

MODEL TESTS ON GROUTED DRIVEN PILES IN CALCAREOUS SOILS

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ABSTRACT: The capacity of driven piles in calcareous soils can be very low. In order to increase the shaft capacity of such piles, a grouting technique is used. A new apparatus for testing grouted driven piles has been developed at the University of Western Australia. In this paper, the apparatus is described along with the grouting technique. The results of tests performed on calcareous soils with different degrees of cementation are also presented.

1 INTRODUCTION

The capacity of driven piles in calcareous soils can be very low, due to the crushing and rearrangement of the particles near the pile wall and to the breaking of the internal cementation bonds, during the driving process. In order to re-establish the contact between the pile and the soil, a grouting technique is used. This consists of injecting a certain volume of grout between the pile wall and the soil to increase the friction capacity of such piles.

The drilled and grouted pile is the technique used in offshore foundation, which consists of first drilling an oversized hole, and pumping grout into the clean hole, and then placing the pile into the hole. This technique is a time-consuming process and very expensive as shown by Rickman and Barthelemy (1988). Therefore, the grouted driven pile technique seems to be an alternative to the drilled grouted pile.

The concept was developed by Solmarine, a French company specialising in foundation grouting. The technique, and the results obtained in large-scale pull-out tests, are described by Rickman and Barthelemy (1988). They show that the grouted driven piles can provide the same skin friction as drilled and grouted piles. Large scale tests were also performed by Dunnavant et al. (1989) on driven grouted pile at Overland Corner in South Australia. A model pile testing program in a calibration chamber was performed by Parkin et al. (1992).

In this paper, results are presented from tests performed on a model pile of 50.8 mm diameter driven in a sample of 400 mm diameter and 300 mm depth. The samples were prepared with different degrees of cementation in order to reproduce the naturally-occurring calcarenite which can be found in different states, ranging from mud to very hard rock. The details of the apparatus used and the grouting technique are presented.

2 DESCRIPTION OF THE APPARATUS

Figure 1 shows a diagram of the Grouted Driven Pile apparatus. A cylindrical container of 400 mm in diameter and 400 mm in height contains the soil sample of about 300 mm height. The base of the cylinder consists of a shoe which can be detached after driving the pile and before commencing the

grouting process. This permits easy cleaning of dirt found in the shoe and around the pile-shoe interface, in order to minimise the friction between the base and the pile. A piston placed on top of the sample allows a normal pressure to be applied to the sample. A 64 mm hole is drilled through the piston permitting an inner sleeve to seat on top of the sample. This sleeve guides the pile into an outer sleeve which is fixed to the piston and can slide through a hole of 71 mm diameter drilled in the top cap of the apparatus.

During the consolidation phase and the driving of the pile, the inner and outer sleeves are connected and form a single piece. After the grouting procedure, the two sleeves are disconnected in order to allow the inner sleeve to move with the pile, in case the grout reached the piston, as was observed in some cases. This system minimises the boundary effect in such a case. Drainage is allowed from the base during the consolidation, driving and loading processes.

The model pile is 50.8 mm in diameter and 650 mm long (Figure 2). The current version of the apparatus permits injection of grout through a pair of diametrically opposed holes. In the early days of the study, the grout was injected through 5 pairs of diametrically opposed holes, at a vertical spacing of one pile diameter. This resulted in about 100 % coverage of the pile, and therefore affected the boundary conditions. Then the number of holes was reduced to 6 (3 pairs diametrically opposed), however the grout coverage was still too close to the boundaries. Thus, a single pair of holes diametrically opposed and situated at different levels, was adopted and gives much more satisfactory results. For the sleeve tests, initially the holes were situated in the middle of the sample, then at a depth of 2/3 of the sample, and finally at the current position of one pile diameter from the base of the sample. For the pull-out tests, they were situated initially at 3 pile diameters from the pile tip, then at 2 pile diameters and for the current configuration, they are at 1 pile diameter from the pile tip. In order to improve the grout flow and the grout coverage, a pair of diametrically opposed return holes was located at 1 pile diameter above the grout holes, but at 90° rotation, as shown in Figure 2. The grouting procedure will be described in more details later.

