Netherlands Enterprise Agency

Q&A Webinar Ground Model, Geotechnical Parameters and Synthetic CPTs Hollandse Kust (west) WFZ

November 19, 2020

1) **Question:** what has been the rationale applied by RVO for scoping the geotechnical survey, considering WTG layout/positions are not yet known?

   Answer: We have developed a programme with a high density of investigations, a detailed lab test program and in-depth interpretations to provide a good spatial coverage and an extensive dataset for the tender. Even though no turbine-specific measurements are available yet, we feel this will provide a good basis to define these locations

2) **Question:** How was the geology heterogeneity considered in order to decide the CPT position?

   Answer: The CPT locations were selected to investigate all geological units, all significant geological features and to obtain a good geographical spread. This was performed based on the geophysical data acquisition lines, data interpretation, and the derived preliminary geological model the CPT locations.

3) **Question:** You gave a number of seismic samples: is that the number of traces? or the number of traces multiplied by the number of samples

   Answer: the number of seismic samples are based on 1 500 000 common depth points (CDP) for the UHR-MCS seismic reflection data. The number of data samples considers data points versus depth, considering resolution.

4) **Question 4a:** Were the seismic data acquired as 2D or 3D?

   Answer 4a: Seismic reflection data are in 2D.

   Question 4b: that means 1.5 million CDPs, and each CDP has 500 depth samples?

   Answer 4b: the presented statistics consider 1.5 million CDPs with 200 samples per CDP. The statistics do not exactly match with actual data traces that are available - the actual data volume is greater, particularly when combining SBP, UHR-SCS and UHR-MCS data.

5) **Question:** do you have a description of the acquisition parameters?

   Answer: 2D UHR MCS data acquisition parameters can be found in the geophysical results report.

6) **Question:** can you take out any 2D sections from the 3D model or are 2D section "fixed"?

   Answer: Default cross sections are provided in the 3D model which have the same orientation and reference (e.g. cross section 1, cross section 2, etc.) as those presented in the Geological Ground Model report. In addition, the program offers you the option to create arbitrary cross sections through the model.

7) **Question a:** Are the synthetic CPT profiles also used as input for the 3D model? Or are they derived from the 3D ground model directly based on the in-situ data collected from the site?
   Answer a: The synthetic CPTs were generated based on the seismic data and a subset of the CPTs. The results were not integrated in an updated ground model.

   Question b: could you perhaps comment on how the number of required CPTs and Boreholes was selected based on the geophysical interpretation?

   Answer b: The CPT locations were selected to investigate all geological units, all significant geological features and to obtain a good geographical spread at sufficient density.

8) **Question:** How is the variation in geotechnical parameter taken into account in each of the soil provinces?

   Answer: The Soil Provinces represent similar combinations of particular Soil Units. The variation in geotechnical parameters within a given Soil Unit has been analysed and defined in the Geotechnical Parameters report (see also Question 11).

9) **Question:** I notice that the soil classification does not indicate/mention on the soil geotechnical characteristics (e.g. dense sand)?

   Answer: In Main Text Section 3.3 of the Geotechnical Parameters report, you can find all relevant information per soil unit including detailed descriptions. Parameters such as relative density in sands or undrained shear strength in clays are not included in these tables. Results for these parameters can be found per soil unit in Appendix E.

10) **Question:** Is the classification according to ISO? Have you taken into account drainage for assessing the different geotechnical parameters?

    Answer: Classification is in accordance with ISO 14688-1:2017 and ISO 14688-2:2017, yes. Drainage conditions were considered for development of the presented design profiles. The design profiles are linked to calculation models and limit states.

11) **Question:** Within the same geophysical unit, the geotechnical parameters can have a large variation and therefore having representative geotechnical parameters for a specific unit might be over-conservative. How is this taken into account?

    Answer: Initially, checks were performed to assess if there is evidence of significant spatial trends of geotechnical parameters across the soil provinces. For this purpose, the Q_{tn} and percentage fines parameters were used. No trend was found (results are presented in the Geotechnical Parameters report). Therefore, it was decided that derived values will be presented per soil unit site wide.
    So, in terms of derived values, the variation within the soil unit is captured by provision of statistical values, i.e. LE, HE and BE (including a confidence interval).
    In terms of characteristic values, variation is captured using again statistical analysis while taking into account all relevant considerations for obtaining characteristic values for a certain parameter such as principles of the corresponding calculation model(s), investigated limit state, etc.

12) **Question:** As explained, the governing (major) soil unit defines design parameters for a specific soil province. Do you only take into account the main governing soil unit for a specific province? Or do you take a weighted influence from all the soil units? E.g Soil unit F is the major, so we take 80% influence from it, then 15% from the second highest and 5 % from the third?

