CEL numerical modelling of helical pile installation observed in centrifuge tests

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ABSTRACT: Helical piles offer a practical solution for deep foundations, combining rapid and straightforward installation with the ability to support substantial loads, which makes them attractive for projects requiring both efficiency and high performance. Despite these practical advantages, the influence of the installation process is not yet fully understood. Accurate prediction of pile performance requires a detailed understanding of the soil–pile interaction during installation, and in particular, the re-arrangement of the soil caused by the rotating helix, which is difficult to capture experimentally. This study aims to investigate the installation process of helical piles using advanced numerical simulations and to validate the results against centrifuge test data. The simulations are performed in Abaqus/Explicit, with the installation process modelled using the Coupled Eulerian-Lagrangian (CEL) method, allowing accurate representation of large deformations and soil displacement. The comparison between numerical results and centrifuge measurements shows good agreement, demonstrating the reliability of the numerical method. These findings contribute to improving design methodologies and will be used in the future to further understand the installation effects on pile behaviour and to complement centrifuge experimental tests on helical piles.

1 INTRODUCTION

Helical piles are increasingly employed onshore and are a promising solution for offshore anchoring applications, as they combine the strengths of pile response to axial and lateral loads, while offering the advantages of noise and vibration reduction during installation and enhanced axial capacity resulting from the bearing contribution of the helix. However, the installation process of helical piles can be complex, as the helices induce shearing and disturbance in the surrounding soil. Accurately simulating this installation phase in numerical models is essential to correctly reproduce the subsequent pile behaviour under loading conditions. This study focuses on the numerical simulation of helical piles installation in dry sand, with the objective of comparing the results of installation with centrifuge test data.

2 METHODS

2.1 Centrifuge test

The centrifuge tests used for comparison in this study were performed at 10g in the geotechnical centrifuge of the University Gustave Eiffel by Schiavon *et al.* (2018). The single-helix pile consisted of a circular shaft of diameter d = 0.1 m and a helical plate of diameter D = 0.33 m, thickness t = 15 mm, and 97 mm pitch at prototype scale. The helix was embedded at a depth of 7.4D. In the present study, the pile was installed at 5.3 rpm in dry Hostun HN38 (Table 1).

2.2 Numerical model

The model was developed using Abaqus/Explicit (Dassault Systèmes Simulia, 2024) and is shown in
Figure 1. The soil was modeled as a 6.6 m (20D) high cylinder with an equal width and discretised using 219744 elements. With the consideration of the simulation time and precision, the average size of the elements is around 120 mm, which is close to the triaxial soil element test. This domain was enclosed within an Eulerian mesh represented by a cylinder, 8.6 m in height and 6.6 m in diameter. The pile had the same dimensions as the pile described in Section 2.1. The pile was modelled as a rigid steel body. The surrounding soil was represented using *Hyposimple*, a critical state–based constitutive model developed within the hypoplastic framework. This model, implemented through a user-defined material (VUMAT) subroutine, extends the formulation proposed by Li *et al.* (2014) by explicitly incorporating the sand critical state through a state parameter that quantifies the distance to the critical state line in the e–log(p') plane, with model parameters listed in Table 2 and calibrated from triaxial tests carried out by Schiavon (2016). The installation was simulated with the Coupled Eulerian-Lagrangian method (Zhang *et al.* 2026), to accurately capture large deformations. The friction coefficient between the pile and soil is 0.5.

Table 1. *Properties of the HN38 sand (Schiavon et al. 2018).*

d_{50} (mm)	C_u	G_s	d_r	e_{min}	e_{max}
0.12	1.97	2.64	0.87	0.72	1.17

Table 2. Properties of the sand used for the numerical model

G	υ	n_h	φ_{cs} (°)	ψ_d (°)	e	e_0	λ_c	ξ
125	0.05	0.4	37.2	17	0.729	0.98	0.05	0.31

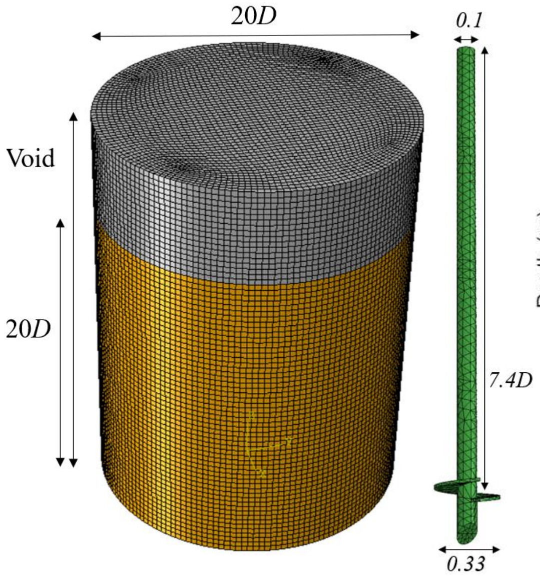

Figure 1: FEM model of the soil and the pile

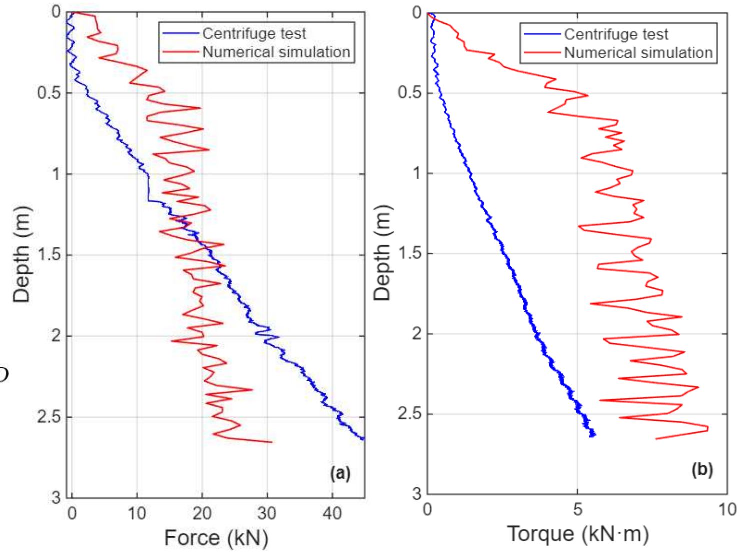

Figure 2: Installation (a) force and (b) torque profiles

3 RESULTS

Figure 2 shows the installation torque and installation force as functions of installation depth obtained from the numerical simulations. The numerical model effectively captured the pile behaviour during installation and showed good agreement with the centrifuge test, with variations observed in the experimental measurements. Both torque and force increase with depth, with the installation torque reaching a maximum of 8 kN.m and the force a maximum of 24 kN. Some noise is observed in the graphs, which is caused by the use of the explicit method under large deformation conditions.

4 CONCLUSION

This first step of CEL approach globally reproduces the installation process of helical piles in dense dry sand, capturing the trends in torque and force development with depth. However, the results still exhibit noticeable discrepancies and numerical noise that must be reduced in future analyses, together with the currently large computational time. Nevertheless, the work presented in this paper forms the basis for future analyses, involving a range of pile geometries, soil conditions and post-installation axial and lateral loading. This will provide a deeper understanding of helical pile installation effects on pile response for energy applications (*e.g.* solar panels, anchors).

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by PINTO and the ANRT.

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