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Performance of Screw Piles enhanced for lateral load capacity

Performance de pieux vissés avec amélioration de la résistance latérale

K. J. L Stone and M. Diakoumi
University of Brighton, Brighton, UK

ABSTRACT: This paper presents a centrifuge model study of the performance of screw piles with enhanced lateral capacity provided by fins (Screwfin Pile), expanded shafts, or high level augers. It is proposed that such systems can be made self-installing whereby the screw pile is utilised to embed the fins or other enhancement, and as such the system would be particularly attractive for applicaions where installation of conventional piles by driving is difficult or unpracticable. The model tests were conducted in a ballanced beam geotechnical centrifuge at an acceleration level of 50 gravities in medium to dense uniformly graded dry sand. The installation of the piles was not modelled, and thus only the post-installation performance was assessed. Monotonic lateral loading was applied, and the results are presented through load versus displacement plots, from which lateral capacities are derived. The data set obtained from the tests is compared with a simple analytical approach based on Broms‘ method.

RÉSUMÉ: Cet article présente une étude portant sur les perfomances de pieux vissés avec une résistance latérale améliorée par des ailerons (Screwfin Pile), un élargissement d'une partie du fût ou de l'ajoût d'hélices supplémentaires. Les tests sont effectués sous formes de modèle réduit en centrifugeuse. L'hypothèse est que ces systèmes soient capables d'auto-installation, c'est-à-dire que l'action de visser le pieux entraine les ailerons ou toute autre amélioration technique sous terre et par conséquent ce type de pieu apporterait une solution particulièrement intéressante dans les cas où l'utilisation de pieux battus serait difficile voire impossible. Les expériences ont été faites à l'aide d'une centrifugeuse géotechnique à faisceau équilibré avec une accélération de 50 fois la gravité terrestre dans un sable sec de densité moyenne à élevée avec une granulométrie uniforme. L'installation des pieux n'a pas été modélisée et, par conséquent, seule la capacité post-installation a été mesurée. Une charge latérale continue est utilisée et les résultats sont présentés sous forme de graphique avec la charge et le déplacement relatif à partir desquels la charge latérale maximale est estimée. Les résultats obtenus dans ces tests sont comparés à ceux de calculs basés sur la méthode de Broms.

Keywords: Screw piles, centrifuge modelling, lateral capacity

1 INTRODUCTION

Screw piles have been used extensively with applications in a variety of geotechnical foundations, and are particularly popular for small scale installations (i.e. domestic housing and small towers/gantries). However, recently they have received attention as a potentially significant contribution to the development of the offshore wind sector. The screw pile is a highly effective tensile anchoring system, and has the advantage that installation from the seabed may be more practical with an autonomous installation system than a bored or driven pile.

The main disadvantage of a conventional screw pile is that the pile shaft is generally of a small cross section for ease of installation. Since the pile is installed by rotation then the smaller the pile shaft the less the shear resistance developed as the shaft rotates against the soil during installation. However the small diameter shaft means that the installed screw pile is unable to develop any useful lateral resistance. To overcome this limitation commercial systems have been developed to retro-fit screw piles with a system of fins or other enhancements to provide additional lateral resistance.

This paper presents a centrifuge model study of the performance of screw piles with enhanced lateral capacity provided by fins (‘Screwfin’ Pile), expanded shafts, or high level augers. It is proposed that such systems can be made self-installing whereby the screw pile is utilised to embed the fins or other enhancement into the soil.

An example of the installation process of a screw pile enhanced with fins is illustrated in the schematic sequence of Figure 1. However it is also noted that the fins could be installed by jacking or using the tensile capacity of the installed screw pile as a reaction to pull the fins or other enhancement into the soil.

An example for a screw pile enhanced with fins is illustrated in the schematic sequence of Figure 1.

