Peak extraction forces when removing temporary steel casings used in rotary bored piling

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ABSTRACT: In rotary bored pile construction the preferred removal method of temporary steel casings is with a handling crane. The feasibility of this largely depends on the judgement of experienced personnel, which may prove fatal if the basic assessment underestimates the force. A series of centrifuge tests were carried out to explore the influence of variables including overburden height, embedment depth, casing diameter and effects of time. It was found that changes in embedment are more critical to extraction forces compared with changes in overburden. Additionally, the increase in peak force when removing a casing a week after a concrete pour only exhibits peak forces 20% greater than if a casing is extracted earlier. The Federation of Piling Specialists (FPS) released guidance notes on predicting peak extraction forces of casings and although the trends are generally correct, this study shows that following these guidelines can sometimes underestimate the magnitude of the actual peak extraction force experienced.

1 INTRODUCTION

Temporary casings are typically used during rotary bored pile construction where loose materials overlie clay, they are installed at ground level and sealed in the clay. Casings prevent the collapse of unstable soils such as sands and gravels into the open bore and prevent the ingress of water. Casings also have the additional benefit of acting as a guide for the auger to maintain verticality during construction. Once the concrete has been placed the casing is removed, cleaned and reused.

Temporary casings can be extracted using a wide range of specialist equipment such as casing extractors and oscillators, however this can be expensive and cause delays to the programme. A preferred option is to utilise the crane on site to pull out the casings thereby avoiding the need for additional plant.

The Health and Safety Executive (HSE) is the UK's statutory safety body and they advise handling cranes should be limited to lifting operations and not be used to pull casings. This is due to the insufficient research and guidelines concerned with the extraction of casings which can lead to fatalities if the judgement of experienced personnel is incorrect.

The FPS (2010) reported that the peak extraction force is not influenced only by frictional forces on the external face of the casing. Other factors include the self-weight of the casing; concrete pressures against the casing; casing installation method and time between concrete pour and casing extraction. Since ground conditions vary considerably across sites, generating an algorithm to calculate the exact expected extraction forces is impractical but this paper presents some trends that can provide insight into the problem.

2 EXPERIMENTAL WORK

The follow procedure adopted for centrifuge tests A, B and C was performed by Gorasia *et al*. (2014):

Speswhite kaolin clay was mixed with a water content of 120% and carefully placed in a greased strongbox, consolidated to 800kPa and then swelled to 400kPa to crease a stiff clay sample.

Upon removal from the hydraulic press the clay was trimmed to create a 100mm high sample before a Perspex template was placed on top of the clay. Collars with an outer diameter equal to those that were being tested were adjusted to provide the required embedment prior to being pushed through the template into the clay to create a shelf that the casing rests on and control embedment as shown in Figure 1. Piles were then bored to the bottom of the strongbox using thin walled steel tube cutters which were marginally smaller than the casing inner diameter.

The Perspex template was then hung from the top of the strongbox and a plywood former was placed above the clay layer which supported the 6F2 overburden; which is a crushed, washed and sieved limestone aggregate, graded to a fiftieth of the size of aggregate used in highway construction (MCHW1, 2009) with particles ranging from 3.35mm to dust.

Figure 1: Perspex template placed on clay layer and adjustable steel collars pushed into clay to cut shelf for each required embedment depth (Gorasia et al., 2014)

Figure 2: Casings rest on precut sheft and supported at the top by Perspex template hung from top of strongbox prior toplacing of 6F2 within plywood former (Gorasia et al., 2014)