To install the pile, a coring tube is first driven into the sample, then the pile is placed on top of the coring tube and both are driven into the soil. After the pile

reaches its final position, the coring tube (at this stage protruding fully below the container) is detached from the pile. Then the shoe is detached from the base and cleaned with the pile tip, and well greased. In some cases, as will be seen latter, the coring tube is pulled out and the pile replaces it. After the pile has been installed, the grouting process can then begin.

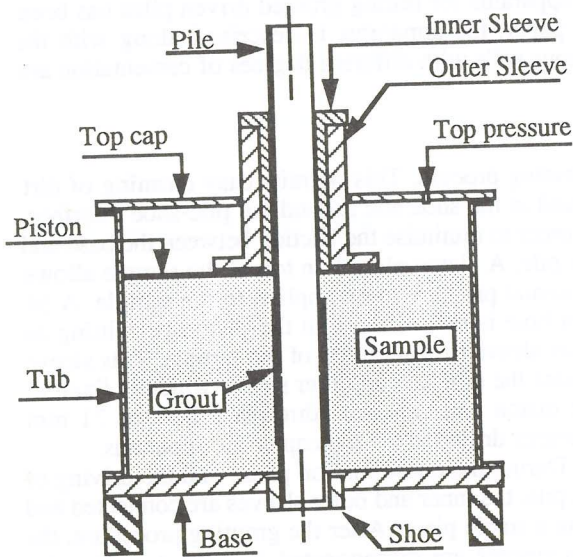


Figure 1 Grouted Driven Pile apparatus

3 SAMPLE PREPARATION

Calcareous soil is found in many of the offshore areas of the world where hydrocarbons are found. It covers the sea bed off Victoria (Bass Strait) and West Australia (North West Shelf). The soil used in this study is the calcareous soil from the North West Shelf. Such formations are found in different states ranging from mud, silts and sands (uncemented) to very hard rock (cemented).

In order to reproduce in the laboratory the state of such formations, a method of preparation of artificially cemented calcareous soils, using Portland cement as the cementing agent, was adopted. The detail of the method of preparation of the samples are briefly presented here. More details of the technique can be found in Joer et al. (1992) and Lee (1993).

The samples are prepared by first mixing the dry soil, with any cement to be added, for half an hour. Then 42 % by weight of water is added and mixed for another half an hour. The whole mix is then placed in a cylindrical tub and a piston is placed on top. A pressure of 100 kPa is used to consolidate the sample for one hour, allowing top and bottom drainage. The cemented samples are then left to cure in a room with constant humidity for a period of time. Two types of cement were used to prepare the samples, Portland cement type A and B (or high early strength). A four week curing period was allowed for the samples prepared with the type A cement and one week for the samples with the type B cement.

