Forces involved with the extraction of casings used in rotary bored piling

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ABSTRACT: Temporary casings are regularly used in the construction of rotary bored piles, to support the pile bore in potentially unstable soils and also to prevent water ingress from loose or water logged soils. The preferred method of removal of casing is by pulling with a crawler crane. However, the magnitude of force generated, particularly during the initial stage of casing extraction, is unknown. This paper describes a series of 50g centrifuge tests designed to model the casing and surrounding soil during extraction by crane. In each test different sized model casings were installed at various embedment depths into a layer of clay overlain by a well-graded sand to provide an array of data. The depth of granular overburden was varied from 60 mm to 120 mm to allow for assessment of the influence of this material on the extraction force whilst the casing sizes modelled 900 mm and 1800 mm prototypes.

1 INTRODUCTION

Temporary casings are routinely used in the construction of rotary bored piles, to support the pile bore in potentially unstable soils and also to prevent water ingress from loose or water logged soils.

The extraction method of the temporary casings has largely been selected on the basis of the judgment of experienced personnel and, in most cases, has been successfully concluded. Where it is thought that casings can be removed easily a handling crane is used to pull vertically. If it is thought that the casing cannot be readily withdrawn then it can be extracted by rotating with the hydraulic rig used for excavating the piles although this leads to reduced rates of production. If the judgment about whether a casing can be withdrawn using a handling crane is incorrectly made the results can be catastrophic. For example, where a crane is being used the sudden failure of a hoist rope will in turn trigger a sudden release of load on the boom, which may cause it to fail dramatically as it whips back hard against the stops and back over the cab. This may result in injury, death, damage to equipment and the works under construction or even surrounding structures (Federation of Piling Specialists, 2010). Furthermore, a failure of the selected extraction method will inevitably lead to delay and increased cost.

Many piling contractors operating in London and elsewhere extract temporary casings with crawler cranes; this operation will likely involve both static load whilst tension is being applied to the casing and dynamic load at the point where the frictional forces are overcome and the casing begins to ascend. The extent of this force is unknown.
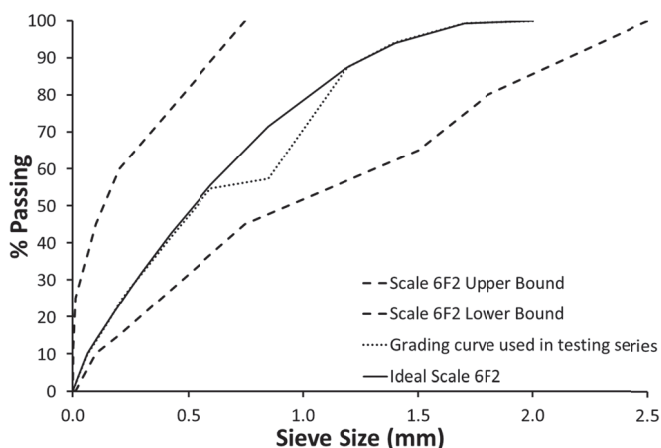
2 OBJECTIVES

The overall objective of this industry funded project is to develop a series of rules of thumb, to provide practitioners with a simple and effective method for estimating extraction force. The project will be supplemented by a prototype scale parametric study, though this is yet to be conducted and hence is not reported here.

This project did not seek to derive the magnitude of extraction force for given soil conditions, pile diameter, and embedment depth. This was thought to be unrealistic owing to the vast number of variables that could exist. Instead the primary objective was to gain an insight into the factors affecting the casing extraction force. With this information it may be possible to correlate the impact a specific parameter may have on the total extraction force. For example, does the total extraction force double if the casing penetration into the clay is increased from 0.5 m to 1.0 m?
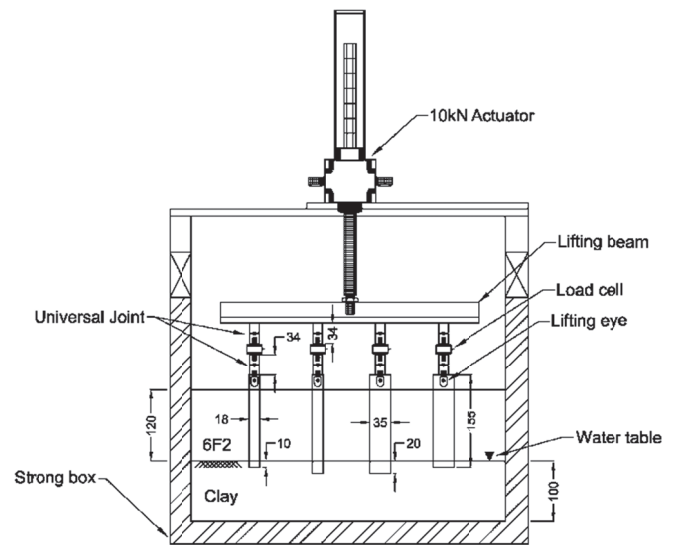
3 SOIL MODEL