    Answer: The Soil Provinces are defined by particular combinations of Soil Units together with some other unique defining feature, such a dominant soil unit within 20m of seabed or a particular unit with a defined minimum thickness. It varies. Full details are provided in the Geotechnical Parameters report.

13) **Question:** Can you give more details on how the seismic data was used? Was it used primarily to extend CPT results laterally based on seismic stratigraphy? Or were seismic attributes compared to the geotechnical CPT & borehole data, and then those correlations used to invert the seismic data? Perhaps this was all discussed in a previous webinar?

    Answer: This was indeed all discussed in the first HKW webinar on 5th November. You can find the recording of the first Webinar on https://offshorewind.rvo.nl/soilw.

14) **Question:** The probability of hazards for cables: does this refer to hazards when cable is exposed on seafloor?
    Answer: No, the cables are assumed to be buried. More information on the geohazards can be found in the Geological Ground Model report.

15) **Question/remark:** It would be beneficial to show graphs with a lot of data full screen and not switch back and forth between presenter and full screen slide.

    Answer: The presentation can be downloaded at
    https://offshorewind.rvo.nl/file/download/55040737

16) **Question:** Did you use machine learning for clustering of CPTs?

Answer: The “real” CPTs per soil province were clustered for the purpose of selecting the design locations. No machine learning techniques were applied for this purpose. Machine learning algorithms were applied for generating synthetic CPTs. However, as mentioned later in the presentation, one of the benefits from the use of synthetic CPTs is the additional reconnaissance of the soil provinces by end-users, giving them the possibility of picking and reviewing more locations of interest from the pool of synthetic CPTs.

17) **Question:** For the PISA numerical based method, how is it know that only these parameters are required without knowing the constitutive model, of which there are many?

Answer: The Geotechnical Parameters report presents design profiles for a selection of parameters. The set of geotechnical parameters that corresponds to the PISA numerical-based method (i.e. γ, s_u, ϕ', δ, G_{max}) is considered fundamental to most soil constitutive models likely to be used for conceptual monopile design. The characteristic values presented in the report can serve as input for calibration of soil constitutive models. They must, though, be verified for the specific soil constitutive model(s) selected by the designer, with regards to potential further transformation within the context (features and limitations) of the selected soil constitutive model, checks for parameter interdependency with parameters not given within the report, etc.

18) **Question:** Is Fs presented for Alm and Hamre in clay which appears to be missing?
Answer: Sleeve friction was not part of the scope of parameters for which characteristic values are provided.

19) **Question:** How reliable is it to define friction angle from the CPT data? Did you validate the friction angle selection based on other laboratory tests?

Answer: A site-specific CPT-based correlation was developed for obtaining the characteristic values for peak friction angle. This correlation was fitted based on site-specific laboratory data, i.e. from laboratory consolidated drained triaxial compression tests. Please refer to the Geotechnical Parameters report for more detailed information.

20) **Question:** Small strain shear modulus from the lab tests (BE, RC) is seen considerably lower compared seismic CPT data and PS. This finding ties well with previous studies and the importance of testing in-situ conditions. The results of seismic CPTs have been used to derive a site-specific correlation and extrapolate that through the site. That's an excellent approach. However, what shall we do with the lab testing? Do you see the need to incorporate a correction factor on the lab test results?

Answer: As for other parameters, the laboratory tests provide background information as well as the opportunity to apply specific stress-strain conditions, where such conditions are fixed by in situ testing. The approach taken for the presented design profiles was to consider the full data set and

consider reference conditions. The focus for the design profiles was on SCPT data as reference, as per common practice.

21) **Question:** Can you please explain about the transformation uncertainty and how the uncertainty be taken into account to derive the parameters?

    Answer: Generally, we considered transformation of derived values to characteristic values according to the specified principles or general use of parameter values within the calculation model. In broader terms, transformation uncertainty relates to probable differences between derived values of a geotechnical parameter (laboratory and in situ) and the actual in situ values of the geotechnical parameter that actually affects the behaviour of a geotechnical structure. In most cases, there are no reliable and affordable geotechnical methods available for obtaining direct and accurate characteristic values required for a calculation model.

22) **Question:** Would it be easy for Fugro to produce the digital LE,BE and HE in digital format because it would be very helpful in future or a retrospective update / variation to HKW. Particularly considering the increasing amount of automation and aim to increase engineering efficiency

    Answer: RVO will consider this for current (HKW) and future works.

23) **Question:** Are the CPT correlations linked to the mean value or the best estimate of a parameter?