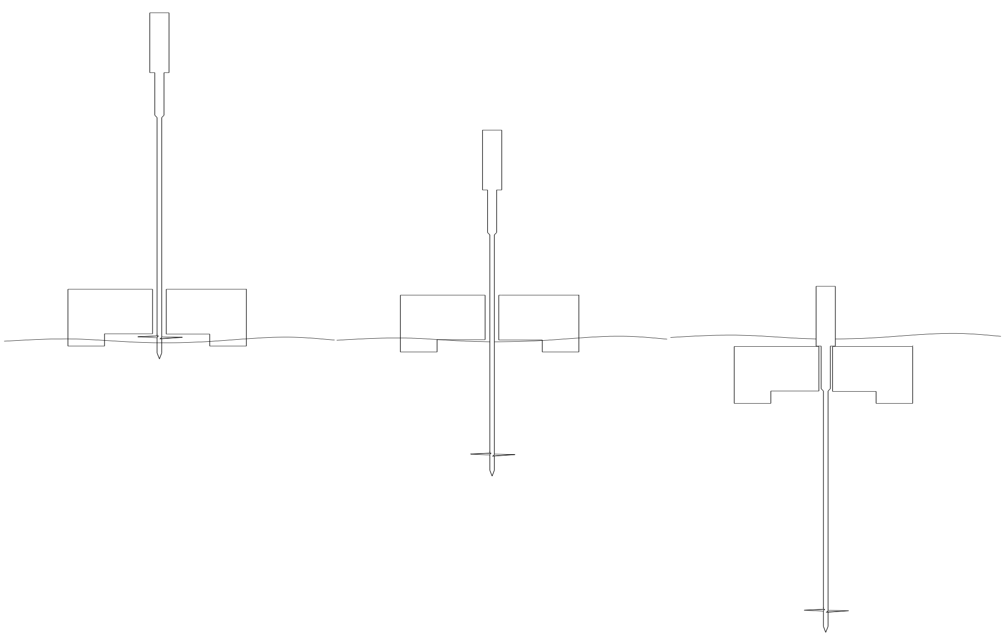

Figure 1: Installation of a screw pile enhanced with fins

There is currently much interest in increasing the lateral capacity of monopiles associated with the developmet of the offshore wind sector. Recent studies have focussed on the use of ‘hybrid‘ systems such as monopiled footings (see for example Stone et al 2007, 2018). The use of fins has also been an area of much research.

Following early studies using tapered fins reported by Lee and Gilbert (1980), later research has clearly demonstrated the enhancement of lateral capacity through the use of fins under both monotonic and cyclic loading, see for example (Sayles et al 2018, Bienen et al 2012, Duhrkop et al 2010, Nasr 2014, Rudolph & Grabe 2013, Duhrkop & Grabe 2008, Peng 2006, DTI 2006, Peng et al 2010). Several of these studies focused on the geometrical arrangement of the fins, in terms of length and projection from the pile shaft (Sayles et al 2018, Peng 2006). Whilst there is not complete agreement in the literature, it is generally observed that the relationship between lateral load and fin length tends to decrease linearly up to a fin to pile length ratio of about 0.3, after which the effeciency reduces.

It is proposed that the fin represents in essence a 'bulge' or widening of the pile shaft and as such any enhancement which results in a similar effective increase in the projected area of the pile would generate an increased lateral resistance. The tests reported here have investigated the effect of local shaft widening through the use of fins, shaft bulges and multiple augers. Furthermore, it is proposed that the enhancements are used in conjunction with a screw pile such that the installation of the screw pile and enhancement will be self-installing, refer to Figure 1.

2 EXPERIMENTAL PROGRAMME

A total of 4 tests are reported herein as summarized in Table 1. The tests were designed to investigate the influence of the various enhancements on the lateral capacity of a straight shafted screw pile. The pile embedment depth for the model pile,and embedment depth of the enhancement remained the same for all the tests. The effective increase in shaft diameter was assumed to be similar for all various enhancements.

Table 1. Summary of experimental tests

Test ID	Pile embedded length	Enhancement
T1	90	None
T2	90	Tapered fins
T3	90	Bulged shaft
T4	90	Double auger

Figure 2 shows the suite of enhancements used in the centrigure model tests presented here. In this figure the length above the enhancements appears different for each of the model piles, however this was adjusted during the experimental set up so that all piles had similar lengths. To enable comparison between tests, the point where the lateral load was applied was the same for all model piles.

Figure 2. Model screw piles with enhancements.

2.1 Material and model preparation

The sand used for the model tests was uniformly graded Fraction C (300-600 micron) silica sand supplied by David Ball Limited. The sand has maximum and minimum void ratios of 1.06 and 0.61 respectively, with a critical state angle of friction φ_{crit} of 32°. The models were prepared though a combination of dry pluviation and vibration using a vibrating table. This method produced consistent soil specimens with a bulk density of 1700 kg/m^3.