The tests were conducted in a standard City University London plane strain centrifuge strong-box with plan dimensions of 200 mm x 550 mm and maxi-

mum soil depth of approximately 300 mm. Standard Speswhite Kaolin clay was mixed to a water content of 120% and consolidated in a hydraulic press to form a clay layer into which model casings could be embedded. The clay layer was overlain with crushed limestone during model making.

The centrifuge samples were prepared from slurry consolidated under 800kPa and allowed to swell under 400kPa, resulting in a sample at 1g with an over-consolidation ratio of 2. These consolidation stresses resulted in a soil sample that was firm but still enabled easy and accurate model making and gave an undrained shear strength, S_u, of around 50kPa.

The material selected for the overburden was a grey Devonian limestone sourced from a quarry in Ashburton, Newton Abbot, UK. It has been used by previous researchers investigating piling mat behaviour (Halai et al., 2012). The limestone was selected from a crushed aggregate stock pile having being passed through the crushing, washing and sorting plant and contained sharp, angular grains from 3.35 mm down in size and was free of any clay particles. The overburden was graded to a fiftieth scale class 6F2 granular material. A class 6F2 material is typically crushed concrete with particle sizes from 75 mm down to dust (Manual of Contract Documents for Highway Works: Volume 1, 2009). The upper and lower bound grading curves have been scaled to 50g and plotted in Figure 1. It follows that the ideal class 6F2 grading curve lies in between the limiting curves. The actual grading curve for the material used for this testing series is also presented. This curve does not replicate the ideal grading owing to a lack of specific particle sizes. However the grading curve for the material used can be classed as 1:50 scale 6F2 since is falls between the upper and lower bounds.

Figure 1. Scale class 6F2 grading curve.

4 APPARATUS

The apparatus for the experiments was an adaptation of a setup previously used for the vertical loading of micro pile groups (Rose, 2012) and is shown in Fig-

ure 2. A loading beam was attached to each casing via Omega 5 kN miniature load cells which were provided with universal joints on either side (Figure 2). This design feature allowed any bending generated by misalignment to be accounted for, and hence only axial load was measured.

Figure 2. Apparatus setup.

The pile casings were manufactured from standard 316 stainless steel tube. The external faces were sand blasted to give the casings a uniformly rough surface. Since the tests were modelling extraction of the casing immediately post concreting of the pile, it was necessary to model the wet concrete pressures exerted on the inside of the casing. This was achieved with latex tubes that were manufactured with a sealed end and to which a thin layer of Fraction C Leighton Buzzard sand was glued (Figure 3). The membranes were installed inside the casings and filled with a Fraction E Leighton Buzzard sand and water. The water and sand inside the latex tubes was considered to simulate the hydrostatic pressure of the wet concrete whereas the sand on the exterior face of the tube was akin to the friction generated by the aggregate within the concrete.

Figure 3. Sand covered latex membranes.

A 10 mm thick Perspex guide plate (Figure 4) was manufactured with a good fit with the internal faces of the strong box. This allowed accurate positioning of the pile casings.

A series of cutters and guide collars were manufactured to allow the pile bores to be cut vertically and in the correct position, and also support the casing before the granular material was placed.

Since the casings were being extracted from the soil there were no concerns over end bearing effects. In view of this, the distance between the bottom of the sample and the bottom of the casing could be reduced to less than the 5d typically used in pile model tests to avoid end bearing effects (Craig, 1995). This was beneficial to the project since it allowed the actuator to be mounted high on the strong box and hence allowed for most of the length of casing to be extracted from the soil. The depth of clay used was 100 mm and this resulted in a worst case distance between the base of the strong box and the bottom of the casing of 2.3d.

A standpipe was used to set the water table level with the top of the clay surface.

5 TESTING PROCEDURE

The testing procedure can be summarised as follows:
1. With the model in-flight, flood the granular layer with water and immediately drain to ensure uniform consolidation of the overburden.
2. Leave the model spinning at 50 g for 5 hours to establish pore pressure equilibrium in the clay layer. (The overburden remained unsaturated throughout the remainder of the test).
3. Extract all casings simultaneously.

