Introduction

In the Danish North Sea, the construction of an energy island was planned around 100 km west of the Danish coastline (Figure 1). The idea behind energy islands is that wind turbines can be placed further away from the coast and more efficiently distribute the generated power between several countries.

To address and quantify the potential risks associated with settlements beneath a planned site for the energy island, a 2D seismic survey was conducted. The collected seismic data, along with geotechnical information and deep borehole data, were utilized for a comprehensive geotechnical quantitative interpretation study. The primary focus was to quantify deformation and elastic soil parameters of the sedimentary layers spanning from the seabed to the Top Chalk surface. Additionally, a mapping of soil classes and pore pressure was performed. Synthetic CPT's were estimated from the UHRS to validate the results against ground truth measurements. All seismic data lines were acquired using a 2D dual seismic configuration which involved the utilization of two distinct systems. The first employed system was a high frequency multi-channel seismic setup, which specifically targeted the shallow sections. The second system used, in contrast to the first system, a relative low frequency multi-channel seismic setup, with a primary focus on providing data for the relative deeper sections down to 1200 meters.

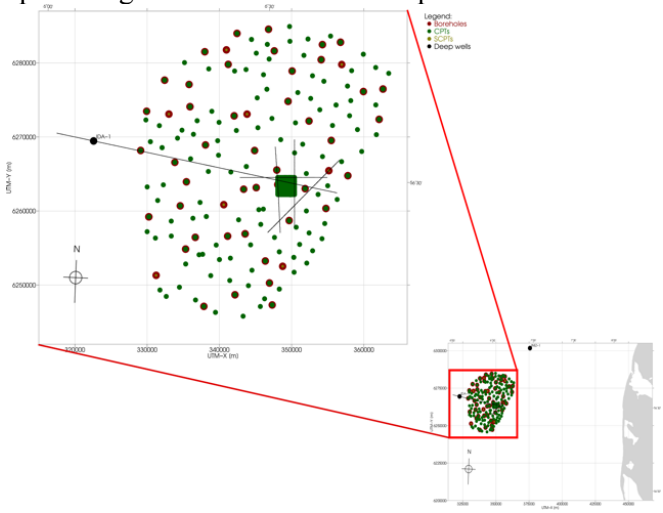

Figure 1 *Overview map of the Energy Island site showing the location of CPTs, seismic CPTs, boreholes and the seismic lines used for this analysis.*

Soil classification and CPT interpretation

Using seismic pre-stack data and the geotechnical data, seismic AVO inversion (Karkov, et al., 2022) was performed for bulk modulus, shear modulus and density, and based on these seismic derived elastic properties, a soil classification was performed. The soil classification makes use of non-Gaussian probability density functions (PDFs) using Gaussian kernel-density estimation. PDFs specific to characteristic soil types were established for the inverted elastic properties. Subsequently, the PDFs were applied to the full seismic volume derived elastic properties to determine site-wide soil properties.

A cross section of the site of the soil classification is shown in Figure 2. This result is consistent with observation from the IDA-1 well located on the seismic line. In the shallow Quaternary section, thicker sand layers are observed to be interrupted by glacial till and cut by glacial valleys. In the deeper part we observe a thick clay unit with sand lenses and occasional layers of lignite. A consistent sand layer with methane is mapped, this gas layer was considered a potential significant risk for the island construction.

In figure 3 we see the result of the synthetic CPT estimation. By mapping the elastic inversion results to the CPT domain using the non-Gaussian PDFs, a direct evaluation of the seismic inversion results

against CPT measurements becomes feasible. This integration links two independent measures, namely seismic data and CPT measurements. There is an overall high level of agreement between the seismic-predicted CPT properties and the actual CPT measurements observed, thus providing confidence in the results.