2.2 Centrifuge test package

All the tests reported were carried out on the balanced beam centrifuge at the University of Brighton. This machine is manufactured by Thomas Broadbent & Sons Ltd. and is 6 g-tonne machine (20 kg payload to 300g). The tests were conducted in a rectangular strongbox with a length of 300mm, width of 155mm and sample height of 140mm. The steel strongbox was placed in a cradle which was then mounted on the centrifuge arm.

A two degree of freedom actuator is then mounted on the cradle, and through the use of a wire and pulley mechanism is able to apply a horizontal load to the model pile, refer to Figures 3 and 4. The steel wire is attached to a load cell fixed to the actuator traveler plate. The applied horizontal load is assumed to be equal to the tension measured in the steel wire (i.e. friction effects are neglected). The horizontal displacement at the point of loading is measured directly by a displacement transducer.

The model piles were installed by screwing into the soil by hand and great care was taken during installation to ensure verticality of the pile. Since the pile is displaced away from the container walls and towards the centre of the sample, boundary effects are not considered significant.

Figure 3. Model package assembled and loaded on the UoB centrifuge.

The model piles were constructed from solid 9.5 mm diameter aluminum rod. The fins were composed of four tapered sections, the bulge was tapered towards the pile shaft and the auger segments were formed from thin 0.5 mm twisted aluminium plate.

The shaft of the pile was loaded via a collar attached at 50mm above the model surface. This height was selected primarily for ease of connection with the pulley and actuator arrangement such that loading could be applied horizontally, refer to Figure 3.

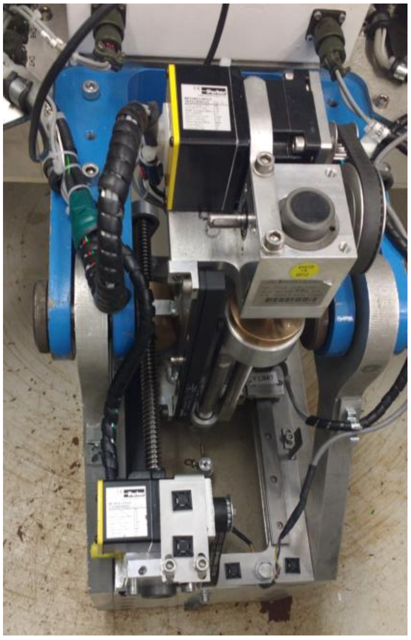

Figure 4. The fully assembled model package loaded on the UoB centrifuge.

2.3 Test procedure

The model and actuator is set-up on the laboratory bench and then loaded onto the centrifuge, see Figure 4. The actuator is connected to the power and control system and a digital video camera is mounted on the top of the cradle to observe the model during the test. All the tests were conducted at an acceleration level of 50g.

Once the model had achieved the test acceleration, the actuator was run at a velocity of 3 mm/minute and data from the load cell and displacement transducer recorded continuously until the end of the test.

3 EXPERIMENTAL RESULTS

The experimental results are best presented through plots of lateral load versus lateral displacement (measured at the point of load application).

Figures 5 and 6 show a summary of the test results with the plots of load versus displacement from all four configurations plotted together. It is apparent that for all the tests where the upper section of the pile shaft has been effectively widened, the lateral capacity of the system is increased over the capacity of the pile alone.

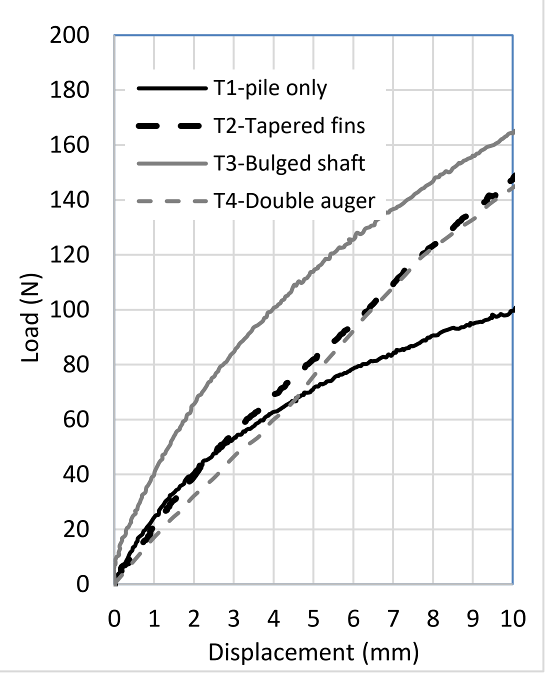

Figure 5. Summary of load-displacement response of model piles up to 10mm (~1D) lateral displacement.

