Peer-reviewed Conference Contribution

On the installation effects of open ended piles in chalk

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Chalk is a highly porous rock formed by cemented calcite grains. It covers areas of the UK and is widespread under the North Sea where offshore wind turbines (OWT) are currently being installed and where future offshore expansion will be sited (Figure 1(a)) [1]. Large piles are often driven in chalk to support OWT. The installation process causes the intact rock below the pile tip to crush into a putty characterised by a mechanical behaviour very different from the intact chalk. The difficulty to predict the final state of the putty and the stress around the pile after installation is the underlying reason for inadequate current design guidance for piles in chalk. Considering that for OWT, foundations account for 20-25% of the total development cost , pile design improvements in chalk, would be extremely beneficial from an economical and environmental perspective.

Current guidelines for the design of piles in chalk (CIRIA C574) originate from the analysis of a limited number of pile tests [2]. These guidelines suggest crude average ultimate unit shaft friction (t_{sf}) design values of between 20 and 120 kPa for low-medium density and high/very-high density chalk, respectively. t_{sf} estimates are thought to be conservative hence introducing significant increases in cost and carbon footprint (Figure 1(b)). Reducing the level of conservatism (e.g. enabling more confident use of higher t_{sf}) would reflect in significant savings of steel and consequent reduction of the cost and embodied carbon. Such design considerations are possible but require a better understanding of the long-term mechanical behaviour of the damage processes intact chalk experiences during dynamic installation in hydro-mechanical (HM) coupled conditions.

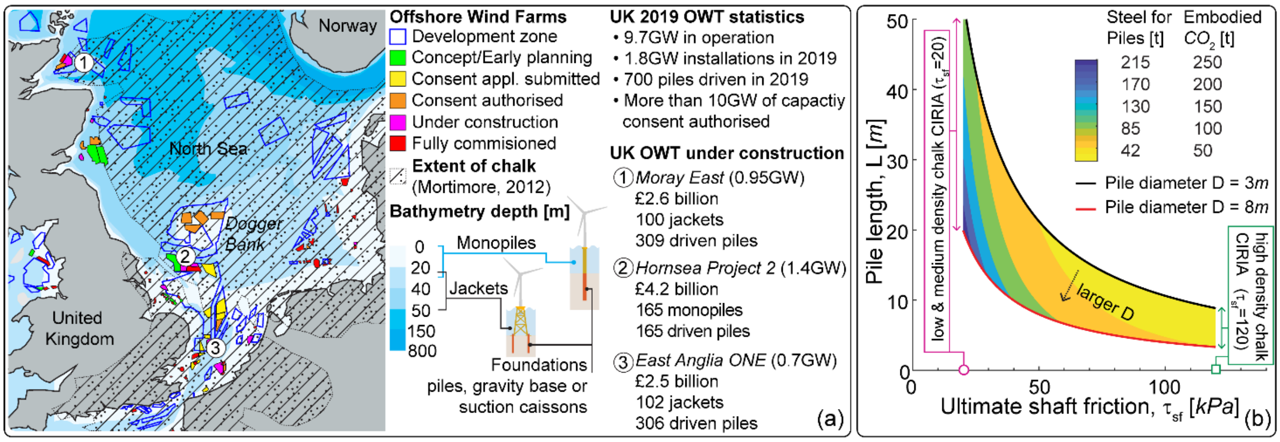

Figure 1: North Sea OWT development (www.4coffshore.com) along with sea water bathymetry, extent of chalk [4]. (b) Embodied CO_2 and steel tonnages as a function of design interface chalk-steel strength, pile length *L* and diameter *D*. Diagram developed for a pile design axial capacity of 10MN after [1]

In this work the coupled HM effects developing during pile installation in chalk are investigated numerically using a robust and mesh-independent implementation of an elasto-plastic constitutive model at large strains. The model, implemented into an open-source Geotechnical Particle Finite Element (G-PFEM) code [3], is shown to be able to capture the damage of the rock until the formation of a chalk putty layer around the shaft of a model piles jacked in chalk. In particular the complex flow processes occurring

DOI: https://doi.org/10.59490/seg23.2023.601

in the soil around both open and closed ended piles of variable shape jacked into saturated chalk are investigated. A fully coupled hydro-mechanical formulation, based on regularized, mixed low-order linear strain triangles is used [5]. To capture the relevant features of the mechanical response of chalk, a finite deformation, non-associative structured modified cam clay is used [6]. The model formulation is based on a multiplicative decomposition of the deformation gradient and on the adoption of an elastic response based on the existence of a suitable free energy function. Bonding-related internal variables, quantifying the effects of structure on the yield locus, are used to provide a macroscopic description of mechanical destructuration effects. To deal with strain localization phenomena, the model is equipped with a non-local version of the hardening laws [7]. The G-PFEM model is shown to be capable of capturing the destructuration associated with plastic deformations below and around the pile shoulder; the space and time evolution of pore water pressure as the pile advances; the effect of soil permeability on predicted excess pore water pressures, and the effect of chalk putty formation on predicted values of the load displacement curve. Installation effects are highlighted by comparing the axial performance between wished in place piles and piles which considered the full installation process.

Acknowledgments

This work is an output from the Installation effects on cyclic axial and lateral performance of displacement piles in chalk (ICE-PICK) project, funded by the EPSRC (EP/W00013X/1).

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