Upon removal from the consolidation press the clay sample was trimmed to the required level and sealed using a small amount of silicon oil. A small vertical drain 20 mm in diameter and 15 mm deep, was cut into the top of the clay surface toward the back of the box to allow quick drainage of the granular layer following inundation immediately after spin up. A drain was connected to a remote solenoid valve via a port in a wall of the strong box.

The Perspex template was placed above the clay and the guide collars pushed through the guides into the clay. The collars served two functions, firstly to accurately control the embedment of the casing and secondly to provide a guide for when the pile was bored out. The collars can be seen in Figure 4.

The pile was bored using thin walled steel tube cutters using the collars as guides. The shelf left in the clay when the collars were removed can be seen in Figure 5. The Perspex template was then removed from the clay surface and hung from the top of the strongbox. A plywood former was placed on top of

the clay (Figure 6), this was used to retain the granular material when it was placed. The model pile casings were then dropped through the top of the Perspex guide template down to the shelf in the clay sample created earlier. The sand covered latex bags were inserted into the pile bore and then filled with the saturated sand. Once this operation had been completed the granular material was placed. This was placed in even layers through holes cut into the Perspex template. It was necessary to keep the template in place until all of the granular material was placed, as the 10-20 mm embedment of the pile casings into the clay was not considered sufficient to temporarily hold the casing vertical.

Figure 4. Casing guide collars.

Figure 5. Shelf left in clay after removal of collar.

Once the granular material had been placed and compacted the Perspex template was removed and the casing extraction apparatus was attached to the strong box. The load cells were lowered toward the head of the casings and attached simply with a single M6 bolt.

The package was installed onto the centrifuge swing, a stand pipe was set up to maintain the water table at the top of the clay whilst a second water feed

was used to provide water to the top of the granular material.

When the centrifuge had reached 50 g the water feed at the top of the sample was turned on allowing the granular material to become fully saturated, this was monitored by the on-board cameras. Once fully saturated the solenoid valve was opened thus draining the granular layers. The motivation for doing this was to assist in compacting the granular material and helped to ensure consistent relative density throughout the model. The package was left in the centrifuge for 5 hours until the pore pressures within the clay had become hydrostatic. At this point the model was ready for testing. The casings were extracted at a rate of 10 mm/min and were extracted by approximately 140 mm. The displacement was measured by correlating the time in the data file to fixed speed of the actuator.

Figure 6. Perspex template used to hold casing vertical.

Figure 7. Post-test deconstruction of the model.

Figure 7 shows the post-test deconstruction of the model where the model casings and most of the granular soil have been removed leaving the sand covered rubber membranes protruding.

6 TEST RESULTS

The results of a total of two centrifuge tests have been conducted and the results are presented here. Each centrifuge test consisted of four test sites and hence a total of eight casing extraction tests were carried out.

In each test two casings with 35 mm outer diameter (OD) and two casings with 17.5 mm OD were used. Of these, one casing which had a clay embedment of 10 mm and the other an embedment of 20 mm. At prototype scale this is approximately 1800 mm and 900 mm outside diameter and clay embedment of 500 mm and 1000 mm.

In Test A the granular overburden was set at 120 mm and reduced to 60 mm for Test B. This scales to 6 m and 3 m respectively. The bulk unit weight of the overburden measured after each tests was 18.76 kN/m^3 and 17.22 kN/m^3 for Test A and B respectively. The tests undertaken are summarised in Table 1.

Test A - 120 mm overburden thickness		
Casing diameter	Casing embedment in clay	
35 mm	10 mm	20 mm
17.5 mm	10 mm	20 mm
Test B - 60 mm overburden thickness		
Casing diameter	Casing embedment in clay	
35 mm	10 mm	20 mm
17.5 mm	10 mm	20 mm

Table 1. - Summary of tests undertaken

Figure 8 shows the load displacement curve for Test B. As expected, the extraction force peaks early in the test and this maximum force gradually decreases as the casing is extracted and has less surface area in contact with the soil. The spike in the extraction force probably reduces as the fictional forces and suctions are overcome. As predicted the largest diameter casing with the greatest embedment showed the highest extraction force. The graph shows that by doubling the embedment there is a marked increase in the peak extraction force for both small and large diameter casings.

Load displacement curves presented in Figure 9 are for Test A where the overburden was 120 mm (twice that for Test B). The effective of doubling embedment for both small and large casings can be seen and is similar to that of Test B. The increased overburden has had little effect on the shape of the load displacement curve and seems to have only affected the magnitude of the extraction force.