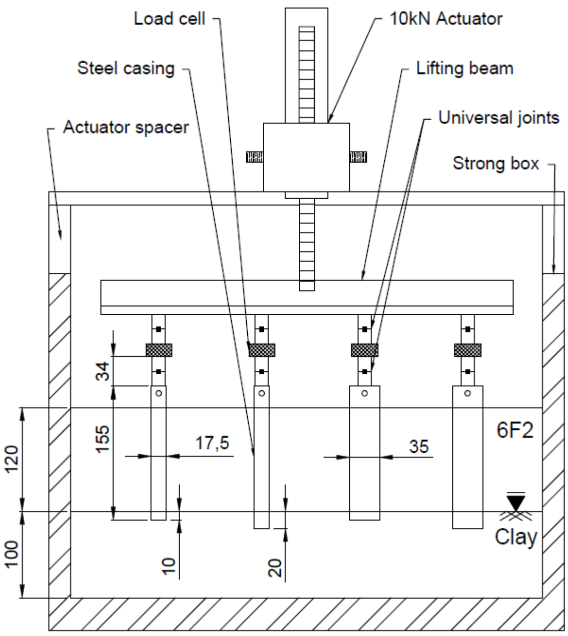

Figure 3: Test A centrifuge set up

The casings were pushed into the clay with the top ends supported by the Perspex template (Figure 2). Sand covered latex tubes were then inserted into the bores and filled with sand and water to simulate the hydrostatic pressures from wet concrete. A small 25mm deep drainage channel was cut into the clay towards the back of the strongbox to allow drainage of the overburden during the test. The 6F2 was poured through the Perspex holes using a funnel and levelled to the top of the former. The Perspex template was then removed as the overburden supported the length of the casings.

Universal joints were connected to both ends of the load cells to the actuator and the casings. These joints assisted with ease of model making and were vertically aligned with the casings to ensure vertical extraction. The load cells were then lowered and secured to each casing by a single M6 bolt.

The strongbox was loaded onto the centrifuge swing with a standpipe connected to the base drain to provide a water table at the top of the clay layer. Once the centrifuge reached 50g the additional water feed at the top of the model was turned on to saturate the overburden and a camera positioned on the edge of the strongbox provided a visual indication that the 6F2 had flooded. A remote solenoid valve connected at the back of the strongbox was then opened to allow quick drainage to aid in the compaction of the granular material and provide an evenly distributed bulk unit weight across the sample. To allow pore pressures in the clay to dissipate the sample was left to spin for five hours before extracting the casings at a rate of 10mm/min.

2.1 *Test A*

Two 50g centrifuge tests carried out by Gorasia *et al*. (2014) investigated the effects of varying overburden and embedment depths.

In each test, two 17.5mm outer diameter (OD) and 35mmOD casings were inserted into 60mm and 120mm depths of grade 6F2 overburden respectively. Each diameter casing was embedded 10mm and 20mm in clay as illustrated in Figure 3.

2.1.1 *Published conclusions from Test A*

Gorasia *et al*. (2014) stated that doubling the overburden increases the extraction force by 55% and 38% for 35mmOD and 17.5mmOD casings respectively. Similarly, doubling the embedment increases peak forces by 19% and 51% for 35mmOD and 17.5mmOD casings. It was concluded that embedment significantly affects peak extraction forces.

2.2 *Test B*

An additional 50g centrifuge test was carried out to validate Test A. Two 17.5mmOD and two 35mmOD casings were inserted into 120mm of overburden. Each diameter casing was embedded 15mm and 25mm into the clay as shown in Figure 4. After the test was completed the 6F2 was removed from the model and weighed to calculate the bulk unit weight as being 17.45kN/m^3.

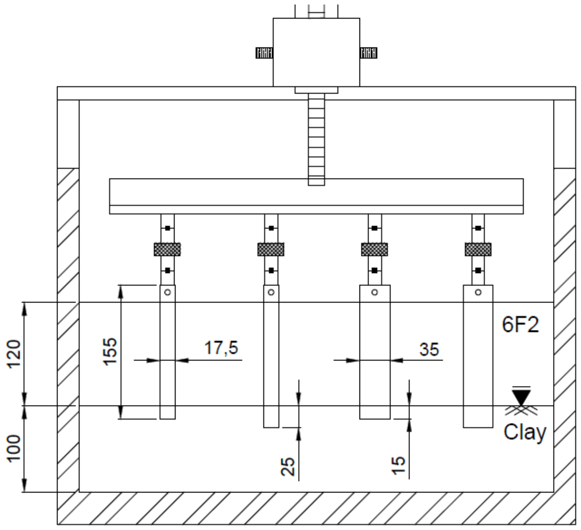

Figure 4. Test B centrifuge set up

Table 1: Peak forces from Test B in 120mm overburden

Diameter	Embedment	Peak force
mm	mm	N
17.5	15	190
17.5	25	251
35	15	356
35	25	459

