V International Conference on Computational Methods in Marine Engineering
MARINE 2013
B. Brinkmann and P. Wriggers (Eds)

COMPUTATIONAL PREDICTION OF NEAR AND FAR FIELD NOISE DUE TO PILE DRIVING FOR OFFSHORE WIND FARMS

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Key words: Simulation, Underwater Noise, Offshore Windfarms, Pile Driving, Time Domain, Frequency Domain

Abstract. One major long-term goal of the German government is to decrease the greenhouse gas emissions by 40 %. This results in a key role of offshore wind farms regarding the turnaround in energy policy. In most cases, offshore wind turbines are erected by pile driving leading to a significant noise impact. In consequence, limiting values for emitted underwater noise have been prescribed to avoid a negative influence on marine mammals. To fulfill these requirements, different sound damping systems are currently developed or under investigation. Thereby, the numerical prediction of the resulting sound pressure level is an important tool to prevent cost-intensive offshore tests.

As a general approach different numerical modeling techniques are used to study the generated pressure wave, taking into account the near and far field propagation separately. To model the area near the pile of the wind turbine, a detailed finite element approach is used. For the far field propagation, numerically highly effective methods are needed to predict the sound pressure level at large distances of several kilometers from the pile. In a combined model, results of the area close to the pile are transferred to a separate model using wavenumber integration to compute the sound pressure in the far field of the pile. Detailed investigations of the far field model and the setup of the combined near field-far field model can be found in corresponding publications of the authors [1]-[4]. The focus of this contribution is on the transformation of the near field model from the time domain to a formulation in the frequency domain to be able to consider frequency-dependent effects, like, e.g., the damping characteristics of bubble curtains.

1 INTRODUCTION

One key technology towards the extension of renewable energy is electricity generation by offshore wind farms. In water depths of 10 to 50 m, pile driving is still the best available technology. Thereby, high energy levels are required to drive the piles into the soil. To protect the marine mammals, limiting values for emitted underwater noise have been introduced by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. In most cases, these limiting values can only be fulfilled by using sound mitigation systems like, e.g., the bubble curtain. The numerical prediction of the resulting sound pressure level with and without sound mitigation system is an important tool to avoid cost-intensive offshore tests and to get a better understanding for the emitted pressure field. To take into account the near and the far field propagation, the model is divided into two parts, for which different modeling techniques are used. While the near field model is based on the finite element method (FEM), the far field propagation to distances of several kilometers from the pile is computed by using a wavenumber integration approach (see [1]-[4]).

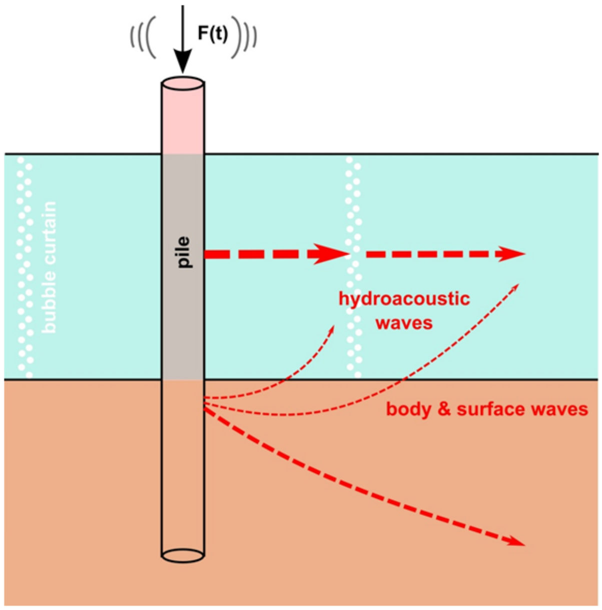

Figure 1: Visualisation of the different possible sound paths of the structure-borne noise and water-borne noise due to pile driving through a bubble curtain

A big challenge for the finite element near field model is to consider the pile driving process combined with a sound mitigation system like, e.g., the bubble curtain. On the one hand, the impact of the hammer on the pile is a highly time-dependent process, on the other hand, a simulation of the rising bubbles is not possible in such a finite element model and the characteristics of the bubble curtain like the speed of sound in a water air-bubble mixture are frequency dependent. In [5] and [6] an approach is shown to calculate the sound speed und density of this mixture. The sound speed of fluids is given by:

$$c = \sqrt{\frac{1}{\rho\kappa}}. \tag{1}$$

The expression for the density ρ and the compressibility κ are:

$$\rho_{mix} = (1 - V)\rho_{water} + V\rho_{air} \tag{2}$$

$$\kappa_{mix} = (1 - V)\kappa_{water} + \Delta\kappa \tag{3}$$

The occurrence of the bubbles in the water causes the frequency-dependent additional compressibility $\Delta\kappa(f)$. Instead of computing the near field in the time domain, which was done so far [1]-[4], it would therefore be desirable to enable near field calculations also in the frequency domain. To compare both approaches, a time-domain simulation is set up and the accelerations of the pile and the soil are transferred to a frequency-domain simulation.