It is interesting to note that the response of the pile with the bulged shaft (Test T3) yields a stiffer response to the double auger (Test T4) and finned pile (Test T2) as well as achieving a marginally greater lateral capacity at 10mm lateral displacement. However it is noted that the initial lateral response of the finned and double auger enhancements are actually similar to the single pile response, the increase in lateral capacity only developing at a displacement of about 40% of the pile diameter. The ultimate lateral capacity for all the piles with enhancements tend towards a relatively common value at high displacements.

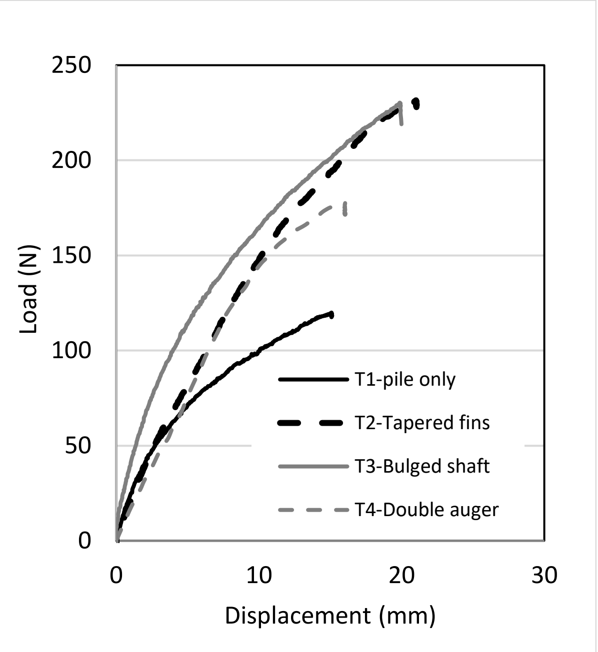

Figure 6. Summary of load-displacement response of model piles for maximum recorded displacement.

4 ANALYSIS AND DISCUSSION

Whilst the number of tests performed to date is rather limited, it suggests that the difference in the response is associated with the disturbance of the soil in the vacinity of the enhancement which occurs during installation. The rotation of the fins and augers will disturb the soil to a greater extent than that occurring with the bulge; it is also noted that the outward displacement of the soil which occurs when the bulged shaft is installed will densify and stiffen the soil surrounding the widened section of the pile, and hence may account for the stiffer response.

A simple analysis has been undertaken using Broms‘ method (Broms, 1964) for the estimation of the lateral deflections of free headed rigid piles at in cohesionless material. From this analysis, assuming a peak value of friction of 45 degrees, the predicted ultimate lateral capacites, at model scale, for the 9.5 and 30mm diameter pile is 71.5 and 227 N respectively. It is apparant that the capacity for the straight shafted 9.5 mm pile is underpridicted by about 60%. However, by assuming a pile diameter of 30mm a reasonable prediction for the capacity of the enhanced piles is obtained. It is noted that this prediction, to be consistent with that for the 9.5 mm diameter pile, is likely to underpridict the measured value of a 30mm straight shafted pile by also up to 60%. It might thus be assumed that the effect of the enhancements can be modelled by assuming a uniform pile of an appropriate effective diameter.

5 CONCLUSIONS

This paper has presented an initial set of experimental results investigating the performance of a screw pile enhanced to increase its lateral capacity by increasing the effective shaft diameter over a seciton of the upper pile length. Furthermore, it is proposed that the screw pile can be utilised to self-install itself and any associated enhancement. Whist the dataset is small, and the tests reported are essentially a ‘proof of concept‘, the results are encouraging. It is noted that installation disturbance may have a significant influence on the performance of the enhancements and this will require further investigaiton. It is also suggested that a simple approach to the analysis of a pile with an effectively widened shaft over part of its (upper) length can be approximated by carring out an analysis assuming an appropriate ‘average‘ uniform shaft diameter.

6 ACKNOWLEDGEMENTS

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