Development of Screw Piles for Deepwater Offshore Wind Turbine Foundations

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1. INTRODUCTION

The expansion of offshore wind turbines into deeper water (up to 80m) requires larger foundations & support structures. Existing technology may be near the limits of cost-effective deployment, while guidelines on offshore noise levels restrict pile driving in some areas. Alternative support & foundation solutions are required.

Screw piles (Fig. 1), (small diameter central hollow steel shaft (D_c), with one or more thin helical plates), are widely used onshore as foundations & anchors in a various soil types. Torque & capacity prediction of screw piles remains an active research topic.

With enhanced capacity (45% more shaft capacity in sand) & lower installation noise than driven piles, screw piles can provide a single foundation/anchor solution for multi-footing & floating structures.

Substantial vertical, lateral & overturning loads acting on offshore wind turbines will require significant upscaling of screw pile geometries currently used onshore. Optimal geometry will maximise performance & minimise deployment requirements (Fig. 2).

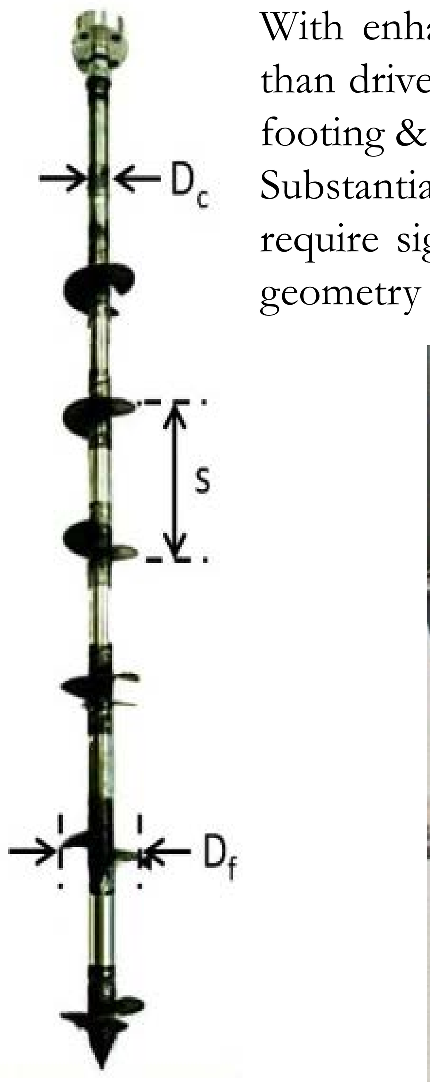

Figure 1. Typical onshore screw pile. See text for symbol descriptions.

Figure 2. Typical nearshore shallow water deployment (image courtesy of Screwfast Foundations Ltd)

2. PREVIOUS STUDIES AT UOD

Various factors are critical to screw pile performance. Optimal helical plate spacing (S) creates a soil-soil shear surface (instead of a smoother soil-steel interface), minimising the size & amount of helices, reducing cost & installation requirements.

1g scaled physical tests & finite element (FE) modelling in sand, showed a helix diameter (D_f) to spacing ratio (s/D_f) of 2-3 optimises capacity & material requirements[1] (Fig. 3). Larger, rather than more helices improves axial capacity, but at the expense of greater installation torque.

3D FE modelling[2] showed that adding a near-surface large diameter helix to the screw pile can improve lateral capacity by 22%. However, large deformations are required for such gains & additional scour protection may be necessary.