2 Time Domain Near Field Model

A sketch of the geometry and the boundary conditions of the 2D axis symmetric time domain finite element model for the near field is shown in figure 2. The steel pile has

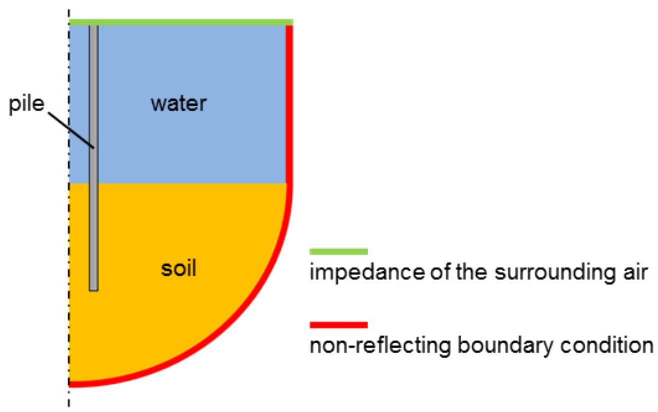

Figure 2: Geometry and boundary conditions of the 2D axis symmetric time domain model

a total length of 15 m and is penetrated 6.5 m into the soil. The resulting height of the water column is 8.5 m with a horizontal expansion of the model of 15 m. In this first approach, the pile and the soil are modeled as solid. The material properties are summarized in table 1.

Table 1: Material properties of soil and pile

	Young's Modulus	Density	Poisson's ratio
soil	$30 \cdot 10^8 MPa$	$1000 \frac{kg}{m^3}$	0.3
steel pile	$210 \cdot 10^9 Pa$	$7850 \frac{kg}{m^3}$	0.28

To describe the characteristics of the force applied by the impact hammer to the pile, the approach of Deeks [7] was chosen (see figure 3). Pile and soil are coupled with a spring-damper connection. Different non-reflecting boundary conditions are selected for soil and water to satisfy the radiation condition (see figure 2). For the water column, a mesh size of 15 cm was chosen to allow for calculations up to 1 kHz with 10 elements per wavelength.

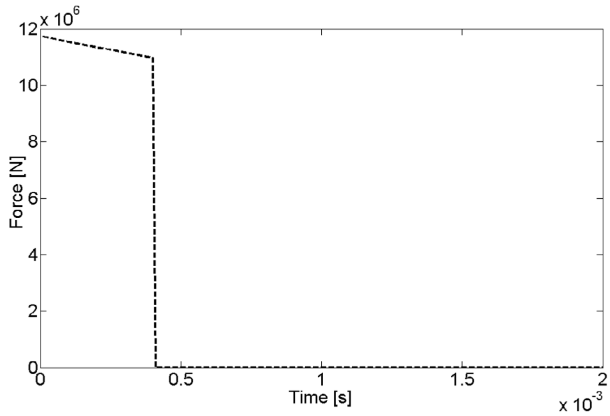

Figure 3: Characteristic behaviour of the time-dependent force applied to the pile

3 Frequency Domain Near Field Model

The frequency domain finite element model for the near field contains only fluid elements to model the water. As in the time domain model, the mesh size is 15 cm. Instead of using a coupled fluid-structure model, the excitation of the water by both pile and soil is applied by corresponding boundary conditions. In a first step, the normal accelerations of the bounding surface of the pile and the soil to the water are extracted from the time domain model, fourier transformed and transferred to the frequency domain finite element model. After the transfer of the data sets, these transformed accelerations are defined as boundary conditions to the model. The cut-off of the soil requires a selection of another boundary condition to replace the influence of the soil to an incident pressure wave. In this case, a solid ground impedance boundary condition was chosen.