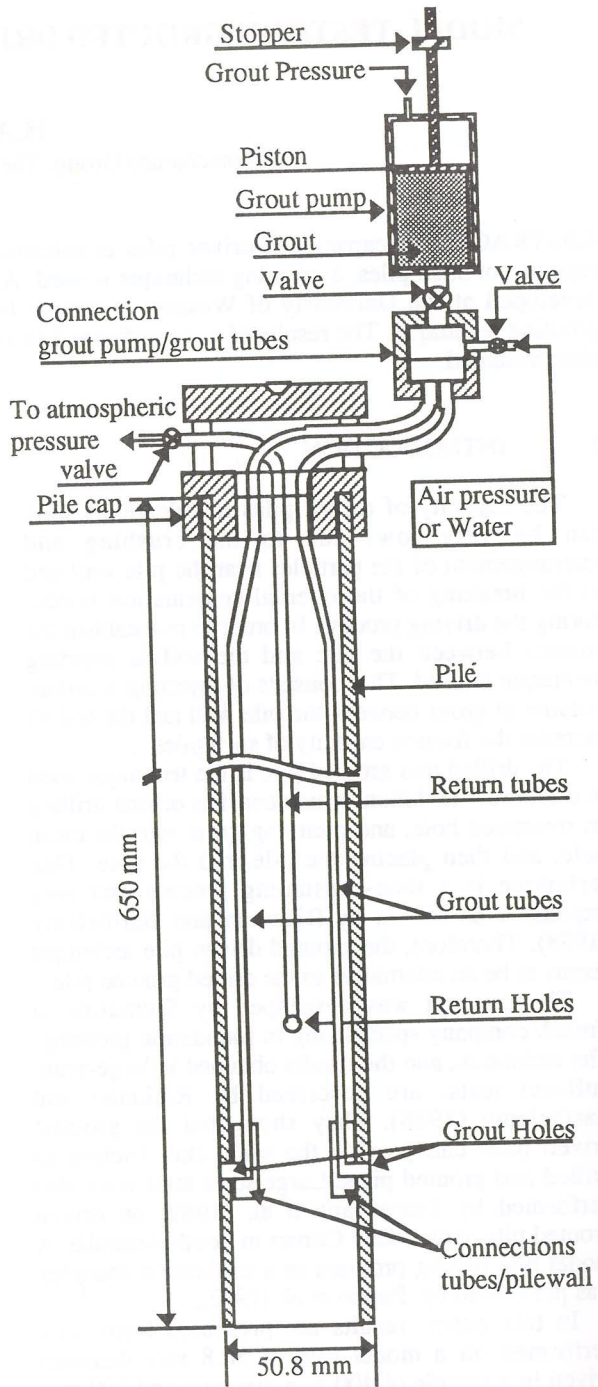


Figure 2 Pile details and Grouting system

4 GROUTING PROCEDURE

The first tests were performed using an epoxy grout of low viscosity ($\nu = 79 \text{ mP}$), which gives full coverage of the pile. Later, cementitious grout (Portland cement type B and G) was used with a plasticiser (Joer et al., 1994). The proportion of cement, water and plasticiser were 68%, 30.6% and 1.4% by weight, respectively.

The bottom holes, at one pile diameter from the base of the sample, are connected to two 5 mm diameter 700 mm long copper tubes, which are in

turn connected to a single grout pump (Figure 2). The return holes are also connected to two copper tubes which come out the pile and are kept at atmospheric pressure. The grout is therefore pumped from the bottom hole into the pile-soil interface, flowing toward the top holes. The distance between the bottom holes and top holes was varied in order to minimise the boundary effect. This technique of grouting was adopted because it has been found that the grout flow is very much affected by the type of sealing achieved between the pile and the base and between the pile and the piston.

For technical reasons, few tests were undertaken with the shoe off. In these tests, the grout flowed freely from the grouting holes to the base. Other tests were performed with the shoe in place. With this setup, before return holes were provided, it was frequently found that very high pressures (up to 500 kPa) were required to force some grout into the soil. This was because, with the shoe in place, there was no way for the air displaced by the grout to escape. However, when the return holes were added, a pressure of 50 kPa was enough to pump the grout, and in some cases a grout coverage of about 70 % of the pile area was achieved (Table 1). Therefore this technique allows us to obtain a larger grout coverage. But the aim of this study is to relate the shaft capacity of a grouted driven pile to the grout pressure. This is achieved by pumping the grout until it flows out the return tubes, then these tubes are closed and the grout pressure is increased. This allows the pressure to be monitored, and hence to obtain a relationship between shaft capacity and grouting pressure. These type of tests are currently being undertaken, and the results are not presented here.

5 TESTING PROCEDURE

Two types of tests were performed: Pull-Out tests (labelled PO) and Sleeve tests (labelled SL).

