Seismic site exploration and monitoring for offshore buildings: Quantification of risk potentials due to soil degradation

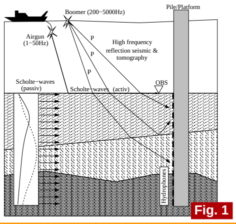

Fig. 1

OBJECTIVES

The main objective of this project is the determination of geological subsurface structure and its elastic properties in the surrounding of an offshore-platform. A new seismic pre-site investigation and building stability monitoring concept will be developed and tested at the new FINO-NEPTUN research platform. Initially high resolution reflection seismics provides the geological structure of the area and a Scholte wave experiment the shear wave velocity distribution. After completion of the FINO-NEPTUN platform a second phase will start: In-situ time-lapse seismic tomography and Scholte wave experiments will be used to investigate structural and elastic parameter changes of the subsoil due to the platform construction and its further mechanic influences on the soil. The scheme will quantify the potential of a construction breakdown due to ground liquefaction and other effects. A hydrophone array mounted at the outer hull of the platform (see **Figure 1**) will be used for tomography and in extend for an analysis of the low frequent eigen-frequencies of the soil. Marine experiments are supported by geo-engineering laboratory studies to find a possible correlation between seismically deduced shear wave velocities and shear stiffness. The coherence of shear stiffness and deformation of the soil due to cyclic stress, as caused by the foundation of the platform will also be investigated.

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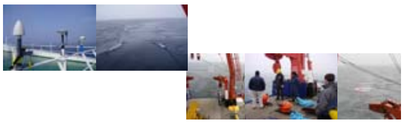
STRUCTURAL INVESTIGATIONS

PHYSICAL PARAMETER STUDY

Aims & Methodology

The structural geology in the immediate vicinity of the planned FINO3 platform location was investigated with a high resolution 2.5D reflection seismic survey, see **Figure 2a**.
The sediment structure thus obtained not only helps giving a starting model for the Scholte wave inversion, but also will lead to a suggestion for the platform location.
The reflection seismic pre-site investigation was a standard single-channel boomer survey. A 2km squared sized area was mapped in North-South and East-West direction, with parallel profiles at 50m separation. The resulting grid is shown in **Figure 2a**.
Acquisition parameters were: 3Hz shot rate, 100kHz sampling rate and 200ms record length, using a 24-bit *National Instruments* data logger (A/D-card: NI-PXI4472). Navigation data was acquired using a radio corrected single-frequency D-GPS system (*Trimble Pathfinder*). Reference station was Heligoland. The GPS antenna was mounted midships.
During the survey two different acquisition geometries were used:
Setup *A* deployed the boomer and single-channel streamer to the portside stern of the vessel in a straight line with 2m source receiver offset. It was used to acquire the North-South profile grid.
Setup *B* deployed the boomer on the portside stern and the streamer starboard stern with 11m source-receiver offset (East-West profile grid).



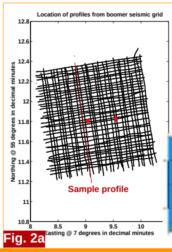


Fig. 2a

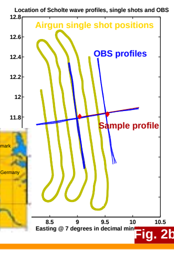


Fig. 2b

The shallow subsurface shear-wave velocity distribution of the FINO3 platform building site is investigated by exploiting the dispersive properties of surface waves.
A low frequency airgun system towed behind RV Alkor was used to excite so called "Scholte waves" which are elliptically polarised waves, comparable to Rayleigh waves, except that wave energy is travelling in the water layer and the subsurface.
Scholte wave energy was recorded with Ocean-Bottom-Seismometers (OBS: 3C-Geophones and Hydrophone). Airgun shots were fired with approx. 5m shot separation along three different profiles. The profiles lie within the boundaries of the 2km area. Two OBSs were placed near each intersection point of the profiles (see **Figure 2b**). The data were compiled to build a common receiver gather for each OBS. From the data obtained one can invert the vertical shear wave velocity distribution of the subsurface.
The inversion is based on a comparison of observed phase slowness-frequency dispersion spectra with artificial spectra resulting from a shear wave velocity model (Bohlen et al.2005).
The inverted shear wave velocities will then be related to the shear stiffness of the soil. This first investigation also provides helpful information for further studies of the area. It gives for example information about the Scholte wave frequency content of the soil and provides data for a start model for further inversion of tomographic exploration in the vicinity of FINO3.