In both models, the typical wave propagation observed for pile driving with a inclination of about 17° can be seen in the results. By reason of the principles of the linear acoustics, the entire pressure can be assembled from the pressure field according to the influence of the pile accelerations and the pressure field according to the soil accelerations.

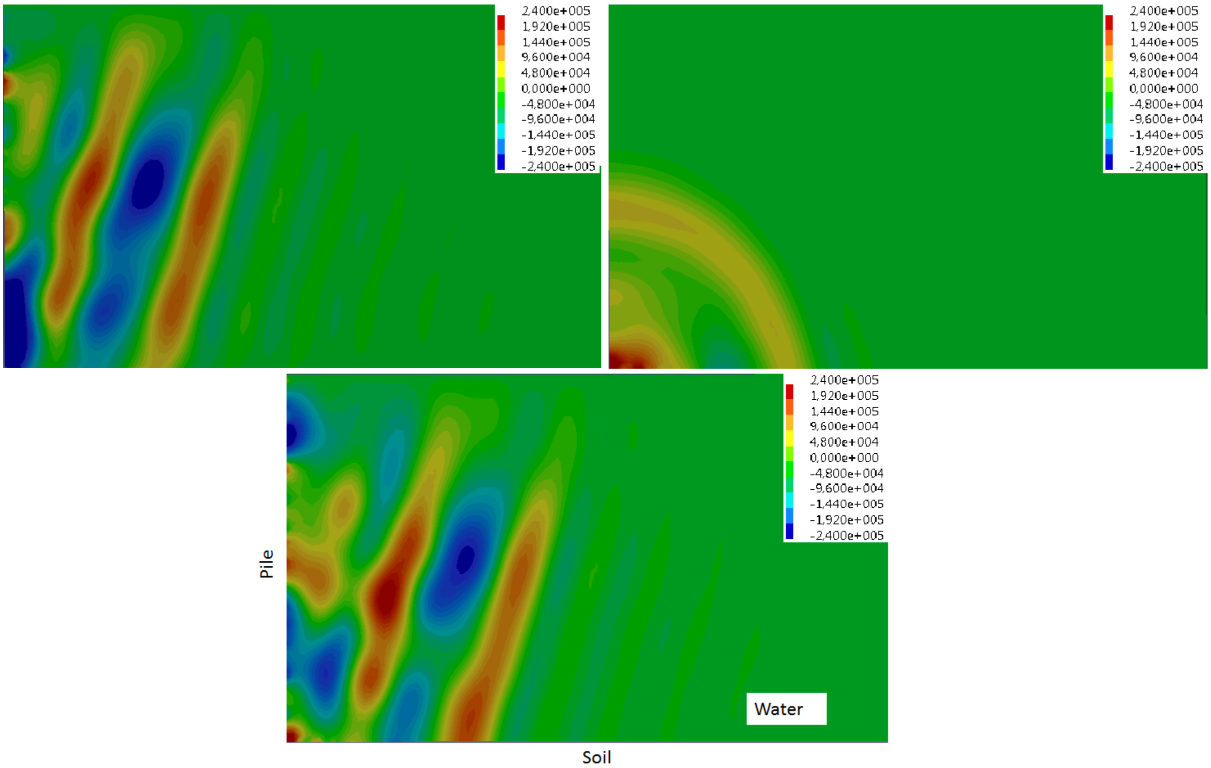

Figure 4: Pressure field in the water column of the frequency domain model, left: pressure field according to the pile accelerations, right: pressure field according to the soil accelerations, bottom: combined pressure field of the pile and soil accelarations due to pile driving

An evaluation of the pressure at different nodes of the water domain indicates the good accordance of both models (figure 5). The difference in the peak pressures can be explained in the frequency step, which results from the fourier transformation and differences of both models in the high frequency range depending on the mesh size. In a range from 0 to 2 kHz the amplitude and the phase of the pressure of both models match well (figure 6).