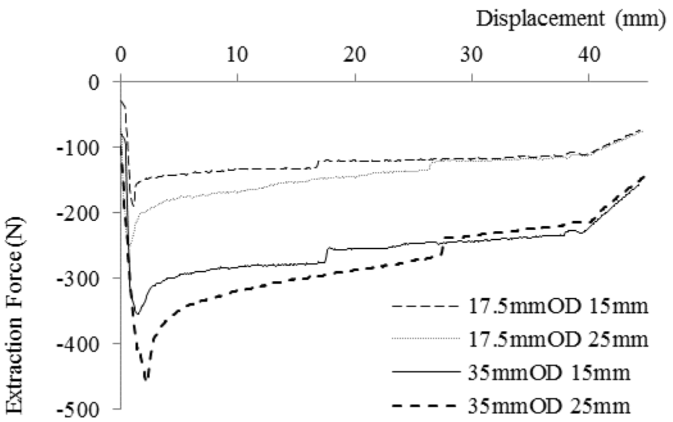

Figure 5: Each casing extraction force in Test B; force decreases as casings are extracted from clay layer at 15mm and 25mm

Figure 6: Post-test; casings extracted in Test B

2.2.1 *Comments from Test B*

The results from Test B are given in Table 1 and Figure 5, showing displacement against extraction force. The point at which the casing is completely pulled out the clay can be identified where the extraction force suddenly decreases, which may be due to suction forces between the clay and casing.

2.3 *Test C: Effects of time and embedment*

This centrifuge test at 50g explored the effects of time between casing installation and removal on peak extraction forces. Four 25mmOD casings were inserted into 120mm 6F2 overburden and sealed into the clay at 5mm intervals as illustrated in Figure 7. The model preparation followed the procedure outlined in section 2.

Once pore pressures had stabilised the test commenced and the casings were consolidated for varying time periods before being extracted by 5mm at a rate of 10mm/min. This process was repeated for the following consolidation periods at prototype scale; 4 hours, 17 hours, 5 days, 6 days and 11 days and the results are summarised in Table 2.

2.3.1 *Comments from Test C*

Generally casings with a similar embedment experience negligible changes in peak forces for longer periods of consolidation. For instance, two casings with 20mm embedment were consolidated for 4 and 250hours however the peak extraction force only increased by 12%. Comparing the rest of the results, the greatest change in peak force was 20% for 5mm embedment.

Figure 8 plots Test C peak forces against the embedment depth and indicates that there is a trend between different consolidation periods. For instance, the rise in peak force with increasing embedment follow a close trend for casings consolidated for 5 and 11 days. This also appears for a casing consolidated for 17 hours and 6 days.

