A modified CPT based installation torque prediction for large screw piles in sand

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1. Introduction

For offshore wind energy to move into deeper water (>40m), alternative foundation solutions are needed (Fig. 1) which overcome issues with manufacturing and installing existing monopile and straight-shafted pile systems[1].

Using physical, numerical modelling and field testing, the Universities of Dundee (UoD), Durham (DU) and Southampton (UoS) plus industrial partners are developing screw pile technology which could address these concerns.

Screw (helical) piles have a tubular core (shaft) with one to several helical plates and are installed with continuous torque and vertical force.

Benefits of screw piles include:
- Quick installation
- Low vibration/low noise
- Efficient material use, generating higher axial capacity through soil-soil shearing when helices are optimally spaced (Fig. 2)

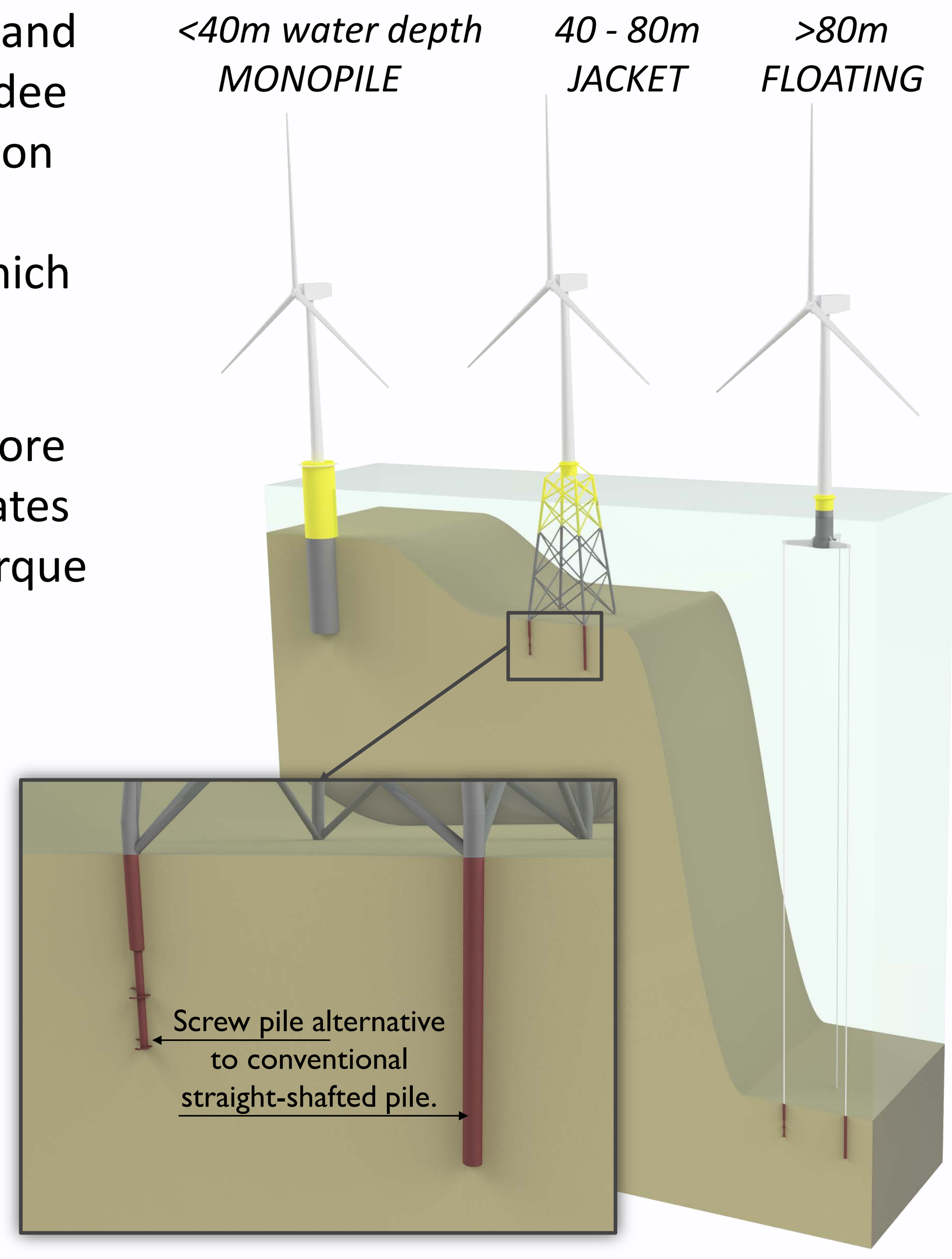

Figure 1: Offshore wind foundation solutions

Challenges:
- Upscaling current onshore designs
- Optimising geometry (e.g. core diameter and number, position, size of helices) for typical offshore loads
- Uncertainty over performance under cyclic loading[2]
- Predicting installation force and torque
  - Existing analytical[3,4] and empirical[5] methods may be unreliable
  - In situ CPT (Cone Penetration Test) correlation methods[6,7] appear more suitable.