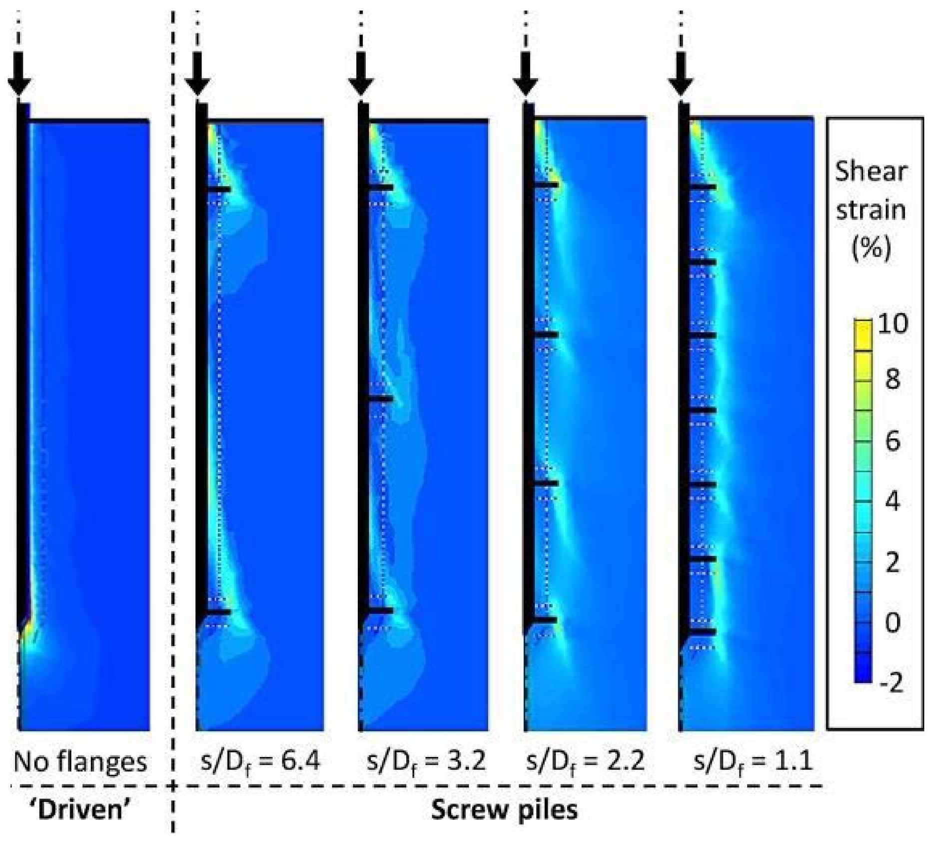

Figure 3. How adding helices changes interface from soil-steel to soil-soil at a helix spacing/diameter ratio of 2 - 3. Decreasing the ratio further has no additional benefit.

3. CURRENT UOD FOCUS

Centrifuge testing of screw piles at UoD includes installation & testing in one continuous in-flight operation using a novel rig[3] (Fig. 4).

This allows accurate modelling of:

- complex installation effects & performance at appropriate confining stresses
- Installation torque
- Monotonic & cyclic axial/lateral capacity

Verification against field data, for installation torque, is evident in Fig. 5, proving the validity of the method. Importantly, current capacity predictions are unreliable leading to reliance on empirical relationships of final torque to capacity.

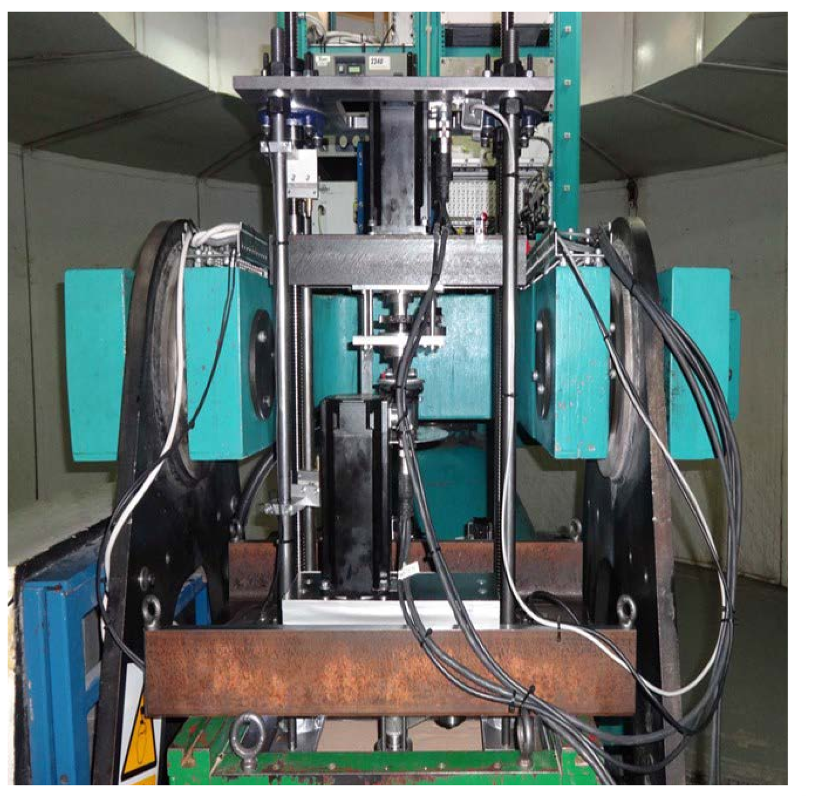

Figure 4. UoD centrifuge with screw pile installation & testing rig[3].