    Answer: The Geotechnical Parameters report considers CPT correlations for derived values and characteristic values. For the characteristic values, the (design) CPT correlations are such that they provide a cautious approach according to Eurocode 7 for the calculation model/ limit state.

24) **Question:** Why do you feel the lab testing for peak phi was significantly smaller than the CPT qt correlation using Mayne and Kulhawy?

    Answer: The tentative conclusion is that the lower lab values are related to the geological setting (fluvial / marine), i.e. fit the lower part of the bandwidth of the M&K correlation.

25) **Question:** For example for Unit F, where in the depth profile should one use soil parameters for sand, transitional, or clay? Is that derived from the (synthetic) CPT data using IC? What if the soils are highly interlayered sand/clay, beyond the boundaries of transitional?

    Answer: Generally, the design approach should assign stratigraphic schematization on a sub-site (WTG), considering sub-site specific CPT data and geological setting. The synthetic CPT data can provide support but should not be leading for highly interlayered conditions.
    However, the report contains information on the relative proportions of the different soil types within a Soil Unit. This information could be used to carry out some sensitivity studies. Alternatively, analyses could be based on specific CPT locations (as per the Design Locations). The synthetic CPTs could also be used to help assess the relative distributions.

26) **Question:** Will the geotechnical parameter report be extended for other engineering applications such as cable burial risk assessment?

    Answer: RVO will consider this.

27) **Question:** Has DNVGL certified also the synthetic CPTs?

    Answer: The synthetic CPT report includes a DNVGL review report. DNVGL did not provide a certification-type report, because of absence of detailed codes and standards for this topic.

28) **Question:** Why were the sleeve friction and pore pressure parameters not predicted as part of the synthetic CPTs. Is this a matter of computational limitations, or are there other reasons for only predicting qn*

    Answer: The prediction of cone resistance showed a higher correlation than the prediction of other CPT parameters. The scope of work and corresponding schedule were thus limited to qn*.

29) **Question:** How do the exclusion of top 2 m of synthetic CPT will have an effect on the cable design/alignment?

    Answer: The strategy for the synthetic CPT generation was for (mono)pile design. Extension to cable design/ alignment is indeed a possibility, albeit challenging.

30) **Question:** Have you used all the CPTs to correlate with the seismic data for the predictions in other locations, or have you focused in one or two CPTs?

    Answer: Only seafloor PCPTs (122) were used for prediction of synthetic CPTs. The TCPT and SCPT data were not used. 88 PCPTs were used for training the neural network, 34 PCPTs were used to check the prediction results.

31) **Question:** Are you just looking at seismic amplitude changes?

    Answer: We have looked at different seismic attributes for the neural network approach:
    - Moving average of the seismic interval velocity
    - Moving average of seismic instantaneous amplitude (envelope)
    - Moving average of seismic model-based impedance

    Apart from these seismic attributes we also used:

    - Soil Units A to G (from the geological ground model)
    - Depth in metres below seafloor
    - q_n* parameter approximating net cone resistance

32) **Question:** What are the attributes used in your neural network approach?

Answer: See answer to Question 31)

33) **Question:** What are the seismic attributes that have been input into machine learning process to build correlations between seismic results and qc?

Answer: See answer to Question 31)

34) **Question:** Have you divided the prediction by making correlations in each specific soil units, e.g. A, B1 & B2, ...

Answer:
No separate predictions were done per unit, however Soil Units (A to G) were used as input parameters for the training of the neural network (i.e. the units were taken into account)

Please note that we used the geotechnical units of the geological ground model (8 Units: A, B, C1, C2, D, E, F and G)

35) **Question:** A 7 point average of seismic interval velocity was used - at what lateral and vertical spacing were interval velocities measured?

Answer: The seismic interval velocities are derived from the velocity picking as part of the 2D UHR seismic processing flow. More details on this can be found in the geophysical results report.

36) **Question:** Were the interval velocities compared to the in-situ velocities measured by CPTs?

Answer: No. The (S)CPTs provided no P-wave velocities. Refer to the Geological Ground Model report for comparisons with P&S suspension logger data (borehole geophysical logging).

37) **Question:** Which method did you use to calculate the 90% confidence interval?

Answer: The (signed) error distribution per soil unit was calculated. This error was calculated by subtracting the predicted q_n* values, from the actual q_n*values.

38) **Question:** The predictions appear to miss some of the long-wavelength variations in qn*. Can this be related to the seismic frequency bandwidth ? Do you know the lower bound of the bandwidth?
Answer: Indeed the very long wavelengths and very short wavelengths in q_n* can be underrepresented. This is primarily due to the band-limited seismic data (refer to geophysical data report). The correlation of seismic data with CPT data also has limits at certain scale lengths. These quantities can generate different soil parameters at very large and very small scales, as a secondary effect.