The Pull-Out tests were undertaken by first installing the pile at a depth of 250 mm to 300 mm into the sample. The installation of the pile is performed by first driving the coring tube into the sample at the desired depth, then pulling it out with the plug. The top pressure on the sample is released before the coring tube is pulled out. The pile is then placed carefully into the hole left by the coring tube, and the pressure is applied again on top of the sample. This method can be only applied for cemented samples. For the uncemented samples, the pile with the grouting tubes and connections is driven into the sample. After the pile is installed, the grout is pumped into the pile-soil interface and allowed to cure for 48 hours. The pile is then pulled monotonically at a constant rate of 0.01mm/s.

The Sleeve tests were undertaken by driving the coring tube into the sample, then the pile is connected to the top of the coring tube and both of them driven into the soil. After the pile reaches its final position, the coring tube is detached from the pile outside the shoe. Then the shoe is disconnected from the base,

cleaned and greased along with the pile tip. As for the previous case, the grout is pumped out and left to cure for 48 hours. The pile is then pushed monotonically, with a constant rate of 0.1 mm/s.

For both type of tests, the piles were installed using the combination of a ramp displacement function (constant velocity of 0.125mm/s) and a superimposed cycling displacement (amplitude of ± 2 mm at a frequency of 0.0775 cycles per second). This was to simulate the cyclic nature of installation by driving, with repeated reversal of the direction of shear stress between pile and soil. Both types of test were performed with an overburden pressure of 100 kPa maintained on top of the sample during driving, grouting and loading of the pile. The tests were performed on uncemented and cemented (2 %, 4 % and 6 %) samples.

Table 1 Summary of the tests performed.

Test Name	Test Type	Cement Content %	Grout Coverage %	Grout Pressure kPa
PO2	Pull-Out	2	70	50
PO4	Pull-Out	4	64	150
PO6	Pull-Out	6	46	500
SLU	Sleeve	0	62	500
SL2	Sleeve	2	55	500
SL4	Sleeve	4	39	500
SL6	Sleeve	6	72	500

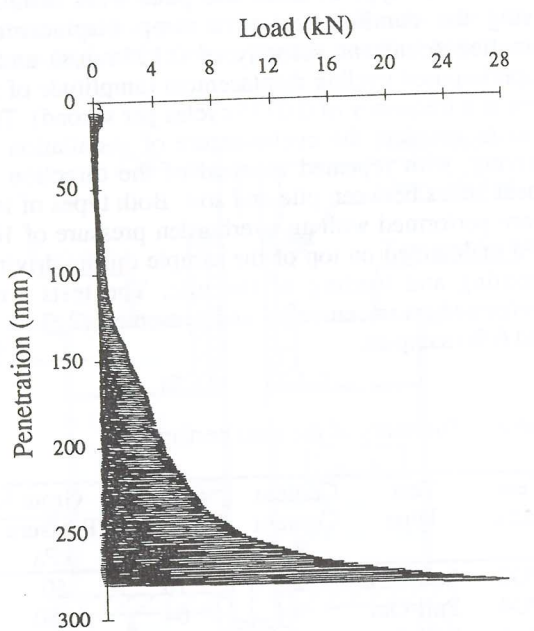
6 EXPERIMENTAL RESULTS

Figure 3 shows the curve load versus penetration obtained during installation of the pile in an uncemented sample (a) and in a sample with 6% cement content (b).

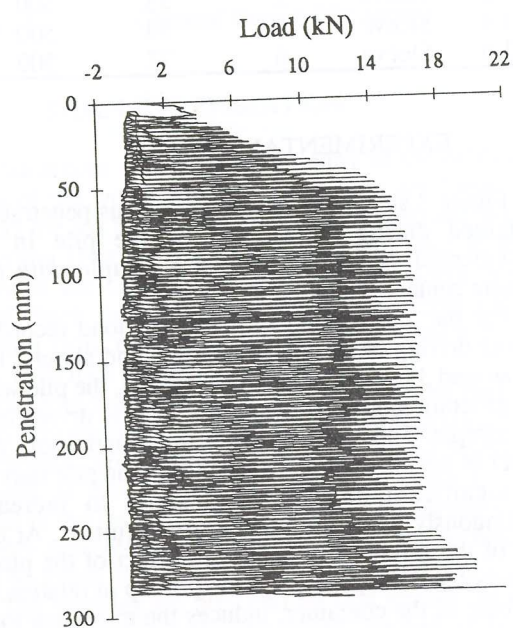
For the uncemented samples, the load recorded during driving of the pile is constant and about 1 kN for around 3 pile diameters. For this test, the pile with the grouting tubes and the return tubes is driven into the sample. Therefore, at about this penetration, the effect of the plug and the tubes inside the pile start to be significant and the load starts to increase continuously while the pile is driven further. At the end of the driving, the combined effect of the plug, the tubes and the position of the pile tip in relation to the base of the container, induces the excessive load which is recorded (about 28 kN).

