Abstract

In 2023, the Netherlands Enterprise Agency (RVO) acquired 5000 km of 2D ultra-high resolution seismic (UHRS) data and more than 200 geotechnical point measurements over the 283 km² area Nederwiek Wind Farm Zone Zuid (NWWFZ), located approximately 100 km off the west coast of the Netherlands. In this paper methodologies to perform an integrated interpretation of the geotechnical and geophysical data for building a quantitative ground model are described. The ultimate objective is to develop a model of geotechnical parameters from the UHRS data -such as shear modulus (G_{max}) and synthetic CPTs - that describe soil conditions site-wide to facilitate and de-risk the design of wind turbine foundations.

A key step in the process is to create a model of elastic parameters from the available geotechnical data This model is then used to create a link between the recorded seismic amplitudes and the actual soil response of the subsurface, and to evaluate the validity of the elastic inversion results. At this site, a stress-dependent law is proposed with exponent and multiplier depending on the soil type. This is semi-empirical in the sense that it captures the expected trends with depth, and soil type, but is still calibrated to the available dataset. The correlations were evaluated for the available regional S-PCPT tests from the Dutch North Sea.

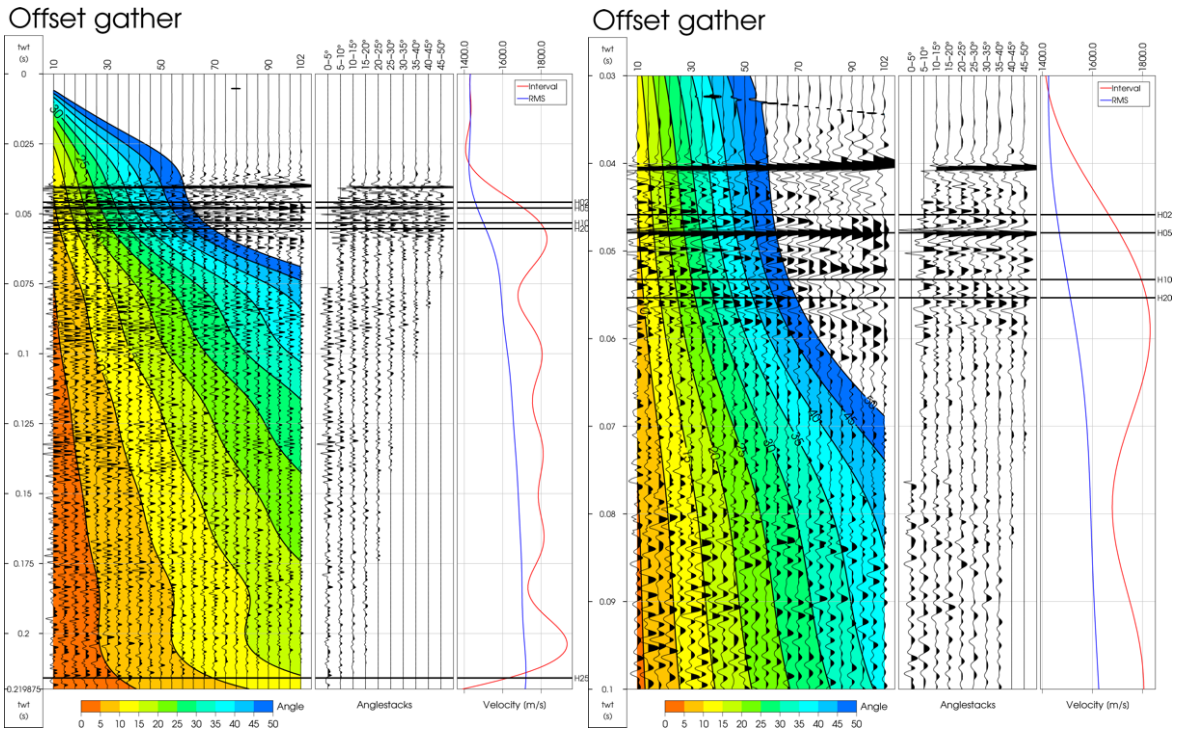

Figure 1 *Example of input offset gathers around PCPT-1016 overlaid with constant angle bands. Left plot going from 0 ms to 0.22 ms below seabed, and the right plot is zoomed in between 0.03 and 0.1 ms. For each plot: left panel are showing offset gather overlain by calculated angle ranges, mid panel is showing the stacked seismic for each angle band, and right panel is showing the seismic interval and rms velocities used for angle band calculations.*

