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Effects of installation advancement ratio on cyclic uplift response of a single-helix screw pile: experimental and numerical investigation in sand

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A screw pile consists of one or several helices connected on a central straight shaft or core. These kinds of piles are widely used onshore and typically installed by applying torque at the pile head with additional vertical compressive force (also referred to as crowd force) if required. Current standards and industrial guidelines recommend that installation follows the pitch-matched approach i.e. advancement ratio AR = 1.0 [1], which means that the pile vertical penetration for each rotation equals the helix pitch, because it is suggested that this leads to reduced installation disturbance.

$$AR = \frac{\Delta z}{p_h}$$

where Δz is the vertical penetration per rotation and p_h is the helix geometric pitch.

Recently this kind of pile has been proposed for upscaling from typical onshore sizes as an alternative silent foundation/anchoring solution for future offshore renewable energy application. This may include use as foundations for jacket structures or anchors for wind turbine in deeper water. However, the increase in pile sizes may require prohibitive vertical force if pitch-matched installation is adopted [2] in sand. One of the solutions to this is over-flighting (AR < 1.0) where the pile is over rotated during installation. When the pile is over-flighted, sand below the helix can move upward through the helix opening resulting in a higher stress and potential densified zone above the helix (Figure 1(a)). The increased stress above the helix can push the pile downward and consequently reduce or even eliminate the vertical installation force. In addition, the increased stress and potential densification in the soil above the helix can result in better monotonic uplift performance [3, 4, 5, 6, 7].

As foundations for offshore renewable energy applications, the screw piles also need to be able to perform under cyclic loading from wind, wave and current for example. Investigations of uplift cyclic performance of pitch-matched screw pile installation have been reported, but the over-flighting effects have not received significant attention. To give confidence in the maintenance of the beneficial effects of over-flighting on cyclic performance, centrifuge tests and discrete element modelling (DEM) were used in this study. The centrifuge tests provide more reliable physical evidence than 1g tests but are less costly and more accessible than field test. Based on the results of centrifuge test, the DEM models are validated and used to allow separate evaluation of the mechanism of the helix and the pile shaft and assessment of soil state evolution during cycling, which are difficult to capture in field or centrifuge tests.

The centrifuge tests show that the screw piles installed at lower AR accumulate displacement at lower rates with cycling. which is also captured by the DEM (Figure 1(b)). In addition, DEM suggests that shaft behavior controls cyclic performance because the shaft friction resistance is stiffer than the helix bearing resistance at small displacements. The radial stress on the pile shaft can be enhanced by over-flighting installation. Although it degrades with cycling, the enhanced radial stress due to over-flighting remains higher than that of the pitch-matched pile and therefore the over-flighted piles have improved cyclic performance. On the basis of improved cyclic uplift performance and low vertical installation force, over-flighting installation may be utilized for offshore screw

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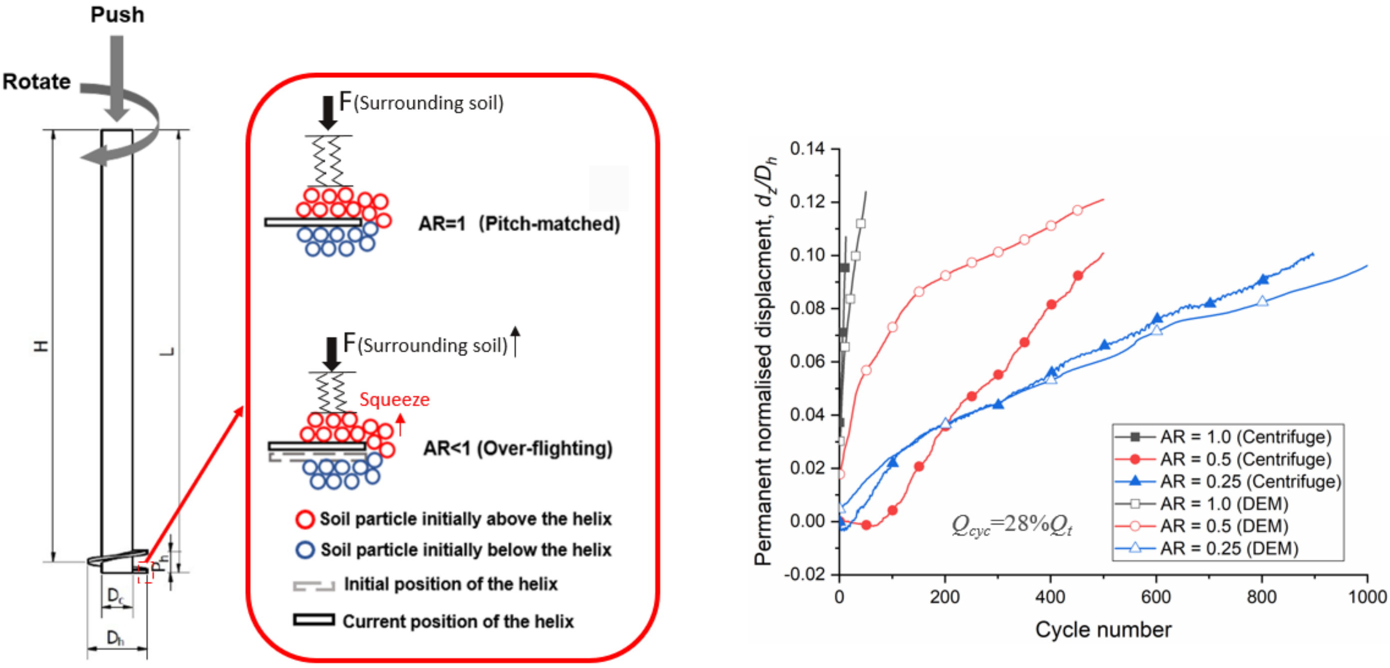
piles performing under cyclic uplift loading where installation forces are a concern or loading is predominantly one-way tensile loading.



(a) (b)

Figure 1: Effects of over-flighting installation: a) idealized over-flighting effects on particle movement; (b) AR effects on cyclic displacement accumulation (comparison of centrifuge and DEM simulation).

Contributor statement

Wei Wang: Conceptualization, Formal analysis, Visualization, Software, Resources and Writing-Original draft. Michael Brown: Conceptualization, Supervision and Writing-Review & Editing. Matteo Ciantia: Supervision and Software. Yaseen Sharif: Resources and Software. Craig Davidson: Resources. Cerfontaine Benjamin: Software

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