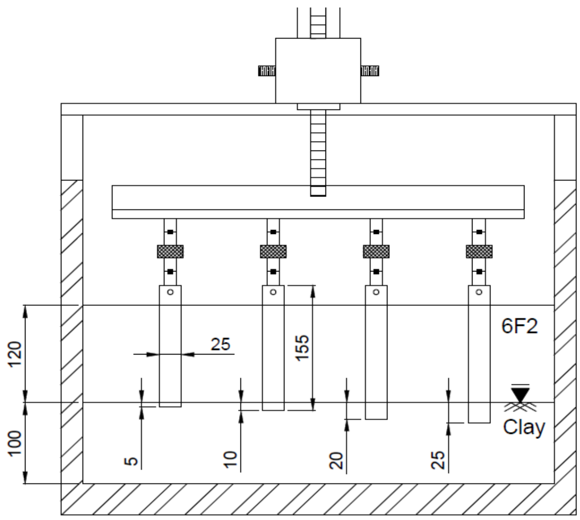

Figure 7: Test C centrifuge model set up

Table 2. Peak forces after different consolidation periods

Casing reference	Embedment	Consolidation	Peak force
	mm	hours	N
A	5	250	255
	0	4	197
	-5	143	188
	-10	17	171
	-15	115	169
B	10	250	279
	5	4	213
	0	143	203
	-5	17	180
	-10	115	180
C	20	250	356
	15	4	282
	10	143	262
	5	17	237
	0	115	234
D	25	250	420
	20	4	317
	15	143	285
	10	17	258
	5	115	253

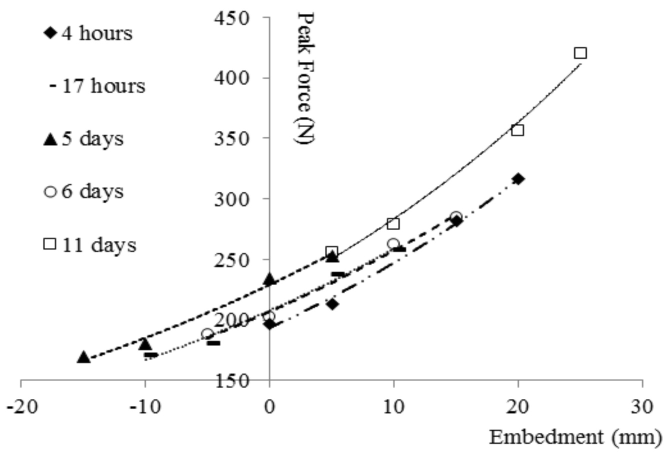

Figure 8: Peak force against embedment depth for varying consolidation periods

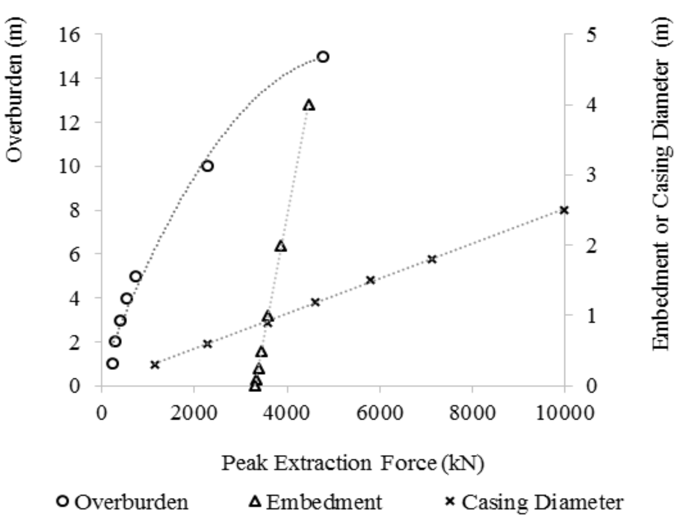

Figure 9: Effect of varying embedment, overburden or casing diameter

3 THE FPS GUIDELINES

The FPS (2010) produced guidelines to estimate the peak extraction force (F_{ext}) using eq.1; where SW is the casing self-weight, Qs_{ext} is the resistance between the external face of the casing, calculated using eq.2. Qs_{int} is the internal resistance from the casing/soil or concrete interface, calculated using eq.3.

$$F_{ext} = SW + Qs_{ext} + Qs_{int} \tag{1}$$

$$Qs_{ext} = EA\ \sigma'_{vo} \tan\delta + EA\ \alpha\ S_u \tag{2}$$

$$Qs_{int} = IA\ \gamma_{conc}\ h\ \mu \tag{3}$$

Where EA and IA are external and internal areas respectively, $\tan\delta = 0.75\varphi'_{cs}$, α is the adhesion factor, h the height of concrete to casing interface and μ denotes the coefficient of friction.

