Peer-reviewed Conference Contribution

Installation of Monopiles: Interpretation of Vibro-Installed Lab-Scale tests

Mario Martinelli[1,2,*], Athanasios Tsetas[1], Andrei Faragau[1] and Apostolos Tsouvalas[1]

[1] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, Delft, 2628 CN, The Netherlands;
[2] Deltares, Boussinesqweg 1, Delft, 2629 HV, The Netherlands;
* Corresponding author: Mario.Martinelli@deltares.nl

Nowadays, monopiles are the most common foundation type for offshore wind turbines, consisting of a single open steel pipe that is driven into the seabed to support the weight of the turbine and tower. Traditionally, monopiles are installed by impact driving, where a hammer repeatedly strikes the pile until it reaches the required penetration depth [1]. However, for large-diameter monopiles, impact hammering can be impractical due to significant underwater noise emissions [2] and the necessity for oversized structures to withstand the high stresses induced by the hammering. Stressing the importance of this issue, it is worth noting that as national standards become stricter in this aspect, noise mitigations face challenges in keeping up.

Furthermore, it should be emphasized that vibratory hammering, although continuous rather than impulsive, also produces significant underwater noise. Currently, noise regulations predominantly concentrate on impulsive noise. However, as more becomes known about the effects of continuous noise emissions on the environment, vibro-driving methods may also be subjected to stringent norms. In recent years, there has been a growing adoption of vibro-driving techniques for installing monopiles, which employ a hydraulic vibrator to generate vertical vibrations that reduce the soil resistance around the pile, facilitating its insertion into the ground

Accurate predictions of the installation of monopiles using the vibro-driving technique are still challenging, as open questions currently remain on the soil reaction during driving and the pile-soil-equipment interaction [3]. The effectiveness of vibro-driving depends on several factors, including soil conditions, pile diameter, and the frequency and amplitude of the induced vibration. Limited data are available for model calibration and validation, especially for offshore conditions; presently, various research works are contributing to the development of new vibratory pile driving modelling frameworks, with a view to engineering practice [4.5].

This presentation shows some of the results of an ongoing research project, namely the Sustainable Installation of XXL Monopiles (SIMOX) in the Netherlands. In particular, the focus is to illustrate the interpretation of the vibratory installation of lab-scale piles (32 cm diameter and 1.5m long) performed in saturated sand and well-controlled initial conditions. This took place at the Deltares research facilities in Delft, the Netherlands. Several properties were varied during the penetration-controlled tests, including the penetration rate, the loading frequency, and the soil relative density.

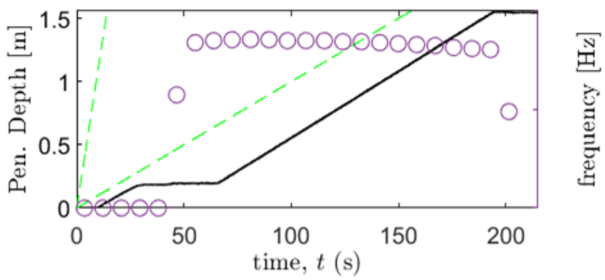

Figure 1. Vibratory driving test of a 'vibrating' pile.

DOI: https://doi.org/10.59490/seg23.2023.609

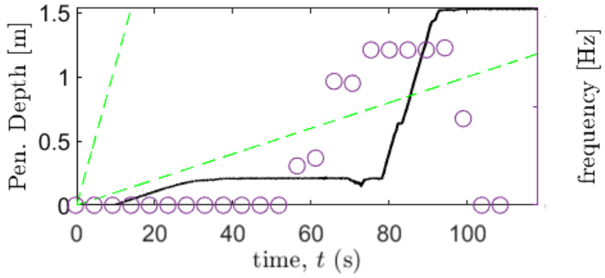

Figure 2. Vibratory driving test of a 'penetrating' pile.

In the SIMOX laboratory experiments on vibratory pile driving, two distinct installation regimes have been identified, i.e. the ‘vibrating’ and the ‘penetrating’ regimes, governed by the interrelation between penetration rate and periodic pile velocity – see Figs. 1 and 2, respectively. For these two regimes, the soil reaction during driving differs in both quantitative and qualitative terms. Through detailed analysis of the experimental data, we have observed that the vibratory pile installation process is majorly influenced – apart from the driving input excitation itself - by the dissimilar soil reaction experienced by the pile for different installation settings. These findings highlight that the effectiveness of vibratory pile installation is not solely dependent on the method of excitation, but also on the specific installation settings employed (i.e. eccentric moment, driving frequency and crane load). By understanding this mechanism, we can comprehend and improve further the present state of drivability modelling approaches and the vibratory pile driving process.The present results serve as a basis for further numerical and experimental investigation, with the aid of field data to be collected in subsequent onshore field tests.

Data Availability Statement

A request for data availability requires the approval of all SIMOX project partners.

Contributor statement

Mario Martinelli: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft.
Athanasios Tsetas: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – review & editing.
Andrei Faragau: Conceptualization, Methodology, Writing – review & editing.
Apostolos Tsouvalas: Conceptualization, Supervision, Project administration, Funding acquisition.

Acknowledgments

This paper is part of the SIMOX joint industry project in the framework of the GROW Research Programme. The project is funded by Topsector Energiesubsidie from the Dutch Ministerie van Economische Zaken en Klimaat, grant number MOOI12001, and financial/technical support from the following partners, in alphabetical order: Boskalis, CAPE Holland, Deltares, Delft Offshore Turbine (DOT), Delft University of Technology, GBM Works, Heerema Engineering Solutions, Heerema Marine Contractors, IQIP, Ocean Winds, Ørsted, RWE, Seaway7, Shell, Siemens Gamesa Renewable Energy, Sif Netherlands, TNO, TotalEnergies, Van Oord, Vattenfall. The contribution to the tests of, in alphabetical order, Bastiaan van der Veen, Brice Dijksman, Cedrik de Roo, Danko Boonstra, Jaap Elstgeest, Kees van Beek and Marcel Busink, is also appreciated.

References

[1] Kallehave, D., Byrne, B. W., LeBlanc Thilsted, C., & Mikkelsen, K. K. (2015). Optimization of monopiles for offshore wind turbines. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 373(2035), 20140100.
[2] Tsouvalas, A. (2020). Underwater noise emission due to offshore pile installation: A review. Energies, 13(12), 3037.
[3] Gómez, S. S., Tsetas, A., & Metrikine, A. V. (2022). Energy flux analysis for quantification of vibratory pile driving efficiency. Journal of Sound and Vibration, 541, 117299.
[4] Tsetas, A., Tsouvalas, A., & Metrikine, A. V. (2023). A non-linear three-dimensional pile–soil model for vibratory pile installation in layered media. International Journal of Solids and Structures, 269, 112202.
[5] Kaynia, A. M., Hebig, J., Pein, T., & Shin, Y. (2022). Numerical model for dynamic installation of large diameter monopiles. Soil Dynamics and Earthquake Engineering, 161, 107393.