

Pre-stack seismic inversion for windfarm applications

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Abstract

A methodology is presented on how to obtain pseudo geotechnical measurements for each seismic data location. With seismic pre-stack inversion it is possible through wave equations to invert directly for physical properties like shear modulus and density for each sample in the seismic grid. Utilizing the physical link, that are present between the geotechnical parameters and the seismic amplitudes, will allow for a full understanding of the results and the associated uncertainties - also away from the geotechnical point measurements.

Introduction

UHRS (Ultra-High Resolution Seismic) data quality in the pre-stack domain have been through a great development in the recent years (Duarte et. Al, 2017). This development has allowed to investigate more advanced methods to extract information from the seismic data, methods like seismic inversion. Seismic AVO (Amplitude Versus Offset) inversion has been an effective procedure for quantitative interpretation in the oil and gas industry for several years (Buland et. Al, 2008). When applied to a site where both continuous UHRS seismic and localised geotechnical data are available, pre-stack inversion can improve the understanding of the geotechnical ground conditions in a quantitative manner. The seismic gathers were stacked into angle bands of 5 degrees prior to the inversion.

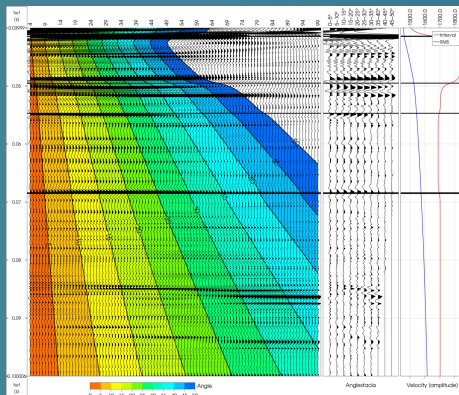


Figure 1. Example of raw seismic UHRS data. Left panel shows raw seismic offset gather overlain with 5° angle bands. Mid panel shows stacked seismic within each angle band. Right panel shows interval and RMS velocities, that are used for angle band calculation.

Methodology

The seismic inversion scheme used is a simultaneous AVO inversion algorithm, which inverts partial stacks directly for bulk modulus, shear modulus and density. Input to the simultaneous AVO inversion is a wavelet for each partial stack, which carries the characteristic phase and frequency content of that partial stack, and a low-frequency model for each property to be inverted for.

The CPT prediction is based on non-Gaussian probability density functions (PDFs) using Gaussian kernel-density estimation. The probability density functions specific for characteristic CPT data levels and soil types are established from the elastic property inversion results extracted at co-located geotechnical stations color coded with CPT measurements and soil identification data. The PDFs are subsequently applied to the full seismic volume elastic property inversion results to arrive at full seismic volume CPT probabilities.

Results

Evaluation of the UHRS seismic inversion results at a geotechnical location (Figure 2) demonstrates that two independent measurements with completely different physics can be correlated, as they relate to the same subsurface. Looking at the general behaviour of the elastic inversion results, there is a good correlation between seismic derived parameters and CPT logged parameters from 0.25-1 meter below seabed down to the first seabed multiple. From the inversion results, geological features and their elastic properties can readily be identified and extracted. From the elastic CPT prediction, geotechnical properties can be extracted throughout the seismic volume. For instance, in Figure 3 the mean value of elastic predicted friction ratio in an interval between 0.042 and 0.044 seconds is shown. This map provides clear information about the spatial variability of the soil and the geotechnical ground conditions.

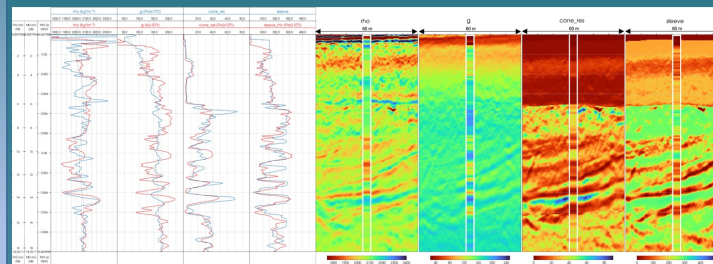


Figure 2. Inversion and CPT prediction results at a geotechnical location. To the left a 1D representation of the results with blue curves showing inversion results and red curves as measured geotechnical data, and grey curves being the applied background model. From left to right: Density, shear modulus, cone resistance and sleeve friction. The panels to the right show the inversion result along the seismic line centered around the geotechnical location with the geotechnical data inserted. Figure from Karkov et. Al, (2022)

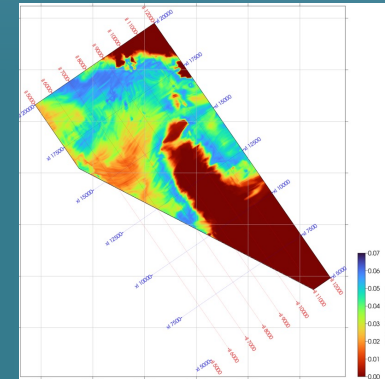


Figure 3 Map view of mean value of elastic predicted friction ratio in an interval between 0.042 and 0.044 seconds. Figure from Karkov et. Al, (2022)

Conclusions

It has been demonstrated that it is possible to obtain a quantitative understanding of the subsurface based on UHRS data. 3D volumes of geotechnical properties like shear modulus, cone resistance, sleeve friction, porewater pressure and friction ratio have been generated with the purpose of an improved planning of wind turbine locations and foundations.

From seismic AVO inversion of UHRS data, elastic parameters like bulk modulus, shear modulus and density can be obtained. Key steps in this process are generation of low-frequency models, and wavelet estimation, which both are based on geotechnical ground measurements. The CPT prediction results resolve CPT parameters within the seismic bandwidth and can be used to delineate spatial variations for specific CPT parameters of interest. A key step in obtaining elastic predicted geotechnical properties is the generation of the non-Gaussian PDFs which are based on the seismic inverted elastic parameters together with the available geotechnical data.

References

- Buland, A., O. Kolbjørnsen, R. Hauge, Ø. Skjæveland and K. Duffaut, [2008] Bayesian lithology and fluid prediction from seismic prestack data. *Geophysics*, **73**, C13-C21
- Duarte H., N. Wardell and O. Monrigal [2017] Advanced processing for UHR3D shallow marine seismic surveys. *Near Surface Geophysics*, **15(4)**, 347-358
- Karkov K.H., E. Dalgaard, A.T. Diaz, H. Duarte, H.J. Hansen, S. Hviid, N.C. Høegh van Gilse, L. Krogh, S. Kuppens, G. Salatin, F. Correia, [2022] Case Study: Avo Inversion and Processing of Ultra-High Resolution Seismic for a Windfarm Application. *83rd EAGE Annual Conference & Exhibition June 2022*