Through centrifuge modelling of screw piles, the proposed CPT-torque correlation updates the previously developed formulae[6] to provide accurate predictions of installation torque.

2. Physical Modelling

Two 1/50th scale model screw piles (Fig. 2) were installed into dense, dry sand at 50g acceleration in the centrifuge at the University of Dundee with a specially developed installation rig[8].

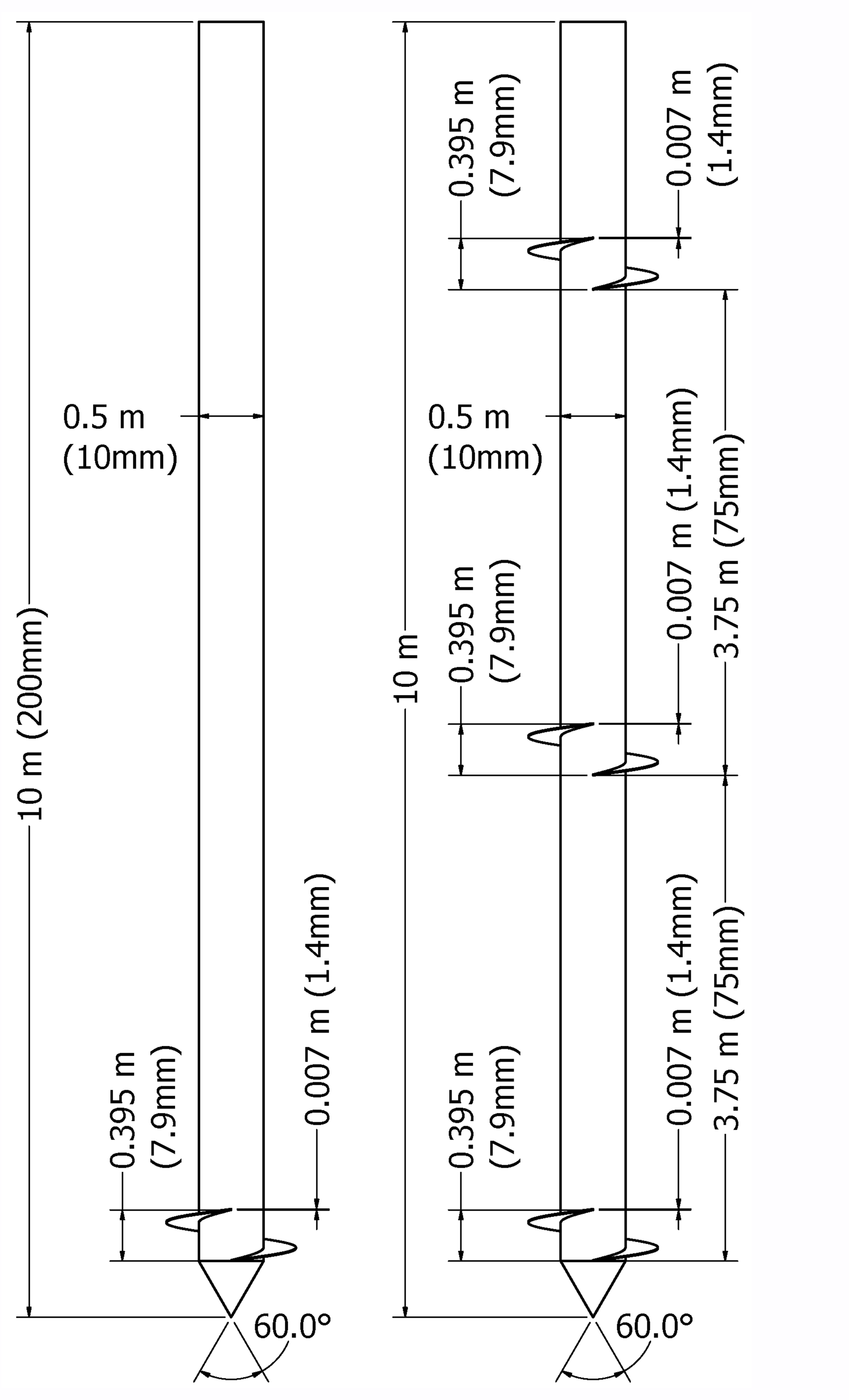

Figure 2: Model screw piles used in centrifuge tests at prototype scale (model dimensions in brackets)

