Reduction of underwater piling noise: An optimization of the impact force to reduce underwater noise during the installation of a large sized monopile.

Offshore wind is a fast growing industry that has the potential to play an increasing role in the near future of power generation. As the industry evolves, wind farms are constructed further offshore where the wind is less turbulent and more space is available to increase the size of the wind farms. Furthermore, the capacity and size of wind turbine generators is growing due to technical developments. As a result, the foundation structure increases in size to assure stability and sufficient support of the generator. In general a monopile (large diameter steel cylinder) is the preferred foundation due to its economic benefits and relatively simple installation. In 2015, approximately 80% of all the offshore foundations installed in Europe were monopiles. This amount is expected to rise taking into account offshore wind farms that are currently being developed.

For the installation of a monopile, a large amount of energy is applied by the impact of a hammer on top of the pile. This impact generates waves that propagate through the surrounding air, water and soil over large distances and disturb the marine life. Consequently, pile driving has become a strictly regulated construction process. Therefore, the offshore wind industry developed a variety of noise mitigation methods to reduce the underwater noise. However, these are expensive methods, driving the costs of noise mitigation till approximately 15% of the total installation costs of an offshore wind farm foundation.

Noise which directly radiates into the water is referred to as the primary noise path. Noise which re-radiates from the soil back into the water is referred as the secondary noise path. With increasing size of the monopiles, the ring frequency of the shell (the frequency at which the monopile moves radially outwards and inwards together) shifts towards lower frequencies. In addition, the amount of energy required to drive the monopile into the soil increases resulting at a longer duration of the impact force and hence lower frequencies to be excited. Low frequency waves are less attenuated in soil compared to high frequencies, increasing the influence of the secondary noise path. However, most of the noise mitigation systems nowadays do not consider the secondary noise path and hence become less effective in reducing underwater noise generated by large monopiles.

The aim of this research is to investigate ways to reduce noise levels directly at the source of the noise, instead of mitigating the radiated noise. This is achieved by optimizing the impact force with respect to noise, while keeping the drivability unimpaired. First of all, insight in the noise propagation during installation of a large sized monopile is obtained. This is done by modeling acoustics with a basic spring dashpot model and a more advanced elastic medium model derived by Tsouvalas and Metrikine (2013,2014). The analysis shows a large amount of energy at low frequencies carried by waves traveling along the soil-water interface, so called "Scholte waves". Both models are validated with measurements from the Veja Mate project where monopiles with bottom diameters of 7.8 m were installed. The impact force, which serves as input for both models, is obtained from the drivability program GRLWEAP.

For the optimization process, multiple steps are taken. Firstly, the dominant acoustic frequencies of the pile-water-soil system are derived that result in a high response after excitation. Secondly, a method is developed to evade the dominant acoustic frequencies in the amplitude excitation spectrum of the hammer. In order to keep the drivability with the adjusted impact force unimpaired, a basic non-linear drivability model is developed based on mass, springs and dashpots. The non-linearity is limited to the description of the sliding of the monopile into the soil with locally reacting non-linear springs. A concept which still needs to be verified for the case of large piles and relatively low frequencies.

Finally, an additional analysis on the effect of the adjusted impact force on the noise levels is performed. The results show an increased amount of energy at low frequencies carried by waves traveling along the soil-water interface. Due to the high geometrical and material damping in the soil, the high frequency compressional waves attenuate rather quickly with increasing distance from the pile, resulting at shear and Scholte waves being dominant at larger distances. The energy carried by the latter is increased compared to the previous analysis with the non-adjusted impact diagram. However, the Scholte waves produce only pressure fluctuations in the water close to the soil-water interface and not further up into the water column. With the current derived analysis method, the noise levels at 100 m from the piling source are reduced while drivability is kept largely unimpaired.

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