SYMPOSIUM ON ENERGY GEOTECHNICS SEG23

TU Delft OPEN

Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

A centrifuge study into the installation response of steel, open-ended, tubular piles, dynamically driven using prolonged impulses

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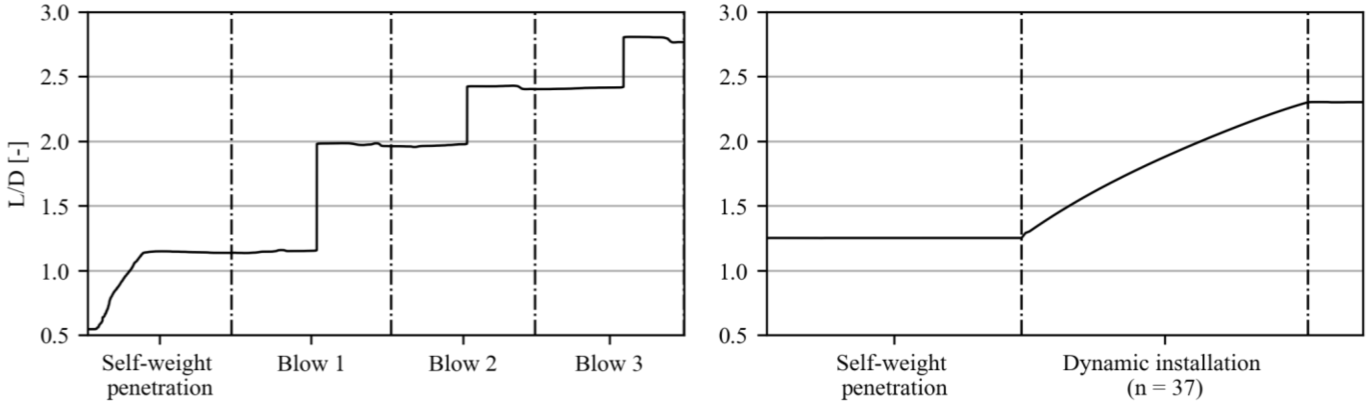
Fuelled by technological innovations and the growing commitment of countries to reduce their carbon footprint, offshore wind has steadily been gaining ground on non-sustainable sources of energy. According to the International Energy Agency (IEA) [2], it is foreseen that wind will be the principal source of energy in Europe by 2027. However, in an effort to protect the marine environment from sound pollution [1], regulations applicable to offshore wind endeavors have become more stringent. To sustain the growth of the offshore wind sector, more durable installation methods are required. Prolongation of the impact duration has been identified as a suitable method to protect the marine environment from sound pollution [7]. However, the market introduction of this technology is hampered by a lack of understanding of its effects on soil-structure interaction. Therefore, concerns exist on (mono)pile drivability, as well as the performance of the foundation under axial and lateral loads. To address this issue, a series of centrifuge experiments is performed in the centrifuge facility of Delft University of Technology (DUT). The experiments are conducted at 50g acceleration and show the effect of blow prolongation on the drivability of miniature steel, tubular pile (outer diameter, D = 42 mm; wall thickness, t = 2 mm) in dry GEBA sand at 80% relative density. The blow-prolongation technology that is assessed is IQIP's BLUE Piling (BP) Technology [4]. Details on the actuator used to simulate BP technology in the centrifuge are provided by the work of Quinten et al. (2022) [6]. Prior to dynamic installation, the pile was allowed to settle in into the sample under 1g conditions. Subsequently, an second self-weight penetration phase is initiated by increasing the centrifuge acceleration to 50g, while the ram acts as dead-weight on top of the pile. Following the self-weight penetration phase, the centrifuge is intermittently stopped and reinitiated to (re)set the actuator. The BP ram has a mass of 1.889 kg ram and stroke of 40 mm. The results of the BP experiment are compared against those from centrifuge experiments involving impact hammering (IH), the most widespread method of installation for monopiles in the offshore sector. A detailed description of the actuator, the miniature impact hammer of DUT, is provided by Quinten et al. (2022) [5]. The model pile was pre-embedded at a depth of 50 mm under 1g conditions prior to the dynamic installation phase. The hammer operates at a driving frequency of 10 Hz and is equipped with a ram of 0.140 kg, which is released from a height of 40 mm. Comparison of the results of both experiments, reveals striking differences in the cumulative settlement behavior of the pile as well as the pile stresses. The cumulative pile displacement charts, as shown in Figure 1, show significant differences between the two installation methods. For BP (Figure 1a), a series of 3 single blow experiments was conducted. For IH (Figure 1b), the experiment lasted for a total of 37 consecutive blows. The realized pile set during the experiment is comparable between the two tests. The average normalized displacement equates to 0.5D and 0.03D per blow for BP and IH respectively. The soil level inside the pile cavity was measured following the execution of both experiments. The associated measurements indicated that both piles were driven in a fully coring mode. When considering the prototype pile dimensions and soil conditions, this finding corresponds well with the work of Jardine et al. (2005) [3]. Further differences between IH and BP were observed in terms of (peak) pile stress. The driving forces are reduced from 25 kN for IH to 6 kN for BP, respectively. The driving factor behind this reduction is the decrease in interface stiffness between the ram and the anvil. The latter completely offsets the effects associated with the use of a significantly heavier ram mass in the case of BLUE Piling. When the driving forces are expressed as a percentage of the pile

DOI: https://doi.org/10.59490/seg23.2023.618

yield limit, aforementioned figures respectively equate to 42% and 10%. Extrapolated over the full installation sequence, the latter would contribute to a reduction in the fatigue accumulated during installation.



(a) BLUE Piling (b) Impact Hammering

Figure 1: Cumulative pile displacement charts, normalized by pile diameter, D.

The results presented here form the first step towards understanding the effect of blow duration soil-structure interaction for blow prolongation technology. For the set of installation parameters and boundary conditions considered in this study, it is shown that the differences in pile installation behavior can be captured using centrifuge modeling. The prolongation of blow duration results in a significantly different overall installation behavior. When looking at the driving forces, the decrease of the interface stiffness between the ram and anvil produces the anticipated decrease in peak driving force. A sustained physical modeling effort is required to ultimately lay the basis for a predictive installation framework for blow-prolonging technology, which would arguably accelerate its adoption by the industry. The latter should help the reek the associated benefits, particularly in terms of fatigue reduction and sound remediation in the near future.

Contributor statement

T. Quinten: Conceptualization, Formal Analysis, Visualization and Writing – Original Draft; C. Ioannou: Formal Analysis, Visualization; Amin Askarinejad: Conceptualization, Writing – Review and Editing, Resources; M. Cabrera: Conceptualization, Writing – Review and Editing; K. Gavin: Writing – Review and Editing, Recourses.

Acknowledgements

This work is supported by a research grand from Topsector Energie bearing the reference TSE-19-04-01- Hernieuwbare energieproject. The authors wish to thank their industrial partner, IQIP, for its continued constructive criticism and invaluable suggestions.

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