Cone resistance (q_c) data from CPT were also acquired for use in the torque prediction method. The q_c data matches well with field data from other studies investigating screw pile installation torque (Fig. 3).

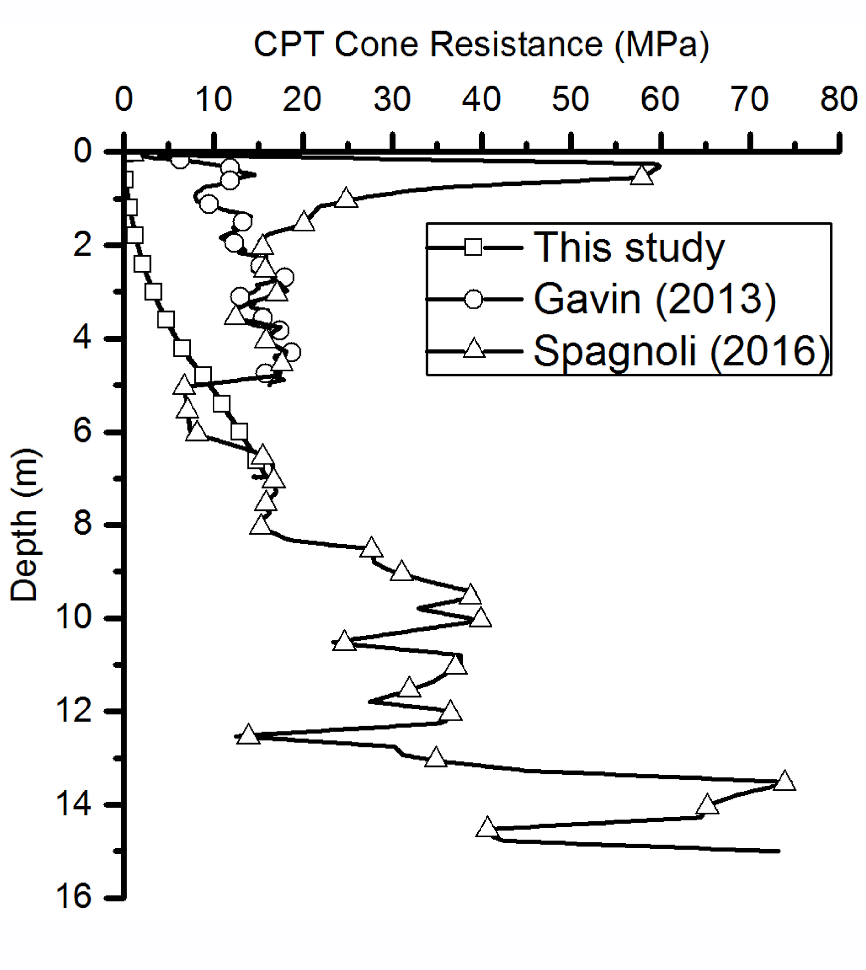

Figure 3: CPT cone resistance from: this study, Gavin et al. (2013) and Spagnoli (2016).

3. CPT-Torque Correlation

Principle torque resistances on a screw pile act on: the shaft (T_s); base of the pile (T_b); and the lower surface (T_{h1}), outer circumference (T_{h2}) and leading edge (T_{h3}) of the helix (Fig. 3). Cone resistance (q_c) data from CPT is correlated with installation torque using the proposed relationships shown below.