For all the cemented samples the load-penetration responses of the pile during driving were similar in shape to the curve obtained for the Sample with 6 % cement content and shown in Figure 3 (b), but with lower values for lower degrees of cementation. The load increases rapidly and reaches a constant value of about 16 kN (with 6% cement content), which is constant until the base effect starts to become significant. During the unloading phase of each cycle of loading-unloading, the load becomes negative due to the tension exerted on the pile by the plug and the external friction. It has to be noted that, for the case

of cemented samples, the coring tube is used for the driving phase. Therefore, there is no effect of the grouting tubes and only the base effect can be noted at the end of the driving phase.



(a) Uncemented Sample.



(b) Sample with 6 % cement content.

Figure 3 Load versus penetration during driving.

Plots of cone resistance versus penetration for the uncemented samples and the samples with 2 %, 4 % and 6 % cement content are presented in Figure 4. Cone resistance values of 1.1 MPa for uncemented samples, 3.5 MPa, 7 MPa to 8 MPa and 20 MPa for the samples with 2 %, 4 % and 6 % cement content respectively were obtained. The shapes of the cone

penetrometer tests can be compared with the load-penetration curves obtained during driving.

After each test, the sample was carefully dismantled, and the pile was inspected. The grout coverage was then measured using an overhead transparency wrapped around the pile and the area grouted was drawn on the overhead. Then a planimeter was used to determine the grouted area. Table 1 shows the grout coverage obtained for the tests presented in this paper

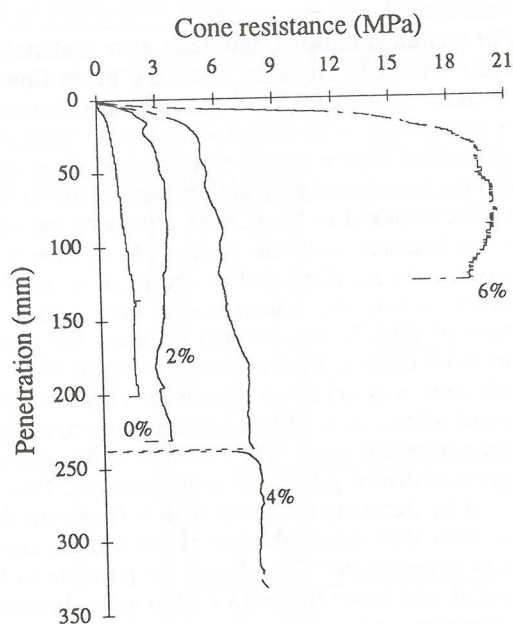


Figure 4 Cone Penetrometer Tests.

Figure 5 shows the curves of shaft capacity versus displacement for the pile divided by the pile diameter for the Pull-Out tests performed on 2% (PO2), 4% (PO4) and 6% (PO6) cement content samples. The curve from test PO2 shows a maximum shaft capacity of about 175 kPa, followed by a small decrease in stress. However the friction then increases after the peak stress is reached, due to the grouted area of the pile reaching the piston on top of the sample. After a stress of about 190 kPa, the stress decreases again as the result of the breaking down of the grouted area. No residual stress was recorded for this test. Test PO4 shows the same trend as PO2, with a peak stress of about 200 kPa. However, the subsequent increase of the stress after the peak is due to the same reasons as for the 2% cement content sample. Test PO6 shows a peak stress of about 360 kPa followed by a softening behaviour. An average residual stress of 210 kPa can be observed. These values are comparable to those obtained by Nauroy et al. (1988).

