Modelling of underwater noise and mitigation systems during installation of wind farms

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Introduction

The emission of underwater noise during installation has become an increasingly important issue to the offshore wind power industry. To understand the issue properly DONG Energy Wind Power have initiated detailed studies. These comprise measurement programmes and the pursuit of various numerical modelling schemes.

The purpose of the measurement programmes is to provide data for research as well as for calibration and verification of numerical modelling.

Emphasis in the modelling work is on understanding the general noise propagation patterns in water and seabed when a pile is driven into the ground. The end objective is to derive robust methods for accurately estimating the noise impact of any future project and being able to include the effects of varying soils as well as the effects of various noise mitigation measures. The approach taken is to divide the problem into three parts: The behaviour of the pile and its interaction with the soil, the generation and transmission of sound in the near-field and the transmission of sound in the far-field.

Motivation

Because of the impact on the marine life it has always been necessary to estimate installation noise and provide necessary mitigation means. In the pursuit of cheaper production of electricity the offshore wind business is using larger turbines and foundations which lead to an increased level of installation noise per pile. The duration of the noise will however decrease since fewer positions are needed to reach the same installed capacity. Recently, quite strict regulations have been implemented in Germany leading to severe financial implications and increased risks if the problem is not well understood. This means that there is both an environmental and a commercial urge to being able to estimate installation noise and the effects of mitigation measures accurately.

Current mitigation methods

Currently, the dominating foundation type is the monopile due to its simplicity and efficient manufacturing. This is most commonly installed by impact hammering, thus making this method the primary focus. Noise mitigation methods currently considered by the industry are:

- Vibration instead of impact hammering
- Near-field mitigation by resonance-related methods e.g. 'small' bubble curtain
- Near-field mitigation by impedance-related methods e.g. 'cofferdam' and Noise Screens
- Outside near-field mitigation by resonance/impedance-related methods ('large' bubble curtain)

To be feasible any method has to be time- and cost efficient in addition to being able to mitigate the noise.

Field trials and full-scale tests

During the installation of the Anholt Offshore Wind Farm in 2012 DONG Energy undertook tests of a cofferdam as well as vibro-driving. At each test location the resulting noise levels were measured using hydrophones hanging at 3 and 10 m depth below the sea surface. These measurement stations were placed in 40, 750 and 1500 m distance along a radius. An additional station was also placed in 750 m distance but perpendicular to the measurement line. See Figure1 for a sketch of the measurement setup.

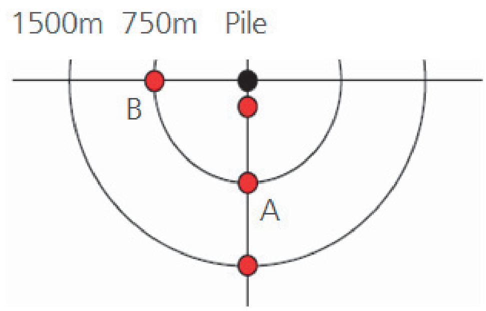

Figure 1 Schematic of measurement setup at the Anholt pile driving noise measurements. Hydrophones were installed 3 and 10 meters below sea surface and accelerometers were installed on the seabed.

In connection to the noise measurements accelerometers were also placed on the seabed to record seismic waveforms propagating along the seabed and finally reference shots were performed using an airgun to get known-source data for estimation of transmission loss level as function of distance.

The cofferdam technology was tested at one position. It consisted of a steel cylinder, pre-positioned on the seabed and stabilised by a seabed-frame. Unfortunately, the seal failed to function properly and the cofferdam was flooded.

During piling at this location a noise level of 169 dB SEL at 750 m distance was recorded, comparable with the reference measurements. In conclusion, the flooded cofferdam provided practically no noise reduction which is also to be expected. An outline of results from the measurements can be seen in Table 1.

Table 1 Measurement results from impact pile driving and vibratory pile driving at the Anholt Offshore Wind Farm

Pile	Description	L_{SEL} @ 750 m (dB re 1 µPa^2s)	L_{EQ} @ 750 m (dB re 1 µPa) Average during piling
1	Hammer	172	
2A	Vibro		150
2B	Hammer	169	
3	Hammer	175	
4A	Vibro		166/156
4B	Hammer	171	
5	Cofferdam	169	

Vibro-driving was performed at two positions. For the 1st vibro test average noise (Leq) at 750 metres was 150 dB with a maximum of 153 dB. During the 2nd vibro test noise levels started off lower than the 1st test. However by the end of testing noise levels reached a maximum Leq of 166 dB and thus the average value ended up at 156 dB. This increase in noise level occurred as the pile met refusal approximately 1 m before reaching its target depth.

It was concluded that vibrodriving is a potential low-noise installation technology with the ability to meet the requirements in certain situations and if the soil conditions are favourable. In harder soils refusal may occur resulting in significant higher noise levels.

Analysis show that the eigenfrequencies of the Wind Turbines mounted on the vibrodriven piles are comparable to those of impact driven piles, indicating that vibrodriving has no effect on the soil bearing capacity.

Understanding the acoustic problem

As a first attempt FE (Finite Element) modelling of the noise propagation close to a pile was performed. This proved promising and a more detailed FE model was set up to model the near-field noise propagation. This model was also using a number of simplifications: Axial symmetry, geometric generalisation of the pile, an elementary elastic soil model and an analytical calculation of the impact force not modelling hammer and anvil. Comparison between calculated and observed was performed as a reference case. For a case with 50 m separation between pile and hydrophone the spectra showed good agreement from 100 to 500 Hz. Calculated spectra showed much lower values below 100 Hz. Calculated and measured SEL values differed less than 1 dB. For a case with 60 m separation SEL values differed around 2 dB, while the spectra showed the same similitude above 100 Hz.

Sensitivity analysis was conducted by varying Youngs modulus and the interval friction angle. The conclusion was that the effect was insignificant.

Propagation outside the near field

Noise propagation at the Anholt site was modelled at certain pile locations in terms of sound Transmission Loss (TL). This was performed using the method *Wavenumber Integration* as implemented by Scooter and Fields. This involved definition of the acoustic environment, including the geoacoustic properties of the seabed. Based on comparison of empirically vs. model based TL, a set of environmental parameters was found that provided a good match. The parameter adjustment was based on physical reasoning and calibrated using airgun shots recorded at different distances.

The resulting propagation model was used to estimate an equivalent Source Level (SL) of approximately 168 dB re 1µPa2.s, having the main part of the energy roughly within 100 to 500 Hz. This shall be compared with pile 2dB for a hammer energy of circa 400 kN-m and nearly final penetration depth.

Mitigation methods

A generic noise shield consisting of a double steel cylinder with air-gap and static seals has been further evaluated. For use at the Borkum Riffgrund 1 in spring 2014 a similar system will be used and detailed noise measurements will be performed including reference measurements with and without the noise screen in place.

Big Bubble Curtains have been used on a number of projects. Unfortunately reference measurements do not exist for the piling of large piles. During installation at Borkum Riffgrund 1 substation (Ø2.1 m piles) around 10 dB noise reduction compared to the noise prognosis was achieved using a single BBC.

Conclusions

Noise propagation can be modelled with high precision in the near-field as well as in the far-field. Reference measurements will soon be available allowing validation of modelling of transmission loss obtained using state-of-the art noise mitigation methods.

Further work is in progress regarding refining of the source model and also the modelling of noise mitigation systems in the near field. In order to provide a complete model to assist design and planning, the goal is to integrate the blocks into a coupled model including the effect of noise mitigation both in near- and far-field. It is expected that it will be possible to estimate source levels and damping effects within approximately 2 dB.