$$T = T_s + T_b + \sum_{1}^{n} T_{h(n)}$$

$$T_h = T_{h1} + T_{h2} + T_{h3}$$

$$T_s = \sum_{\Delta x=1}^{\Delta xi=L} a\bar{q}_c \tan\delta_{crit}\, \pi \Delta x \frac{{d_c}^2}{2}$$

$$T_b = \bar{q}_c \tan\delta_{crit}\, \pi \frac{{d_c}^3}{12}$$

$$T_{h1} = a\bar{q}_c \tan\delta_{crit}\, \pi \frac{{D_h}^3 - {d_c}^3}{12 k_0}$$

$$T_{h2} = a\bar{q}_c \tan(\delta_{crit} + \theta)\, \pi t \frac{{D_h}^2}{2}$$

$$T_{h3} = a\bar{q}_c t \frac{{D_h}^2 - {d_c}^2}{4}$$

$$a = \frac{F_r}{\tan\delta_{crit}}$$

$$k_0 = 1 - \sin\phi$$

$$\theta = \tan^{-1}\left(\frac{p}{\pi}\frac{D_h - d_c}{2}\right)$$

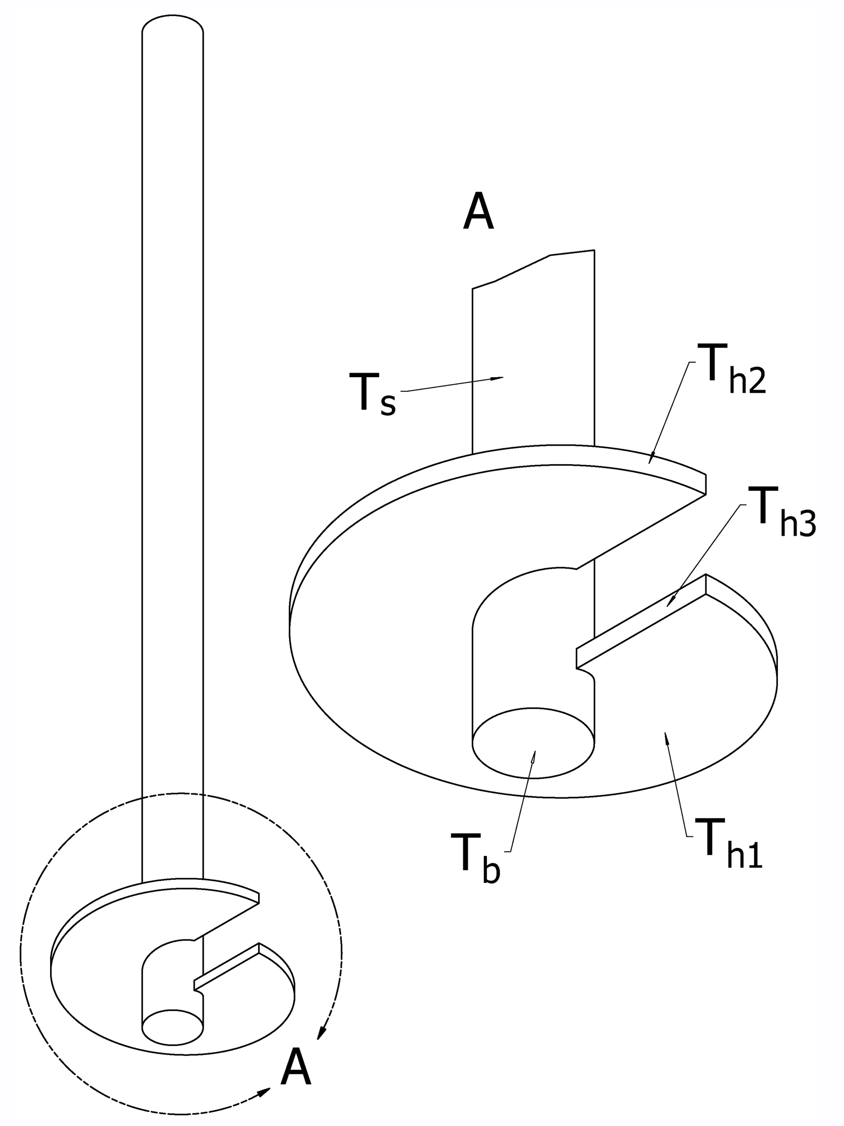

Figure 4: Torque resistances acting on a single helix pile during installation

D_h = helix diameter, d_c = shaft diameter, t_h = helix plate thickness, θ = helix pitch angle, p = helix pitch, L = screw pile shaft length, x = calculation interval length, a = stress drop index, F_r = CPT friction ratio, $\bar{q}_c$ = average q_c over $\pm 1.5 D_h$ distance from calculation depth, k_0 = earth pressure coefficient at rest, δ_{crit} = interface friction angle of soil, ϕ = friction angle of soil.