3.1 *Overburden height*

The effect of varying overburden is shown in Figure 9. As the overburden exceeds 5m the expected extraction force increases logarithmically. This is due to the change in vertical effective stresses against the length of the casing.

Figure 10 shows a parallel relationship between increasing overburden from say 10m to 20m and peak forces for any casing embedment.

3.2 *Embedment depth*

Figure 9 shows a linear relationship between peak forces and embedment. Figure 11 shows that increasing embedment from 1m to 5m causes the change in peak force to remain constant for any overburden height.

3.3 *Casing diameter*

Similarly, Figure 9 illustrates a linear trend between casing diameter and extraction forces but Figure 12 shows a divergent trend which predicts that doubling the overburden has a larger effect on peak forces than doubling casing embedment.

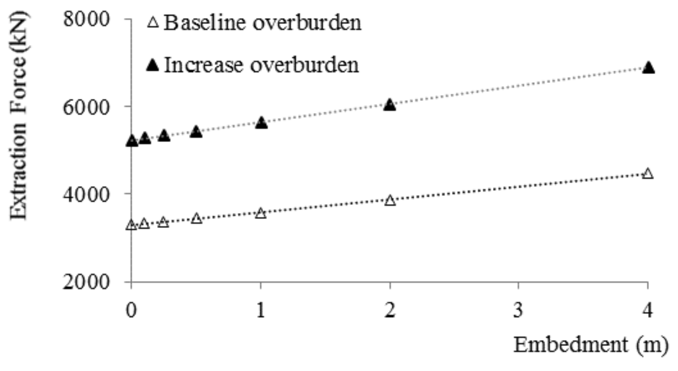

Figure 10: Effects of changes in overburden height on extraction forces

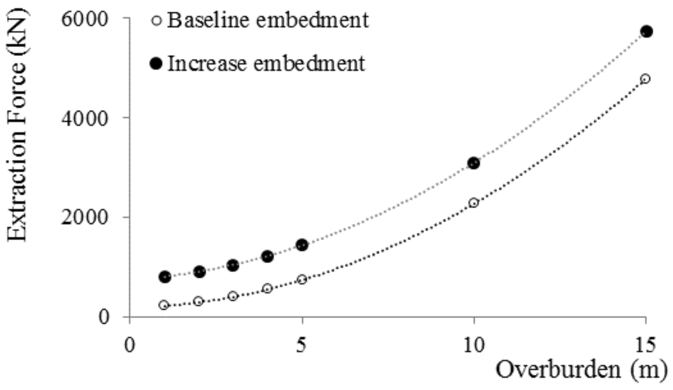

Figure 11: Effect of increasing embedment on extraction forces

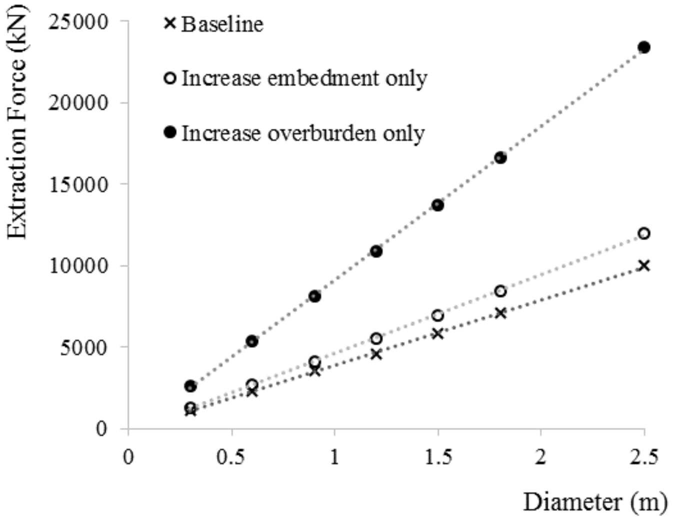

Figure 12: Effects of varying overburden or embedment on casing extraction

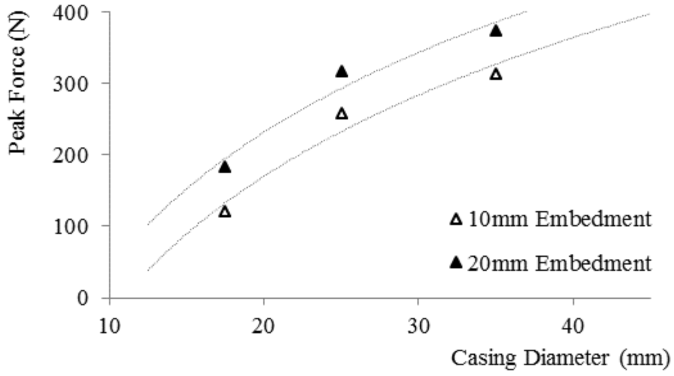

Figure 13: Change in peak force from Tests A & C when doubling embedment from 10mm to 20mm in 120mm overburden. Note: A similar trend was observed for constant overburden of 60mm

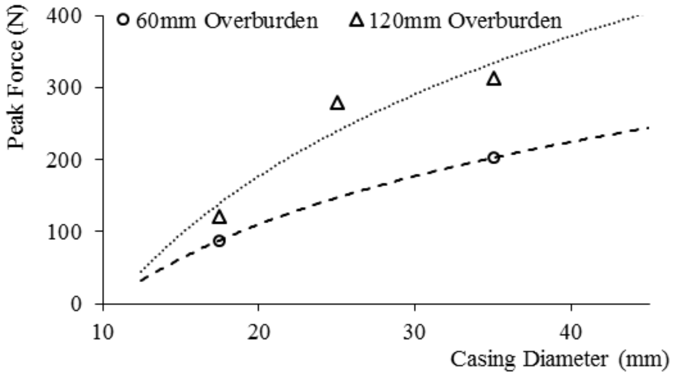

Figure 14. Peak forces when varying overburden heights against casing diameter for constant embedment of 10mm from Tests A & C. Note: A similar trend was observed for constant embedment of 20mm