39) **Question:** Would you be able to predict cone resistance for a soil unit for which you don't have available CPT data?

Answer: Yes, it is possible. However, the quality of the prediction will depend on how well the characteristics of this new unit have been captured by training the model on other soil units.

40) **Question:** Does the resolution of synthetic CPTs relate to UHR data, or selected sampling interval?

Answer: For prediction of synthetic CPTs we used a depth interval of 0.1m. This is in accordance with a depth sample interval selected for the 2D UHR data.

41) **Question:** So the qn* profiles at each CDP are in SEG-Y format?

Answer: The provided synthetic CPT profiles (q_n*) are provided in SEG-Y format whereby each CDP position has an associated predicted q_n* profile. A selection of q_n* profiles (approximately 15 800) is provided as ascii files.

42) **Question:** Why has qn been selected for prediction instead of qt?

Answer: The parameter q_n* has potential for better predictions in low-strength soils, compared to q_t. The difference is probably small in most cases.

43) **Question:** Though the sampling interval of the seismic data is 0.1 m, the resolution is lower (especially at larger depths). This is definitely the limiting factor for prediction.

Answer: Indeed. As was indicated in the webinar, with depth the prediction becomes more a trend-type prediction (i.e. not all layers are predicted).

44) **Question:** Why wasn't SBP data used in this project to improve the understanding of the shallow geology (which could be tied in better to CPTs)?

Answer: SBP data were used, as explained in Geological Ground Model report.

45) **Question:** Has it been considered to use the HKN and HKZ data sets to add to the prediction basis for synthetic CPTs?
Answer: Yes, however the scope of work and corresponding schedule were limited to HKW data.

46) **Question:** Can the geophysical and geotechnical data used for machine learning be used for other locations having similar soil or geological characteristics?

Answer: Yes, potentially this is possible. Minor tweaking of the neural network may be required. The input datasets (e.g. seismic attributes, CPT parameters, Unit interpretation) need to be in similar

format and same depth measurement interval as used for HKW. Also the geology needs to be similar to the HKW area, and the same geological units need to be interpreted.

47) **Question:** How is the transitional soil defined as transitional by your standards? And what is the significance in design.

Answer: Transitional soil is defined in between Sand and Clay based on application of certain criteria for Sand and Clay, as explained in the Geotechnical Parameters report. The significance in design depends on the design situation and the assessment on the expected behaviour of these soils within the context of the particular limit state(s) to be verified.

48) **Question:** So, it means, there are Geotechnical parameters available all across the WF area?

Answer: Geotechnical parameter values were obtained from results of in situ and laboratory testing performed at the specific investigated locations across the site. The results were subsequently integrated in a geotechnical ground model for the site (see Geotechnical Parameters report). The synthetic CPT profiles (which comprise values of the parameter qn*) were obtained at all CDPs across the site.

49) **Question:** Is an IHS Kingdom license required to navigate synthetic cpt results?

Answer: No, you can load the SEG-Y files containing the synthetic CPT results in any software that reads SEG-Y files (e.g. OpendTect, IHS Kingdom Suite). Alternatively you could load and interrogate the files with a SEG-Y viewer (e.g. SeiSee). A readme file with guidance on how to read and interrogate the SEG-Y files is included in the digital deliverables. In addition, installation files of both OpendTect and SeiSee are also provided. Please note that ascii files with synthetic CPT results are provided for a subset of predicted location (i.e. approximately 15 000 ascii files at 80-metre spacing).

50) **Question:** I've only found the webinar 1 presentation on the website - is the video recording available for download as well?

Answer: The video recording can be found here.

51) **Question:** Do you consider the distance from CPT to line in the uncertainty (90% confidence interval), and if so, how?

Answer: No, this distance is not considered in calculation of the 90% confidence interval.

52) **Question:** What is the added benefit from the use of the 3D SubsurfaceViewer model?

Answer: The 3D model allows an interactive visualization of the ground model. As I mentioned earlier, the user can interrogate the ground model from different viewpoints, create cross-sections through the model and get a closer look at geological features of particular interest. Therefore, the

main purpose of the 3D SubsurfaceViewer model is to help the end-user gain better insight and understanding of the complex geological and geotechnical setting at the site.

53) **Question:** What is the purpose of the soil groups?
Answer: The purpose of defining soil groups is the identification and separate parameterisation of distinct strata with particular soil types within soil units. Derived values for geotechnical parameters where this subdivision is relevant are presented also per soil group. This can aid selection of characteristic values of geotechnical parameters at the depth intervals where these soil groups are encountered.