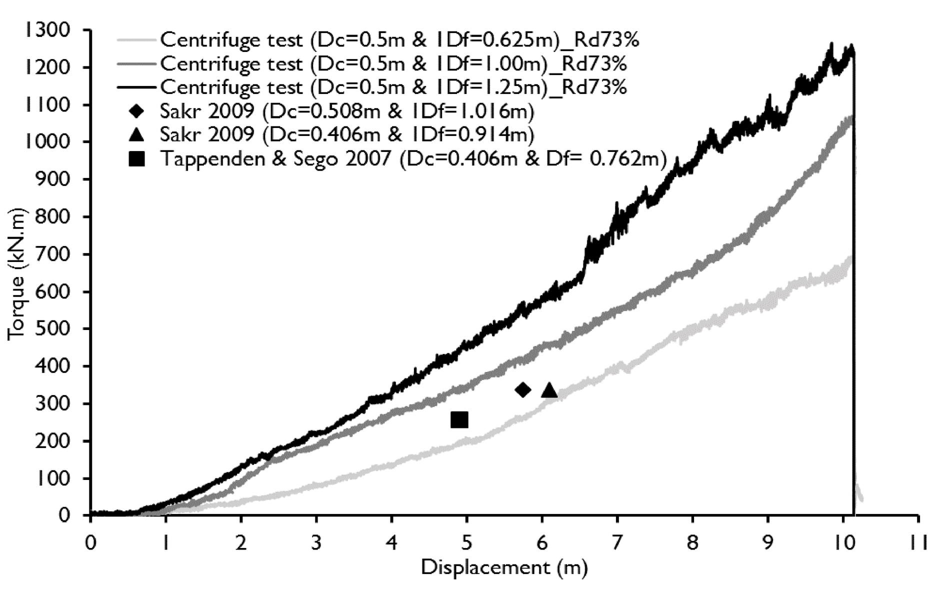

Figure 5. Up-scaled data from centrifuge tests showing screw pile installation torque in dense sand in comparison to field scale data.

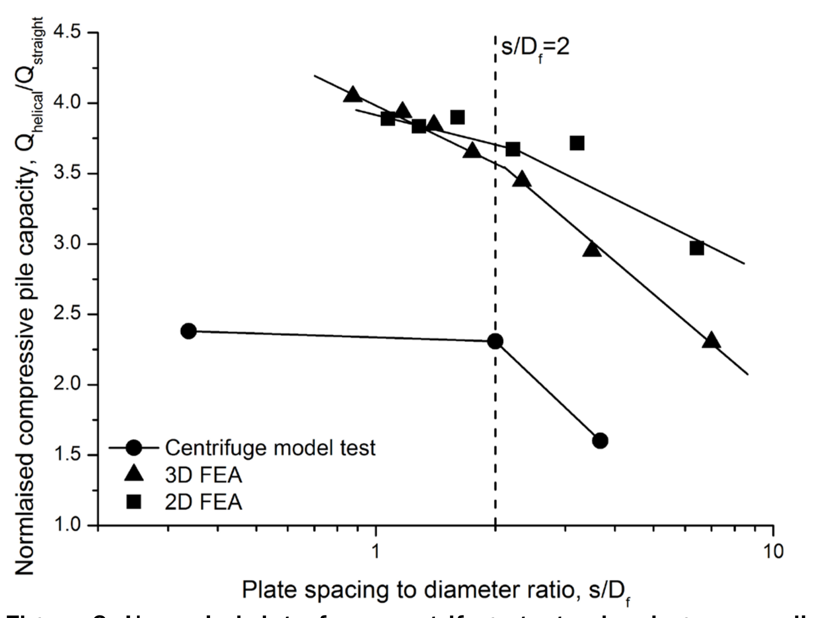

Figure 6. Up-scaled data from centrifuge tests showing screw pile installation torque in dense sand in comparison to field scale data.

Centrifuge tests have also confirmed the FE modelling results of 2-3 as the optimal helix spacing to diameter ratio, as shown in Fig. 6. The difference in capacity ratios between FE tests where piles were wished in place and centrifuge tests with inflight pile installation illustrates the importance of considering installation effects on the soil properties.