First results

Figure 3 shows a sample seismic profile to illustrate achievable data quality and penetration depth ($\sim$ 20-25m below seafloor). The data shown here were filtered with a 100,200,2000,3000Hz boxcar bandpath filter.
Seafloor two-way traveltimes were determined with a threshold criterion and traces were thus shifted to an average and constant time of 0.028ms to flatten the seafloor event (see **Figure 3**). A ghost seismic reflection mimics the seafloor event and is ondulating because of wave motion otherwise suppressed by the flattening procedure. The second main horizon shows significant topography and could be either a glacial till or sand. However, coring performed as part of the *DanTysk* windpark pre-site investigation (East of our survey area) only shows evidence for sand. **Figure 4** displays the elevation of that second horizon relative to the seafloor as obtained from interpreting all lines in the grid (see **Figure 2b**). Deeper events are also visible but have not been interpreted yet.

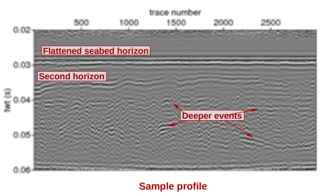


Fig. 3

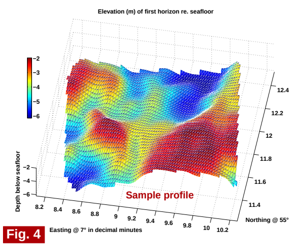


Fig. 4

Depending on the maximum frequency of the Scholte wave and the largest phase slowness there is a maximum shot distance to avoid spatial aliasing. If we assume a maximum frequency of 25Hz and a maximum slowness of 5s/km that shot distance is 8m. This can vary strongly from one acquisition area to another, so that these assumptions and estimations are very vague.
On the other hand, the shot intervall is clearly restricted by technical parameters. The used VLF-airgun (provided by BGR) was able to shoot nearly every 6s. Due to weather conditions the minimum speed of the vessel was about 4kn, which lead to a minimum achievable shot distance of approx. 15m. In order to reduce the shot distance to at least 5m the profiles were sailed three times. During each run the shots were placed by GPS-triggering with 15m separation obeying the technical limitations. It was thus feasible to place shots in between positions already fired. However, due to maneuvering limitations of the vessel the profiles do not exactly overlap. Therefore binning of the three runs failed but despite the original shot distance of 15m we were able to calculate proper p-f-spectra as seen in the example **Figure 6**. The spectrum is derived from the eastern part of the main profile recorded at the western OBS (see **Figure 5**, red box and **Figure 2b** red line). The Scholte waves here are observed in a frequency range from 3 to 15Hz with four higher modes visible.

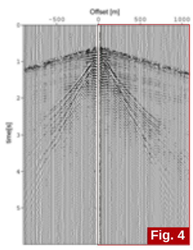


Fig. 4

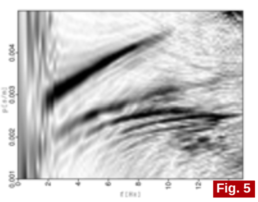


Fig. 5

OUTLOOK

Sediment structur: In order to obtain a more detailed interpretation also including the deeper horizons ghost echoes and multiples have to be removed from the seismic sections. Resulting structural information will aid positioning the coring well for geological pre-site investigation.
Physical parameters: Derived Scholte waves p-f-spectra will be used for 2D inversion. A 2D shear wave velocity distribution for each profile (**Figure 2b**) will be computed by inverting for 1D shear-wave velocity functions at a series of offset positions. This will lead to a first estimation of the 3D shear-wave velocity distribution in the area.
Further surveys: In the following part of the project coring samples will be probed for shear stiffness and correlated to the shearwave velocity distribution obtained from seismic data.
A 6-8 OBS 3D Scholte wave tomographic experiment and a true VHR-3D reflection seismic survey will be carried out centered on the coring well to reveal the undisturbed 3D-structure and velocity field of the building ground prior to erecting the platform. After completion of the platform the soil condition (structural and mechanical) will be monitored with high frequency P-wave tomographic and active/passive Scholte wave timelaps surveys.

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