The grout coverages in term of percentage of area grouted divided by the total area of the embedded pile are 46 %, 64 % and 70 % for PO6, PO4 and PO2, respectively (Table 1).

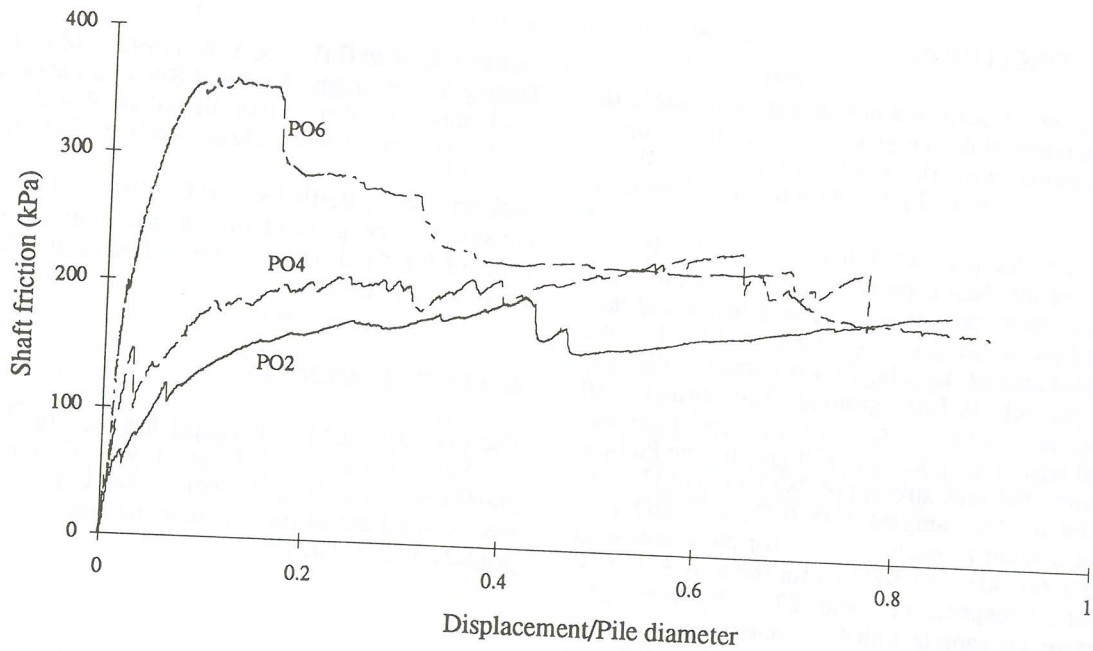


Figure 5 Shaft Capacity: Pull-Out tests.