4. ONGOING RESEARCH

Computational Modelling (DU)

The key problems in modelling pile installation are:

- Material nonlinearity
- Geometric nonlinearity (finite deformation mechanics)
- Spatial (3D) discretisation
- Large deformations

Durham University have implemented a 2D model based on the Material Point Method[4] to accurately determine the initial soil state surrounding an installed screw pile (Fig. 7).

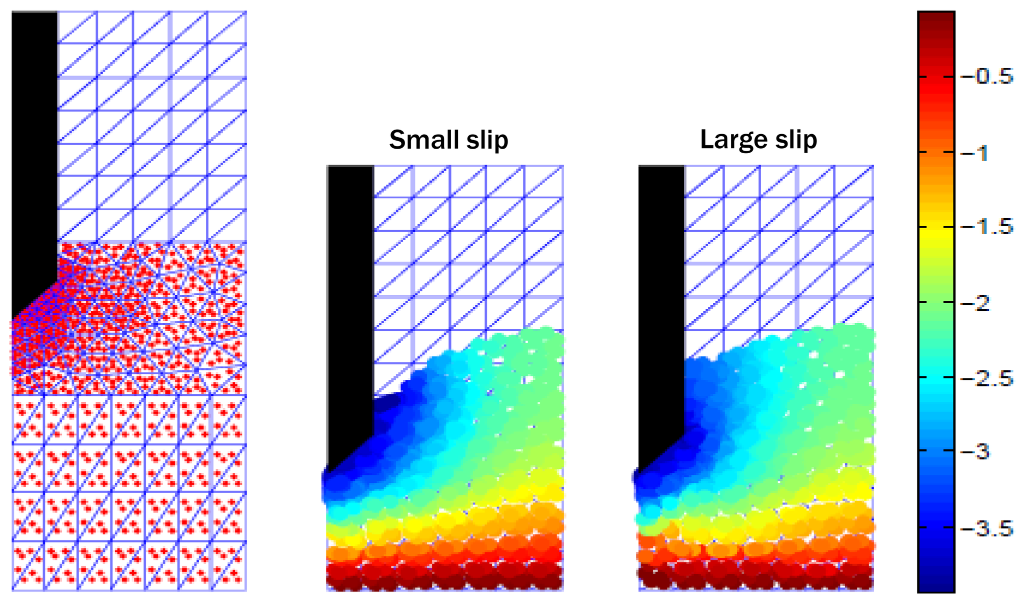

Figure 7. Material Point Method simulation of pile penetration[4]. Colours show the vertical displacement.

This method overcomes deficiencies in standard FE modelling caused by mesh distortion due to large deformations. The 'moving mesh concept' has been extended to include pile rotation during installation.

Novel techniques will transfer the initial conditions after pile installation to conventional FE software (e.g. Plaxis, Abaqus) which then models the in-service screw pile performance.

3D FEM of in-service loading of screw piles will be validated against experimental and field scale tests and a parametric study of screw pile geometry, in various soil types, under different loading conditions will be completed.

Experimental Physical Modelling (UoD)

Validation of numerical modelling with centrifuge tests, focused on two key areas:

- Prediction of installation torque requirements
  - Different soil types and stress history
  - Various pile geometries
- Capacity and stiffness of screw piles
  - Various pile geometries
  - Monotonic and cyclic loading in compression and tension
- Verification of structural element requirements

