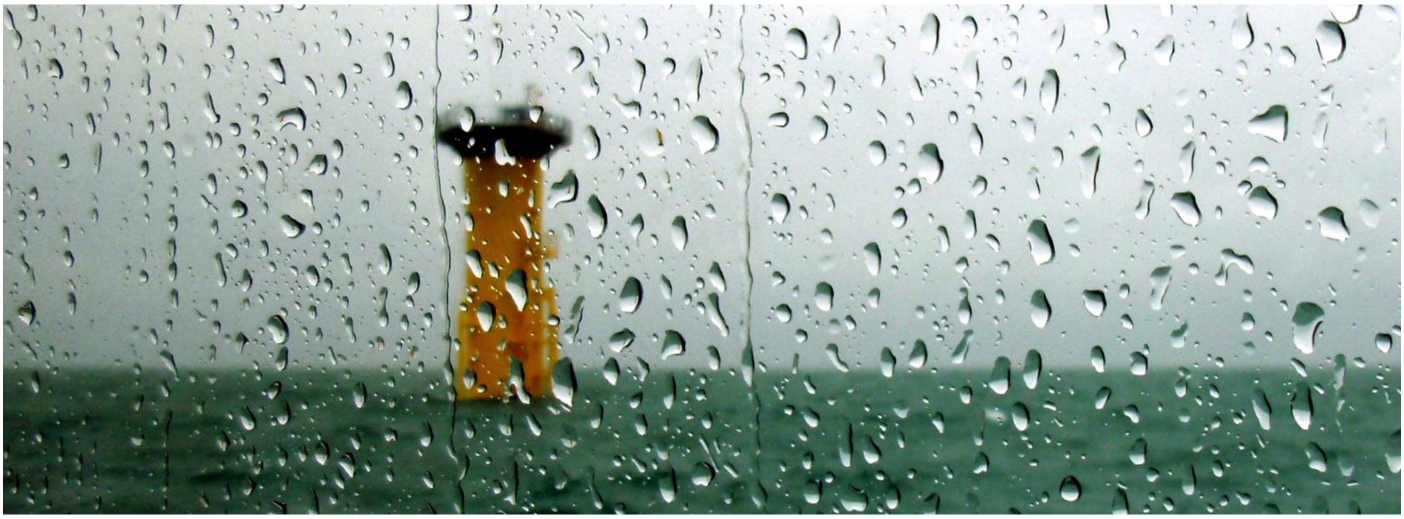

GEOSTATISTICAL ANALYSIS FOR OFFSHORE WINDFARMS

Geostatistics is an efficient statistical analysis and prediction method, using geophysical and geotechnical properties with the purpose of improving the subsequent geological knowledge by quantifying the associated uncertainties.

Introduction

The increasing demand for renewable energy resources is driving the rapid development of offshore windfarms in Western Europe. These wind farms typically consist of more than 40 turbines which are supported with piled, jackets or gravity based foundations. Due to the large number of relatively closely spaced foundations, a very extensive site investigation program is often required. Such program often requires one or more boreholes at each turbine location. Drilling boreholes at every turbine location represent a significant cost. Using geostatistics during the site investigation can not only help optimize the number of required boreholes, but also gain further geological knowledge by quantifying the associated uncertainties to the geotechnical soil properties.

Geotechnical parameters

Decisions are frequently made based on limited sample data. Example: Strength of a material must be at least X. For sampled data it is possible to estimate mean strength or probability of exceeding limits, but it provides no information about the precision of the estimates. Statistical analysis can help quantify the uncertainty associated with an estimate.

For example a statistical approach to CPT measurements could be based on a block bootstrapping analyses method, where the CPT data set is re-sampled a large number of times to estimate the distribution of regression lines. It is assumed that the values of the simulated regression lines for a given depth follow a normal distribution. The block structure is obtained by resampling entire