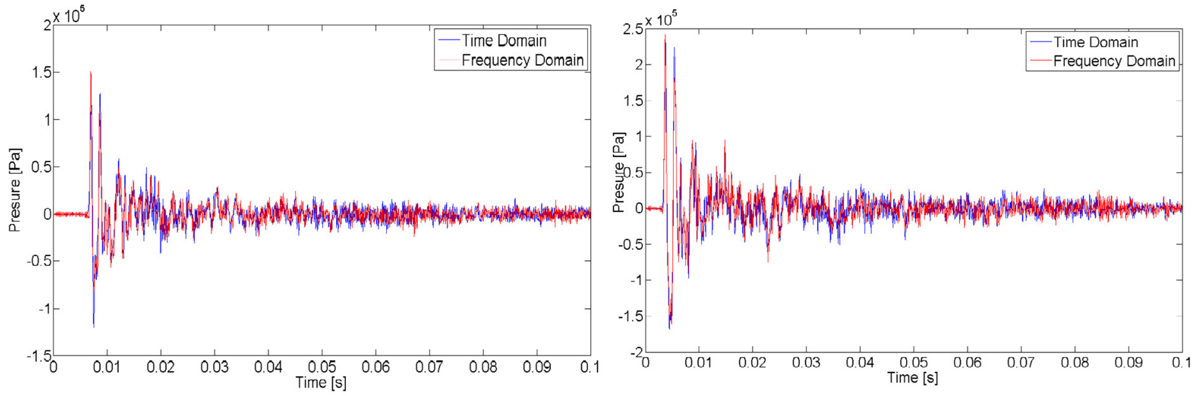

Figure 5: Comparison of the pressure in the water domain at two nodes in a water depth of 4.75 m, left: 10 meter distance to the pile, right: 5 meter distance to the pile

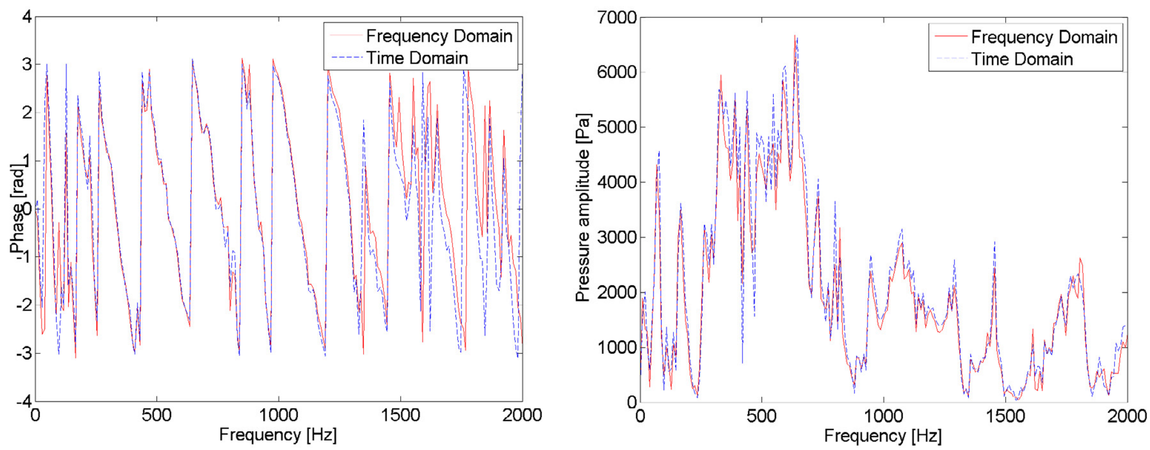

Figure 6: Comparison of the phase and the amplitude of the pressure in a distance of 10 meter to the pile and a water depth of 4.75 m of both models

4 Conclusions and Outlook

Up to now, the near field model for the prediction of pile driving noise has been formulated in the time domain. To be able to efficiently consider frequency-dependent parameters, as for example when applying sound mitigation measures, an approach to formulate the near field model in the frequency domain has been shown. A comparison of the results calculated in the time domain and the frequency domain, respectively, showed a very good agreement. By reason of modeling only the fluid elements in the frequency domain model, the computation time further decreases significantly compared to the time domain model. Based on these results, it is planned to develop and investigate modeling techniques for the bubble curtain in the frequency domain. Furthermore, the coupling of the soil with the water will be studied more extensive. To get a more realistic model, a two phase soil model will be implemented in the time domain model and boundary conditions for the frequency domain model will be analyzed to get an identity between the results in both domains. Finally, the simulation results will be validated with measured data from extensive offshore tests that are performed with in the BORA project.

5 Acknowledgements

The research on the prediction model for the pile driving noise and its validation is carried out in the frame of the BORA project at Hamburg University of Technology together with project partners at the University of Kiel and the University of Hannover. The authors gratefully acknowledge the funding of the BORA project by the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety due to an act of the German Parliament (project ref. no. 0325421). For further information, please visit the project homepage at www.bora.mub.tuhh.de.

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