For the purpose of casing extraction, for obvious reasons, the most critical force is the peak force, which occurs almost immediately after extraction

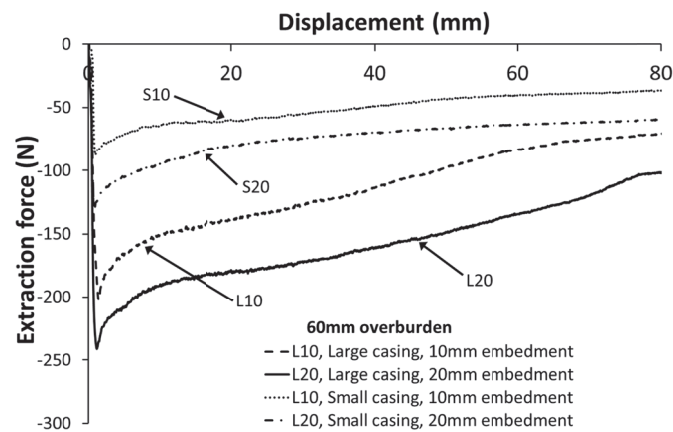commences. Table 2 shows the peak extraction forces for each test conducted.

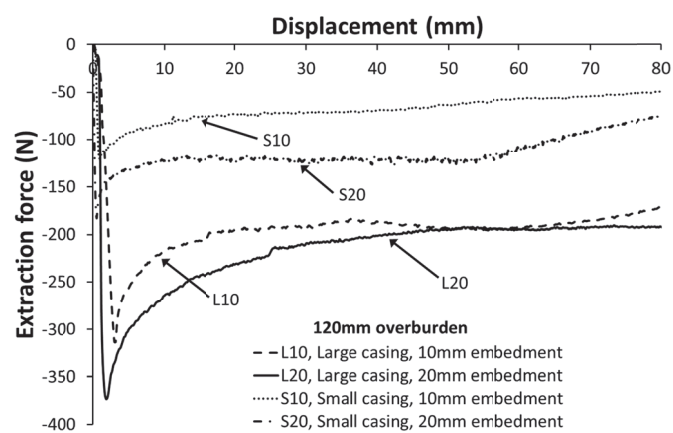Figure 8. Extraction force for 60 mm overburden test.

Figure 9. Extraction force for 120 mm overburden test.

Diameter (mm)	Embedment (mm)	Overburden height (mm)	Peak force (N)
35	10	60	202.5
35	10	120	313.6
35	20	60	241.3
35	20	120	373.3
17.5	10	60	88.0
17.5	10	120	120.3
17.5	20	60	131.7
17.5	20	120	183.2

Table 2 - Peak extraction forces.

7 DISCUSSION

It is clear from the tests conducted that the maximum extraction force results from a combination of the dead weight of the casing, the frictional forces in the granular and clay materials and some suction. The casing diameter, embedment and the height of overburden have all been varied. By comparing the peak extraction forces from these variables, remarkable consistencies can be seen. The doubling of the overburden height from 60 mm to 120 mm has the following effect on the peak extraction force:

Casing dia x embedment	Increase in force
35 mm x 10 mm	155 %
35 mm x 20 mm	155 %
17.5 mm x 10 mm	137 %
17.5 mm x 20 mm	139 %

Table 3. – Effect of overburden.

The greater depth of overburden had a slightly greater effect on the extraction force required for the smaller casing. The effect of doubling the casing embedment in the clay from 10 mm to 20 mm can be seen in Table 4.

Casing dia x overburden	Increase in force
35 mm x 60 mm	119 %
35 mm x 120 mm	119 %
17.5 mm x 60 mm	150 %
17.5 mm x 120 mm	152 %

Table 4. – Effect of clay embedment.

Table 4 suggests that the extraction force on the smaller diameter casing is more heavily influenced by increased embedment in the clay than for the larger diameter casing.