From the UHRS pre-stack data, bulk modulus, shear modulus and density are inverted for. In addition to the UHRS data, inputs to the inversion are statistical wavelets calculated from the seismic data, along with a prior model for each property to be inverted. The pre-stack UHRS data are stacked in 5-degree angle ranges calculated based on the seismic processing velocities. Figure 1 shows an example of offset gathers from the area and how the pre-stack data are stacked into angle-bands. The angle-stacking is performed to enhance signal to noise ratio and to describe the amplitude versus angle domain as detailed as possible prior to the inversion. From Figure 1 we observe angle coverage up to 50 degrees down to 0.70 ms and 30 degrees down to 150 ms. The seismic angle gather demonstrates in general that seismic

events are consistent across offsets. The angle range from 0 to 10 degrees is low in fold and shows lower correlation to the remaining seismic. Based on inversion initial inversion tests the best results are achieved by leaving out seismic data below 10 degrees of incidence.

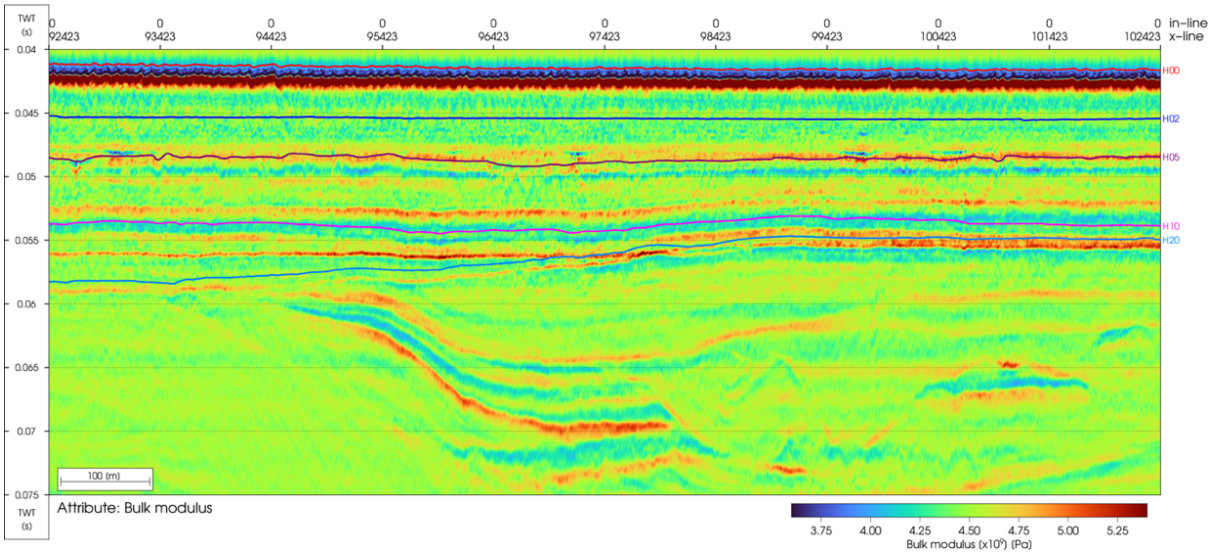

Figure 2 *Elastic relative inversion results of bulk modulus along a seismic line from the windfarm area.*

Figure 2 shows an example of the relative inversion result of bulk modulus along a seismic line at the site. Synthetic CPTs can be interpreted from the seismic derived elastic properties. Soil physical links together with site-specific observations from the geotechnical measurements will form the basis of this interpretation. Interpretation relies on non-Gaussian probability density functions (PDFs) using Gaussian kernel-density estimation. PDFs specific to characteristic soil types are established from the inverted elastic properties. Subsequently, the PDFs are applied to the full seismic volume elastic property inversion results combined with the soil specific geotechnical response to determine synthetic CPTs across the full seismic volume.