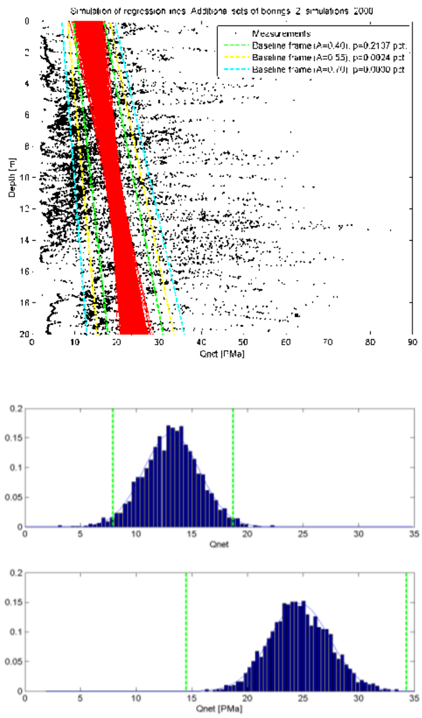

Figure 1: Top figure show the Qnet values from CPT measurements together with regression lines (red). Bottom figure show the normal distribution at two different depths and the baseline frame.

Examples on performing geostatistical analysis for offshore windfarms. The purpose of the investigation is to obtain additional and improved geological knowledge that can be applied for optimizing the design values for turbine foundation and to the planning of soil investigations:

- **Quantifying uncertainties of geotechnical parameters.**
- **Obtaining objective geological information at un-sampled locations.**
- **A cost-benefit analysis for performing additional soil investigations could be based on information obtained by a geostatistical approach.**

boreholes such that possible correlations between measurements from the same borehole are maintained. For this example the estimated probability for falling outside the baseline frame (set by the client) are found to be less than 5%.

This investigation can provide the necessary geological insight for optimizing the design values of each turbine foundation.

Spatial interpolation
Geostatistics can be used as part of the prefeasibility study for offshore windfarms. A geostatistical simulation can provide objective information at an un-sampled point on the basis of existing knowledge from for example well logs and geophysical investigations. The ability to predict geotechnical properties of subsurface soils using non-invasive geophysical measurements is undeniably useful to the geotechnical engineer.

Let X denote a soil variable, such as a strength, which has been measured in a number of positions within the soil volume, but is in principle unknown in all other positions. It is assumed that the autocorrelation function for X can be established based on the available observations.

A spatial interpolation method, such as kriging, is an estimation technique which, based on the measured values of X in conjunction with the correlation function, allows for estimation of the value of X in positions where X has not been measured, e.g. at un-investigated turbine locations. For each specified position of estimation, the kriging technique provides both an estimate of X and a standard deviation of the estimate, accounting for spatial correlations.

Kriging can be applied to the planning of soil investigations, e.g. determination of the most optimal position for an additional soil boring when an extra soil boring is to be carried out to supplement an existing array of soil borings in a soil deposit. In this context the most optimal position is the position that will provide as much new knowledge and as little redundant knowledge about the random field X as possible.

Cost-Benifit analysis
With geostatistics it is also possible to perform cost-benifit analysis to estimate whether it is worthwhile to make a geotechnical drilling at each planned offshore turbine. The estimate is based on a number of parameters, such as cost and probability of an error in the pile foundation.

A cost-benefit model such as this could be incorporated into a full financial risk model for the overall development.

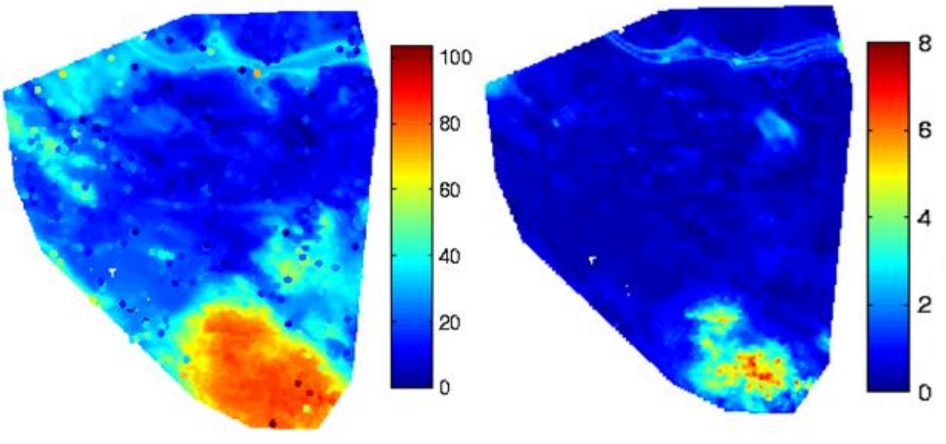

Figure 2: Left figure show the estimation of a well-log property using a geostatistical spatial interpolation method. The right figure shows the standard deviation for this estimation.

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