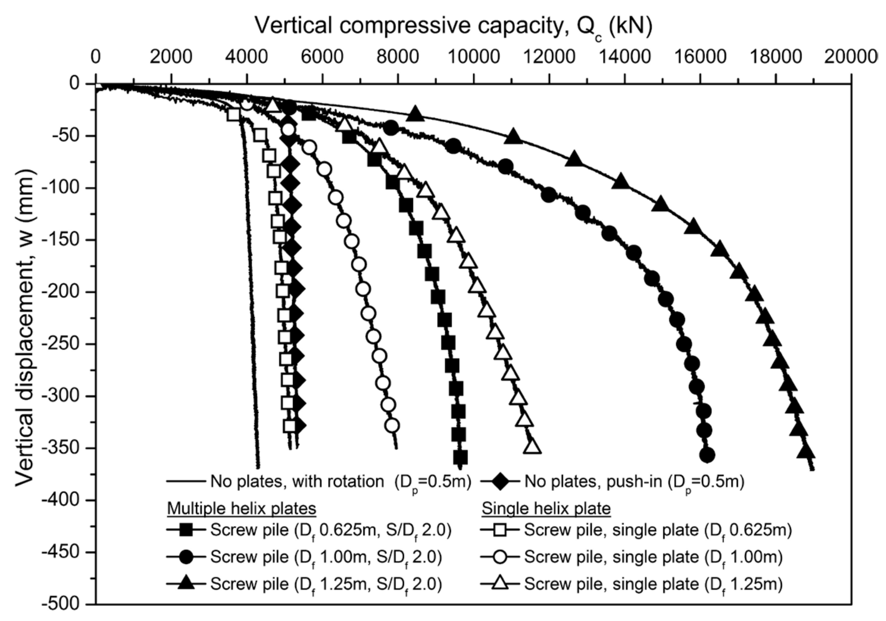

Figure 8. Compressive capacity of single and multiple helix screw piles from scaled up centrifuge tests.

Centrifuge modelling of scale models develops realistic stress regimes and overcomes the problems of low effective confining stresses inherent in 1g modelling, particularly for cyclic lateral loading.

Centrifuge tests at UoD are installing and testing the screw piles during one continuous in-flight procedure. Piles are instrumented to verify load/moment distribution along the pile giving deconvoluted results of shaft and tip performance, allowing for improved design techniques.

The compressive capacity of screw piles over a straight shafted pile (Fig. 8) can be further increased by enlarging the helix diameter and including multiple helices. The screw pile geometry will be optimised to give the greatest capacity for the lowest torque requirements.

Onshore Field Trials (UoS)

Field scale testing (Fig. 9) of the screw pile geometries developed from the numerical and experimental modelling in an onshore UK setting.

Identified need for simultaneous torque and crowd (vertical compressive force) measurements during installation. Currently working on prototype wireless instrumentation.

UoS working with Roger Bullivant to identify test sites which have soil representative of offshore UK conditions and will allow the de-risking of later offshore demonstrations.

The piles will be instrumented in the same way as those in the centrifuge tests.

Class A and B predictions based on the outputs from the numerical and physical modelling will be performed, with results re-iterated through the numerical modelling to provide further refinement.

Figure 9. Example of field testing of pile capacity.

5. EXPECTED OUTCOMES

The case study dataset will be of significant value to future studies of screw pile behaviour & will be used to create a decision making tool-kit for the offshore wind & the wider offshore renewables industry. The project will accelerate the development of an alternative foundation system for offshore wind which is expected to carry a reduced overall foundation system cost, compared to currently proposed solutions.

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References

1. KNAPPETT, J.A., BROWN, M.J., BRENNAN, A.J. & HAMILTON, L. (2014) Optimising the compressive behaviour of screw piles in sand for marine renewable energy applications. Int. Conf. On Piling & Deep Foundations, Stockholm, Sweden, 21st-23rd May 2014. (IC-2014).
2. AL-BAGHDADI, T, BROWN, M.J., KNAPPETT, J. A. & ISHIKURA, R. (2015) Modelling of laterally loaded screw piles with large helical plates in sand. In V. Meyer (eds) 3rd Int. Symp. on Frontiers in Offshore Geotechnics. Oslo, Norway. 10 -12 June 2015. Taylor & Francis Group, London. pp. 503-508.
3. AL-BAGHDADI, T, BROWN, M.J. & KNAPPETT, J. A. (2016) Development of an inflight centrifuge screw pile installation & loading system. In Thorel, L., Bretschneider, A., Blanc, M. & Escofier, S. (eds) 3rd European Conference on Physical Modelling in Geotechnics (Eurofuge 2016), Nantes, France. 1-3 June 2016. pp. 239-244.
4. WANG, L., COOMBS, W.M., AUGARDE, C.E., BROWN, M.J., KNAPPETT, J., BRENNAN, A., HUMAISH, A., RICHARDS, D. & BLAKE, A. (2017) Modelling screwpile installation using the MPM. 1st International Conference on the Material Point Method for Modelling Large Deformation & Soil–Water–Structure Interaction, MPM 2017, 10 – 13 January 2017, Delft, The Netherlands. Accepted in press 25/06/16.
5. AL-BAGHDADI, T, BROWN, M.J., KNAPPETT, J. A. & HUMAISH, A. Effects of vertical loading on lateral screw pile performance. Proc. Inst. of Civil Engineers: Geotechnical Engineering Journal, Vol *, GE*. pp. *-*.. Accepted subject to minor comments 03/10/16