The proposed method predicts installation torque well for both centrifuge and field scale studies (Fig. 5), providing improved accuracy over other CPT-torque correlation methods for single and multi-helix designs, while other methods[6,7] have previously restricted their predictions to single-helix piles only.

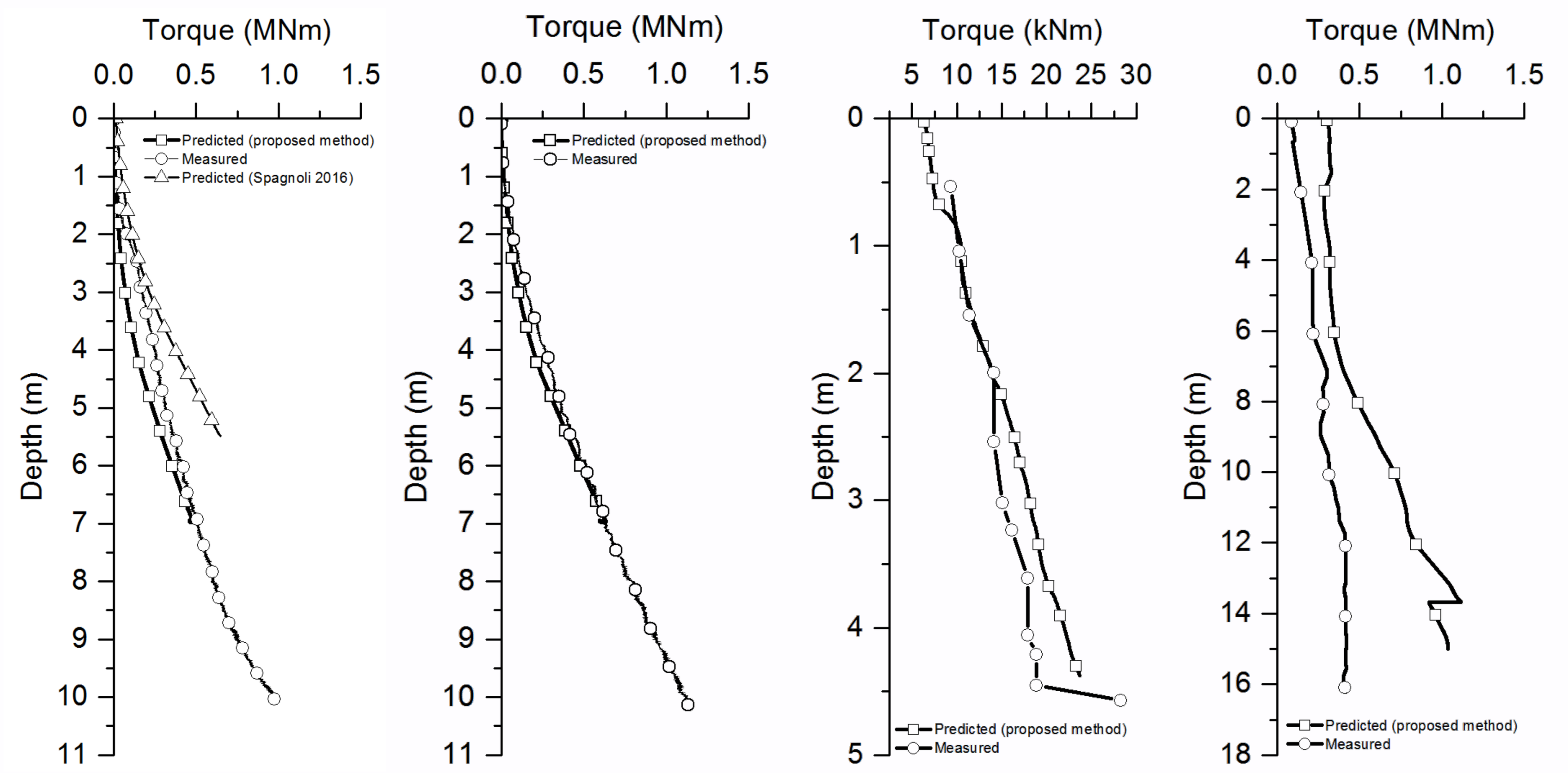

Figure 5: Predicted and measured installation torque for centrifuge tests of the single helix (Fig. 2a) and multi-helix (Fig. 2b) are shown in a) and b), while field tests of screw piles reported in [6] and [9] are shown in c) and d) respectively.

4. Acknowledgements

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5. References

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