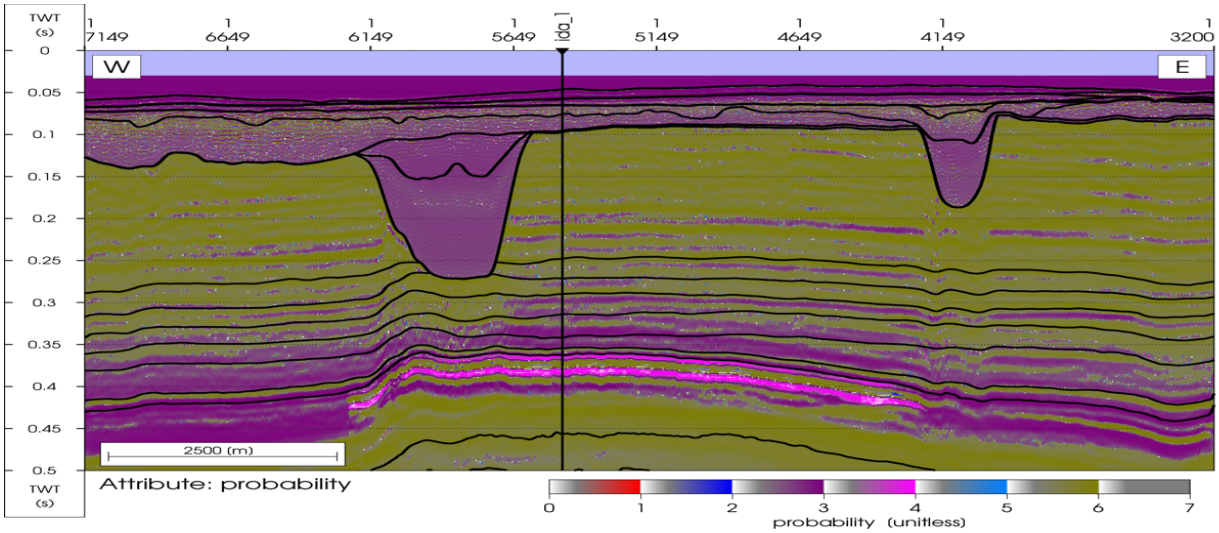

Figure 2 *Soil classification along a seismic line passing the well IDA-1. Mapped soils are clay (green, sand (purple), gas sand (magenta), hard soils (dark blue), lignite (dark red). Chalk (light blue) were encountered at deeper depths. Figure from Hansen et al. (2024)*

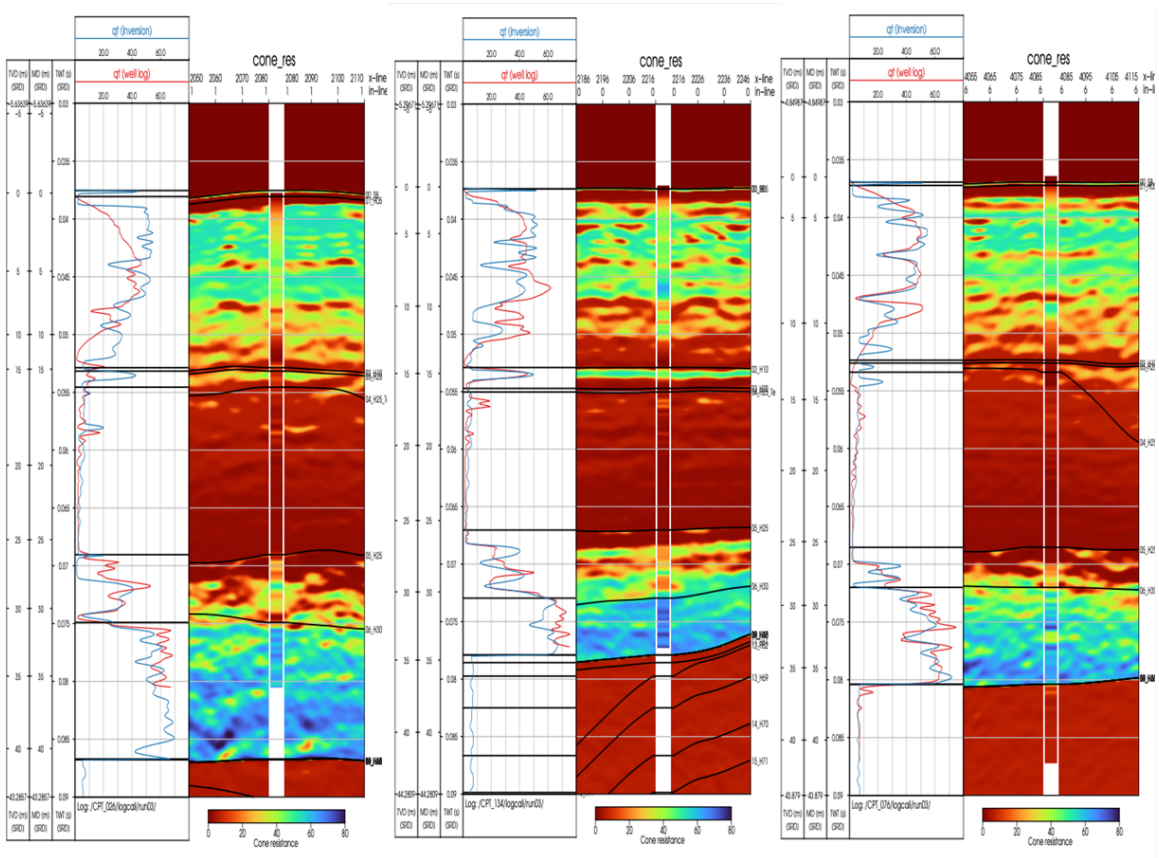

Figure 3 *Synthetic CPT results at 3 different CPT measurement locations. Red curve is the measured cone resistance from the CPT and the blue curve is the predicted cone resistance from the seismic.*

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References

1. Hansen M.B., Sørensen L.S., Colberg-Larsen J., Maia A., Duarte H, Stuyts B., Dalgaard E [2024] Bridging the gap between seismic acquisition and geotechnical parameterisation, GEO EXPRO 2-2024, Volume 21 70 – 72.
2. Karkov, K.H., Dalgaard, E., Diaz, A.T., Duarte, H., Hansen, H.J., Hviid, S., Høegh van Gilse, N.C., Krogh, L., Kuppens, S., Salaün, G., Correia, F. [2022] Case Study: AVO Inversion and Processing of Ultra-High Resolution Seismic for a Windfarm Application, 83rd EAGE Annual Conference & Exhibition, Jun 2022. Volume 2022 1 – 5. DOI: 10.3997/2214-4609.202210942