A three-dimensional semi-analytical model for the prediction of underwater noise generated by offshore pile driving

Apostolos Tsouvalas[1(*)], Andrei Metrikine[2], Bob Jung[3]
[1, 2] Section of Structural Mechanics, Faculty of Civil Engineering and Geosciences , Delft University of Technology, The Netherlands
[3] IHC Merwede, Kinderdijk, The Netherlands
[(*)] *Email:* a.tsouvalas@tudelft.nl

ABSTRACT

In this paper, the problem of underwater noise generated during the offshore installation of steel monopiles is addressed. Steel monopiles are the most widely used foundation method of offshore wind turbines and are driven into place with the help of hydraulic hammers. To meet today's increasing energy demand, piles of larger diameter are installed which require larger amounts of input energy to be driven into the soil. This results in very high sound pressures at the surrounding water environment which are known to produce deleterious effects to both mammals and fish. The total system consists of the following sub-systems: a hydraulic hammer, a circular cylindrical shell, a compressible fluid domain and a water-saturated seabed. In this work, a mathematical model is established able to represent the dynamics of the coupled vibro-acoustic system. A number of parameters influencing the noise levels generated is analysed in the frequency domain with additional emphasis placed on the examination of the contribution of the soil in the overall response of the coupled system for high acoustic frequencies.

Keywords: pile driving, underwater noise, cylindrical shell, vibro-acoustics, fluid-structure interaction, soil-structure interaction

DESCRIPTION OF THE NUMERICAL MODEL

The pile is described with an appropriate thin shell theory including the effects of both shear deformation and rotational inertia [1]. The fluid is treated as a three-dimensional compressible medium with a pressure release boundary describing the sea surface. The soil is described as a three-dimensional visco-elastic continuum able to support both dilatational and shear waves. The soil domain is terminated at the pile tip level and the remaining part is substituted by a local impedance boundary (Fig.1).

The response of the complete system is sought for in the form of the modal expansion with respect to the in vacuo modes of the shell. The analytical approach is based on the following steps: i) solution of the eigenvalue problem of the shell without the presence of the soil and the fluid; ii) the solution of the governing equations for the soil-fluid domain by expressing the interface conditions at the shell-soil contact surface in the modal domain; iii) the solution of the coupled system of equations resulting from the substitution of the obtained solutions for the shell and the soil-fluid domain into the interface conditions. Because the orthogonal set of eigenmodes employed is based on the in vacuo shell structure, modes of different axial order are coupled via the mutual impedances of the fluid-soil domain, whereas modes of different circumferential order remain uncoupled due to the axial symmetry of the system.

VALIDATION OF THE MODEL AND RESULTS

The model is validated with complete sets of measured data collected from real pile driving tests. On the basis of this validation, strong and weak points of the current model are discussed. In this study, simultaneously recorded time series from accelerometers positioned on the surface of the pile, hydrophones positioned in the water environment at different ranges and water depths, as well as geophones positioned at the surface of the seabed are analysed in time, frequency and time-frequency domains. Apart from the validation, such an analysis allows for the identification of the main sources of underwater noise as well as of their frequency content. We examine how the energy is distributed over the various sub-systems, i.e. what percentage of the energy radiates into the water environment, what percentage enters the soil domain and how this distribution varies with time.

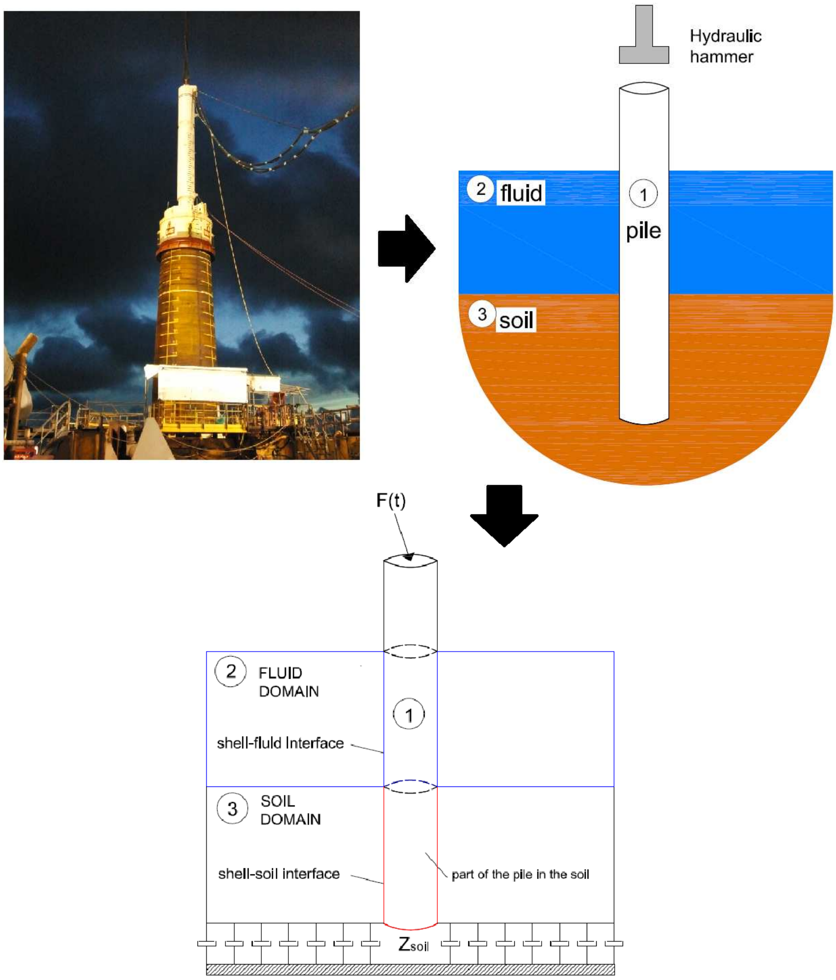

Figure 1: Representation of the actual situation and of the modelling approach

A comparison of the results of the present model with those ones based on a previous model developed by the same authors [2] is also discussed. In the previous model, the soil was simplistically described with the help of springs and dashpots and the true three-dimensional characteristics of the soil were not considered. Such a comparison aims mainly to highlight the contribution of the soil in the underwater noise levels, a contribution which is almost always overlooked in practice.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of IHC Merwede which provided valuable sets of data during this process.

REFERENCES

[1] A.V. Belov, J.D. Kaplunov, and E.V. Nolde. A Refined Asymptotic Model of Fluid-Structure Interaction in Scattering by Elastic Shells. Flow, Turbulence and Combustion, 61:255-267, 1999

[2] A. Tsouvalas, A.V. Metrikine. A semi-anlaytical model for predicting the levels of underwater noise from offshore pile driving, Proceedings of the 15th International Conference on Experimental Mechanics (ICEM15), Portugal 2012