The Federation of Piling Specialists (2010), propose a theoretical calculation for the total extraction force of the casing by considering the casing size, embedment and overburden. The method takes into account the following contributing factors:

- The friction from the wet concrete pressures,
- the skin friction against the clay layer,
- the skin friction against the sand layer and,
- the self-weight of the casing

The adhesion factor between the clay and the casing was taken as 0.2. The 6F2 material is estimated to have a critical state angle of friction of 45°, and the coefficient of friction between the wet concrete and casing or in this case the Leighton buzzard sand was taken as 0.1. The FPS method does not make any allowance for any suction generated by the extraction of the casing. Figure 10 shows the theoretical extraction force for a 17.5 mm casing, embedded 20 mm with a 60 mm overburden; also plotted is the measured extraction force with displacement. By comparing the two curves it is evident that the theoretical calculation shows reasonable correlation to actual test data. The initial or peak force is slightly under predicted; the difference is around 18%. Toward the end of the test where the casing is nearly fully extracted the difference between the theoretical prediction and measured extraction force is marginal. This can be reasonably expected as in the latter stages of extraction the self-weight of the casing is the dominant resisting force.
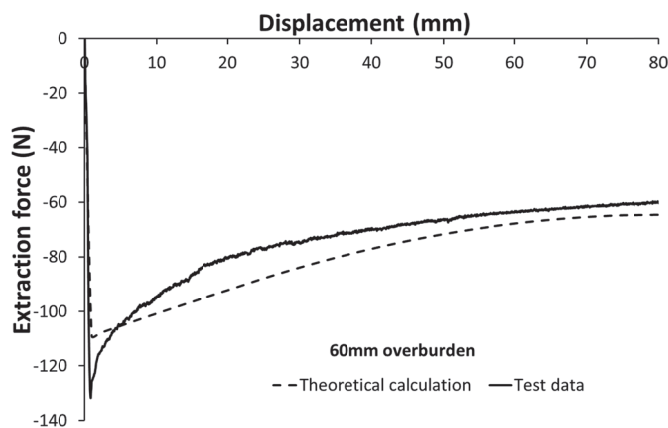
Figure 10. Comparison of theoretical and actual extraction force for 17.5 mm casing embedded 20 mm in clay and 60 mm in 6F2 overburden.

Figure 11 shows the theoretical and measured test data of the extraction force against displacement for a 35 mm casing, embedded 20 mm, with a 120mm, overburden.

In comparison to Figure 10 the theoretical calculation in Figure 11 over predicts the peak force required to extract the casing. Moreover, the differences between the theoretical and measured curves are significantly greater than for the 17.5mm diameter casing with 60 mm of overburden. The initial or peak force is slightly over predicted; however this difference is around 14%. The behaviour would suggest the theoretical extraction force prediction is heavily influence by the calculation for the component of resistance from the 6F2 material. Furthermore, it seems the theoretical calculations reasonably predict the peak extraction force.
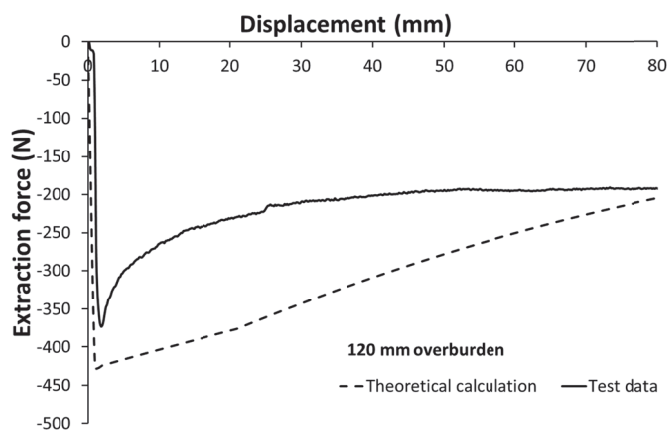

Figure 11. Comparison of theoretical and actual extraction force for 35 mm casing embedded 20 mm in clay and 120 mm in 6F2 overburden.

8 CONCLUSION

A limited number of tests were conducted that involved simultaneously extracting four model pile casings from a soil sample that consisted of a heavily over consolidated clay overlain by a 6F2 grading crushed limestone overburden. In each test two casing diameters, each with a differing clay embedment were used. The thickness of the 6F2 overburden varied between tests. The results that were obtained were consistent and showed that the effect of doubling the embedment of the casing into the clay caused the peak extraction force to significantly increase. Comparisons have been made to the theoretical prediction of extraction force and suggest that the theoretical calculations appear to reasonably predict the peak extraction force.

9 FURTHER WORK

To further investigate the influence of each component of resistance to extraction a further series of tests is being planned. It is proposed to consider an intermediate casing size of 26 mm diameter with clay embedments of 5, 10, 15, and 20 mm, with a constant overburden 120 mm of 6F2. It is envisaged that this will give greater insight into how casing diameter and embedment influence the total extraction force.

10 ACKOWLEDGEMENTS

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