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The post-installation performance of piles installed with a novel driving method: field tests and numerical modelling

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Since the industrial revolution, humanity's impact on the planet has increased significantly. The growth of global economies and population size in the 20th century was fueled by the combustion of fossil fuels. In an effort to reduce the impact of human kind on the environment, governments ratified landmark agreements such as the Montreal Protocol in 1987, the UNFCCC in 1992, the Kyoto Protocol in 2005, and the Paris Agreement in 2015.

To support this effort, the European implemented the European Green Deal (2019), which aims to achieve no-net greenhouse gas emissions by 2050. Offshore wind energy, particularly large-diameter monopiles, is expected to play a substantial role in this transition. Europe has already developed over 28 GW of offshore wind power, with a global capacity of 37 GW as of 2021 [8]. However, to meet the goals of the European Green Deal, offshore wind capacity needs to scale up significantly in the next 28 years.

The installation of monopiles, the most selected foundation option for offshore wind turbines, has traditionally relied on impact hammering. This method has drawbacks such as lengthy installation times, and noise emissions harmful to marine life. An alternative approach is axial vibratory pile driving, which offers faster and quieter installation. However, certification bodies have yet to endorse its use for offshore wind farm construction owing to uncertainties relating to the post-installation monopile performance. Research efforts are being devoted to understanding the dynamic behaviour of the soil during vibro-driving and the effects of vibro-installation on pile performance. Several geotechnical research teams are investigating the post-installation lateral behaviour of monopiles and comparing the performance of impact piling and vibratory piling [1-7,9-13].

To complement the effort towards noiseless pile driving researchers from TU Delft proposed the novel Gentle Driving of Piles (GDP) method which aims to enhance traditional axial vibro-pile driving by incorporating high-frequency torsional vibrations [9]. The addition of torsional vibrations is expected to consume/redirect soil frictional resistance and limit radial expansion during pile driving, resulting in faster and quieter installation – the GDP shaker is presented in Figure 1.a.

To demonstrate the GDP technology and compare its performance with traditional pile-driving methods (impact pilling and axial vibratory driving), comprehensive medium-scale field tests were conducted in an inhomogeneous sand deposit at the Port of Rotterdam. Eight identical test piles with a diameter of 0.762 m and an embedded length of 8 m were installed using impact hammering, traditional axial vibratory piling, and the GDP method. Out of the eight test piles, four were heavily instrumented out of which two were GDP-driven, and the remaining two were installed with impact pilling (IH) and axial vibro-driving (VH).

The tests performed on the four main test piles consisted of two stages: the first stage focused on driving performance, while the second stage examined the cyclic lateral behaviour of the piles under repeated loading for different installation methods -cyclic loading programme in Figure 1.b. The test results highlighted the promise of the method towards faster (Figure 1.c.) and less perturbing pile driving [1,9,13] but also enhanced post-installation lateral response [5,6,7] compared to the traditional alternative installation methods (Figure 1.d.).

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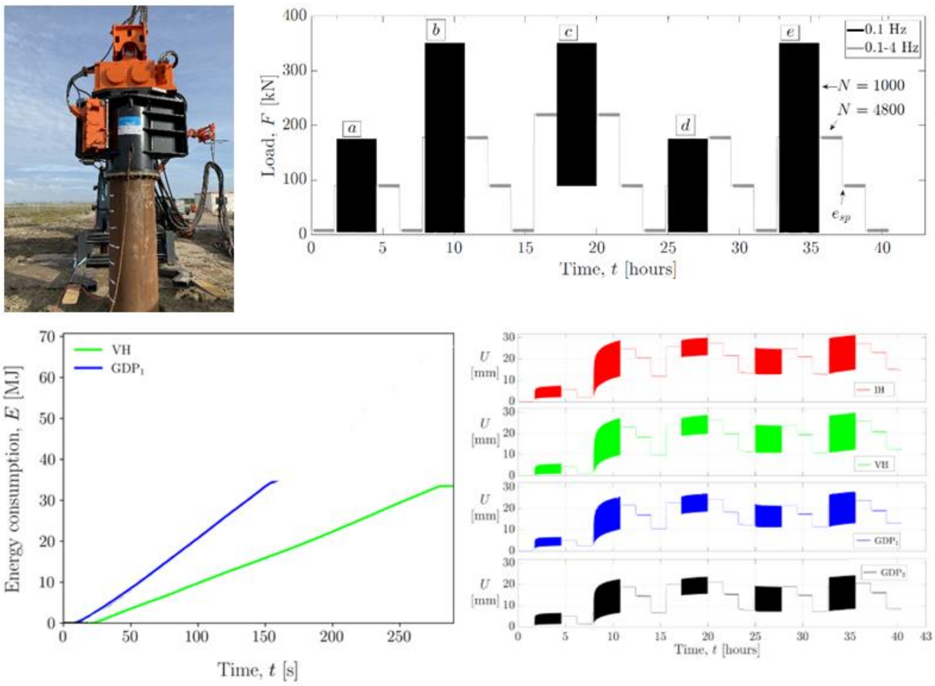

Figure 1: a. (top left) The GDP shaker. b. (top right) The cyclic lateral loading programme applied to the test piles. The loading programme consisted of approximately 82.000 loading cycles (N). c. (bottom left) Energy consumption – and driving duration, during axial vibratory driving (VH) and GDP pile driving (GDP¬1), in the Maasvlakte 2 test site. d (bottom right) Displacement time histories at the pile head for the four test piles installed measured during the cyclic lateral loading programme in Figure 1.b.

Contributor statement

E. Kementzetzidis: Conceptualization, Formal analysis, Writing-Original Draft, Writing- Review & Editing. **F. Pisanò**: Conceptualization, Formal analysis, Writing- Review & Editing. **A. Tsetas**: Conceptualization, Formal analysis, Writing- Review & Editing. **Sergio S. Gòmez**: Conceptualization, Formal analysis, Writing- Review & Editing. **A. Metrikine**: Conceptualization, Writing- Review & Editing, Project Administration, Resources.

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