54) **Question:** Have you checked for potential spatial trends of soil units that extend to more than 1 soil province?
Answer: Yes, this was checked and the potential added value for presentation of parameter values per soil unit per soil province was assessed. The outcome of the assessment was that the soil units are quite similar across the site, displaying no significant spatial trends. The assessment included checking of Q_{tn} and percentage fines values across the different provinces. The report presents profiles of Q_{tn} and percentage fines (i) versus depth per soil province and (ii) in the form of probability density functions.

55) **Question:** Was spatial soil variability taken into account for the layering?
Answer: The stratigraphic schematisation is based on the stratification at the individual CPT design location, since the main aim of the design locations is to aid in the reconnaissance of the soil provinces for conceptual design. Therefore, soil variability across a spatial extent of the pile placement area, assuming a monopile or a jacket structure is positioned at a design location, was not taken into account.

56) **Question:** Are the design profiles presented in the report applicable only to the selected calculation models or they can potentially be used for other calculation models as well?
Answer: The procedure followed for selection of characteristic values is according to Eurocode. This involves, among others, the consideration of specified principles or general use of parameter values according to the selected calculation model(s). Therefore, in that sense, the presented design profiles correspond to the specific calculation models outlined in the report.

However, it is possible that the design profiles may be used in other calculation models with little to no modifications but guidance for this was outside the scope. As an example, the characteristic values corresponding to the ISO p-y method can be mentioned. Although this method is specifically applicable to long piles (i.e. jacket piles), there are various workarounds in literature with which the method is modified to account for large diameter effects and subsequently used for monopile design.

57) **Question:** How do the characteristics values given in the report reflect the difference between the PISA numerical-based method and the rest of the calculation models?

Answer: Indeed the PISA numerical-based method entails a procedure to be followed in contrast to the rest of the calculation models that prescribe formulas. The design framework of the PISA numerical-based method requires the use of FEA for which a soil constitutive model must be selected. Each soil constitutive model requires a different set of input geotechnical parameters and

has specific features and limitations. Therefore, without knowing the model being adopted, a full set of characteristic parameter values applicable to a specific soil constitutive model is not possible.

Nevertheless, the set of geotechnical parameters that is covered by the report (i.e. γ, s_u, ϕ', δ, G_{max}) is considered fundamental to most soil constitutive models likely to be used for conceptual monopile design. The characteristic values presented in the report can serve as input for calibration of soil constitutive models. They must, though, be verified for the specific soil constitutive model(s) selected by the designer, with regards to potential further transformation within the context (features and limitations) of the selected soil constitutive model, checks for parameter interdependency with parameters not given within the report, etc.

58) **Question:** The concept of site-specific CPT-based correlations is quite appealing. What are the benefits of having a CPT-based correlation calibrated with site-specific data?

Answer: Key geotechnical parameters (e.g. G_{max}, ϕ', s_u) have been correlated directly to CPT data via the procedure outlined earlier. This allows characteristic values for these parameters to be obtained on a location-specific basis at any location within the site where a CPT is performed, thus resulting in the potential for optimised foundation design at that location. So, having in mind also the subsequent design phases, you only need to carry out a CPT which you can plug in the parameter correlation and quickly acquire the design profile at that location.

59) **Question:** How can synthetic CPT profiles be used for a specific wind turbine location? The bandwidth of the cone resistance values seems too large for practical use.

Answer: If we assume that the synthetic CPT profiles are at a short distance from the wind turbine location, then the available data can be used to enhance the understanding of the soil variability across the wind turbine location, taking account of one or more actual CPT profiles for the wind turbine location. The bandwidth of the data allows correlation of data but does not allow allocation of design parameter profiles.

If we consider the case of new geophysical data acquired specifically for the wind turbine location, then the added value of synthetic CPT profiles and, for example, shear modulus profiles, can be quite high.

60) **Question:** The synthetic CPTs look really promising. Can this approach be easily adopted to other offshore windfarm sites, such as IJmuiden Ver?

Answer: In theory this approach can be used for other offshore sites, if the same data are available, i.e. 2D UHR data, CPT data, interpreted units from the seismic data and derived from CPTs. Data quality needs to be assessed if adequate for this approach. In new areas, a new neural network needs to be trained.

If the geological conditions in the new area are similar to the HKW area, and similar geological units (interpretation) have been identified from adequate 2D UHR data, then the trained neural network may work for this new site as well. Tweaking of the ML may be required and ideally results are confirmed with ground truth data.

Using the existing HKW machine learning model (CNN) for other areas with similar geological conditions is something we are keen to try in future.