4 ANALYSIS OF TESTS A, B & C

4.1 *Embedment scaling factor*

Test A showed that doubling the embedment of a casing typically increases peak forces by a factor of 1.2 for small and 1.5 for larger diameter casings. Therefore predicting changes in peak forces for any diameter can be estimated where the overburden remains constant.

Figure 13 shows that doubling the embedment causes the peak force to increase by a similar amount for any casing diameter. This parallel relationship is related to the area of casing in contact with clay. As clay frictional forces are a function of α and S_u, increasing the embedment results in an almost linear change in peak force. As contractors avoid embedding casings deeper than necessary S_u will not vary drastically over the additional embedded depth.

4.2 *Varying overburden*

Figure 14 illustrates the peak forces in Tests A & C when the embedment is constant and the overburden is doubled. It indicates a divergent and logarithmic relationship for increasing casing diameters. This concurs with the FPS predictions as Figure 12 show that peak forces steadily increase with overburden.

4.3 *Varying casing diameter*

Figure 15 displays the effect of different embedment depths in 120mm overburden for three casing diameters.

It shows that the trend line for each diameter is simply translated upwards for larger casings. Additionally, the trend of peak forces for small casings (17.5mmOD) are considerably lower than larger diameters (25 & 35mmOD), verifying that the FPS equations provide the correct correlations.

