches up to 500 bars in the bottom of the borehole.

This study conducted spectral analysis on the basis of the seismic waveforms data, and investigated the nonlinear effects of the rock amplification ratios and the ground response spectrum with the band pass filtering method. By comparing the observation and synthetic seismograms, we described the waveform variation characteristics with depth and its formation mechanisms. The synthetic waveform is numerically simulated by the pseudo-spectral differentiation method with a staggered grid real FFT operator, which is a discrete method resolving the 3-D wave equation.

## Results

In recent years, the seismographs at the borehole observatory have recorded many small and micro earthquakes in and around the Donghai region, with the magnitudes of earthquakes mostly being 0 or 1, and even smaller magnitudes being minus (e.g., -1), which can not be recorded by the surface broadband seismograph at the Donghai observatory or other seismographs at the conventional stations near Donghai. The seismic waveforms are so clear in the seismograms recorded in the borehole that it is possible to obtain zero noise data. Both the initial and subsequent seismic wave phases are clear and sharp; as a result, it is easy for us to identify and detect the wave phases either by computer or naked eyes. As a example, Fig.1(b) shows the waveforms of the 12 June, 2013, Lianshui Jiangsu, China $M_L$ 0.3 earthquake recorded by the borehole seismograph L3 with main frequency 4.5 Hz in the Donghai Long Term Geophysical Observatory. The seismic wave in the top, middle and bottom panel in Fig. 1b are the east-west, north-south, vertical component of the wave, respectively. It can be seen that the initial and subsequent seismic wave phases

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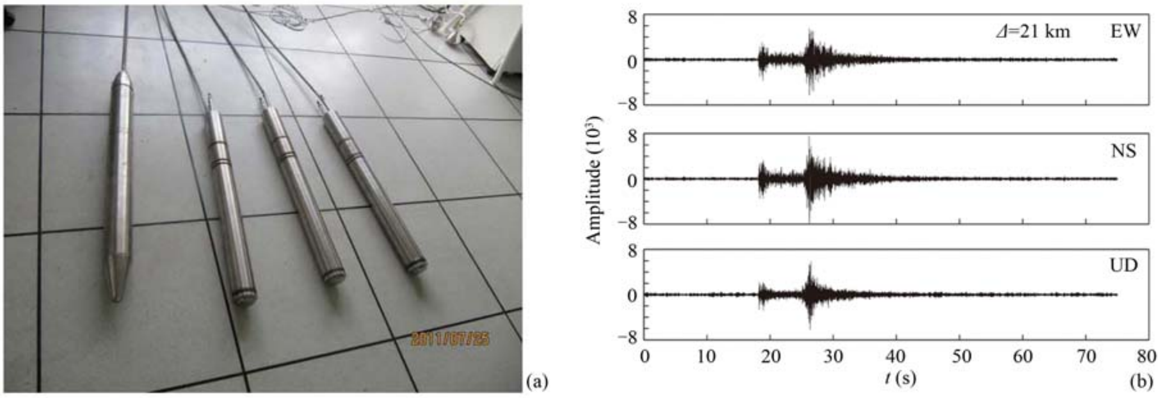


Fig. 1. Borehole seismographs installed in the Donghai Long Term Geophysical Observatory and the recoded seismograms.

(a), Borehole seismographs L4, L3, L2 and L1 lined with the double armour and single armour (from left to right); (b), Waveforms of the 12 June 2013, Lianshui Jiangsu, China $M_L$ 0.3 earthquake recorded by the borehole seismograph L3 with main frequency 4.5 Hz in the Donghai Long Term Geophysical Observatory. The seismic wave in the top, middle and bottom panel are those of the east-west (EW), north-south(NS) and vertical (UD) component, respectively. $\Delta$: epicenter distance; Abscissa: time axis; Ordinate: amplitude.

are clear in the seismogram. Now the accurate digital waveforms without noise can obtain from borehole seismographs, which can improve monitoring and prediction of earthquakes in and around the Tan–Lu fault.

This study investigated the signal-to-noise ratios of waveforms by calculating the waveform amplitudes, and then quantitatively evaluated the observation capabilities of seismographs installed at the different depths according to the ratios. The average signal-to-noise ratio detected by the borehole seismograms is 3–4 times greater than that obtained by surface seismograms, or even nine times greater for some microearthquakes. This result was demonstrated by numerical simulations of seismic waveforms. Using the borehole seismographs has significantly improved the accuracy of waveform measurement. The borehole seismic network observations can effectively eliminate surface noise and provide the information about micro earthquake with high precision from the earth's interior. Usually, the ratios always vary with the depth of the borehole. The average signal-to-noise ratio for seismograms from the L1, L2 and L3 seismographs gradually increases with the depth of the instrument placed. In generally, the deeper the borehole instrument installed, the stronger the ability to eliminate noise can be. However, the signal-to-noise ratios from some seismograms in the lower strata are always not greater than those in the upper strata, indicating that there are nonlinear effects of the rock amplification ratios in the Donghai region.

## Conclusions

(1) The average signal-to-noise ratio from seismograph L2 is close to that from L3. The data from a borehole seismograph at 1500 m might be expected to basically eliminate surface noise.

(2) The average signal-to-noise ratio of seismograms in the borehole is several times greater than that of those on the surface, and the ratio increases with depth.

(3) The research results show that deep borehole seismic observation can effectively eliminate surface disturbance and noise, clearly record seismogram and significantly improve the seismic data accuracy. The seismographs in the borehole are able to record microearthquakes which are not detected by the surface seismographs. The arrival time and amplitudes of all wave phases can be scaled and computed more accurately by this way.

## Acknowledgements

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