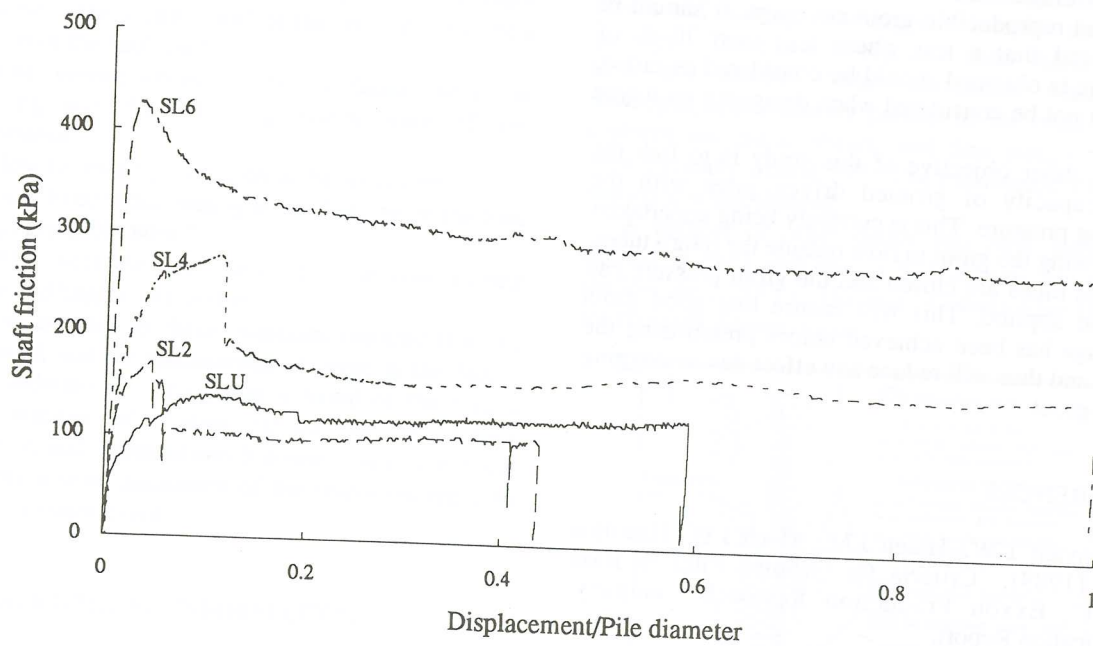


Figure 6 Shaft Capacity: Sleeve tests.

Figure 6 shows the curves of shaft capacity versus displacement of the pile normalised by the pile diameter, for uncemented (SLU) and cemented samples (SL2, SL4 and SL6). These curves were obtained from sleeve type tests. The maximum stress increases with degree of cementation, and all the curves show a peak stress followed by a residual stress. The curve from Test SL4 shows an increase in friction after the peak stress was reached, which is due to the interaction between the grout and the base of the apparatus. However, after an increment of

about 50 kPa, a sudden drop of the friction occurred, allowing the stress to reach its residual value.

Peak stresses of 420 kPa, 260 kPa and 165 kPa are recorded for samples with cement contents of 6 %, 4 % and 2 %, respectively and a peak stress of 135 kPa was obtained for the uncemented sample. The residual stresses are 280 kPa, 160 kPa and 125 kPa for the tests PO6, PO4 and PO2, respectively, and 100 kPa for the uncemented sample. The grout coverage obtained are 72 %, 39 %, 55 % and 62 % for SL6, SL4, SL2 and SLU, respectively (Table 1).

The paper describes a new apparatus capable of testing models of driven grouted piles. The set up of the apparatus, with the system of sleeves, allows testing of fully grouted piles, with minimal boundary effect.

The results presented here show clearly the increase of the shaft capacity with the strength of the material. The capacities of the piles tested are obtained by dividing the measured load by the total embedded area of the pile. This is correct in the case where the pile is fully grouted. The correct shaft capacity should however, take into account the real grouted area of the pile. This will give for the Pull-out tests corrected peak stresses of 783 kPa, 312 kPa and 250 kPa for the samples with 6 %, 4 % and 2 % cement content respectively, and for the sleeve tests 583 kPa, 667 kPa and 300 kPa for the tests SL6, SL4 and SL2, respectively and 217 kPa for SLU. Therefore, the sample with 4 % cement content with a grout coverage of 39 % gives higher shaft capacity than the sample with 6 % cement content with 65 % grout coverage. This shows the importance to have a good and reproducible grout coverage. It should be considered that a test where less than 70 % of coverage is obtained should be considered as failed, and can not be considered when designing such type of piles.

The other objective of this study is to link the shaft capacity of grouted driven piles with the grouting pressure. This is currently being undertaken, by allowing the grout to flow outside the return tubes, then the tubes are closed and the grout pressure can then be applied. This will ensure that good grout coverage has been achieved before pressurising the grout, and thus will reduce any effect due to clogging of the grout.

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