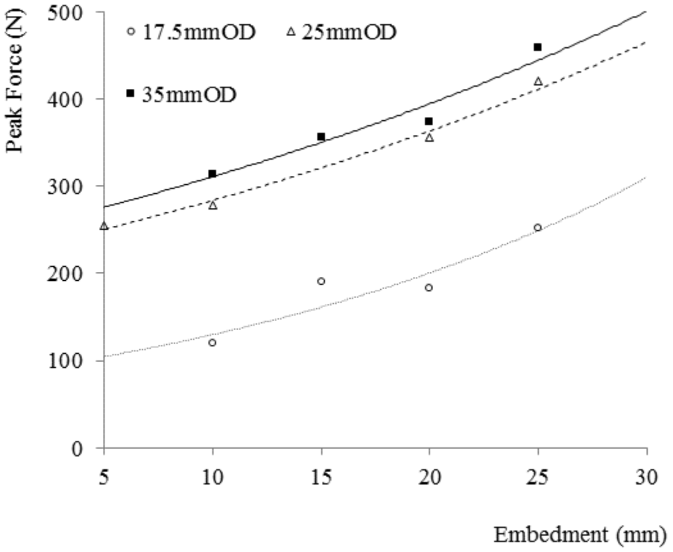

Figure 15. Parallel trend between different casing diameters when the casing embedment is varied in 120mm overburden, data from Tests A, B & C

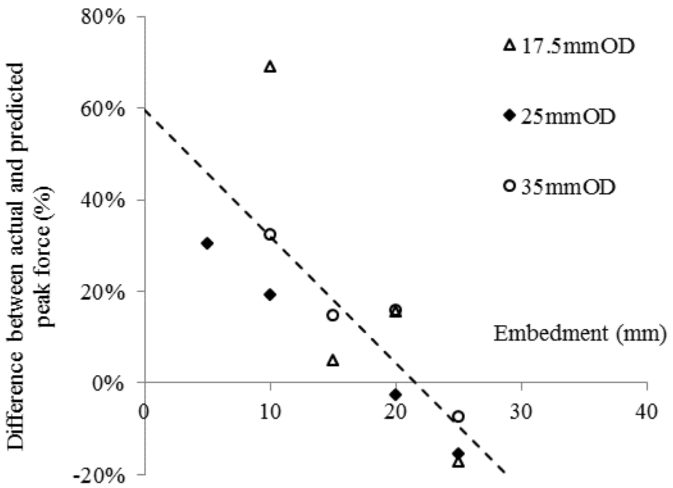

Figure 16. Trend between casing embedment and percentage difference between actual and predicted peak forces

4.4 *FPS guidelines*

For Test A, Gorasia *et al*. (2014) concluded that the FPS equations underestimate peak extraction forces for the small casings in 60mm overburden. Although peak forces of larger casings in 120mm overburden were over predictions of the centrifuge results.

The centrifuge results and FPS predictions for Tests A, B & C were compared and are plotted in Figure 16 plots the percentage difference. Generally the FPS formulae underestimate the peak force for casings with deeper embedment. However for shallower embedment depths the guidelines over predict the peak force which is generally true for all diameters.

The results show for shallow embedment the FPS method over predicts the peak forces for small diameter casings. It also underestimates peak forces of small diameter casings with deep embedment is worse than a larger casing with similar embedment.

5 LIMITATIONS AND FURTHER TESTING

To validate these observations, Test C should be repeated to confirm whether the peak force should lie on the logarithmic trend line as expected. A 15mm embedment should also be tested as opposed to 5mm embedment. It is unrealistic that contractors will embed casings 250mm at prototype scale.

6 CONCLUSIONS

Two additional centrifuge tests at 50g were carried out to validate the findings from Gorasia *et al*. (2014). The same equipment, materials and model set up were employed to allow direct comparison between tests. Three casing diameters with different embedment depths were used to illustrate the effect of varying diameter and embedment on peak extraction forces. These supplementary centrifuge tests were carried out in 120mm crushed 6F2 overburden and thus have only been compared with similar tests by Gorasia *et al*. (2014).

Based on the analysis of past and current data the following conclusions have been made:

Embedment depths appear to be a more significant contributor to the peak extraction force than the overburden height.

Doubling the embedment for one casing diameter results in the change in peak force for any other casing diameter to change by a similar magnitude.

Contractors should be aware that a casing extracted approximately a week after the concrete pour can exhibit peak forces up to 20% greater than one removed immediately.

For large diameter casings the FPS formulae can on average predict peak forces within 14%, however over predictions are made for small diameter casings with shallow embedment and underestimate forces of small casings with deep embedment.

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