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Recent use of the internally-jacked pile test in South Africa

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ABSTRACT: The use of the internally-jacked load test of foundation piles is described. Two recent examples in South Africa are given, one done by an overseas contractor and one done by a South African contractor.

1 INTRODUCTION

In an internally-jacked pile test, load on the pile is obtained by incorporating into the shaft of the pile a (disposable) hydraulic jack, as shown in Figure 1. When activated, the jack pushes up and down with equal force, loading the shaft length above it and the shaft length plus base below it. Separate measurements of movement of the lengths above and below the jack are made and their behaviours are added to give the equivalent head load vs. head displacement graph.

The main advantage of internal jacking is that an external reaction (from kentledge or anchors) is not needed, and sufficient testing force can be generated for any size of pile. This makes internally-jacked tests cheaper than head load tests in many cases, particularly for piles bigger than approximately 600 mm, and sites where only a small number of tests will be done. A further advantage is that most of the preparation for the test is done offsite, so that the time taken on the site construction programme is less than needed for a conventional externally jacked test.

The disadvantage of the internally-jacked test is that after one of the shaft lengths reaches its maximum capacity, no greater force can be generated to see the maximum capacity of the other length. This means that the choice of the position of the jack in the length of the shaft must be done carefully, taking into account the strengths of the strata along the shaft and under the base, so that the maximum resistances of the pile lengths above and below the jack are as equal as possible.

The internally-jacked pile test was first done by Professor Osterberg at north-Western university and a jack device was patented by him in the USA in 1986, (Osterberg, 1998). Another patent for an improved device was granted in the USA in 1996. The patents have also been lodged in other countries, but not South Africa. Internally-jacked tests have been vigorously promoted by osterberg and his associates, so that the name given to his internal jack, "osterberg cell" has become, to many people, synonymous with the test technique.

Compared to many other countries, few internally—jacked tests have been done in South Africa. The earliest was at the university of the Witwatersrand in 1986, by undergraduate students supervised by the present author, and sponsored by the Franki Pile company. Unfortunately few readings were obtained in the loading of the pile and so the results were not published. Since then, to the author's knowledge, only 12 more internally-jacked tests have been done: nine commercially and three as research/development exercises.

2 INTERNALLY-JACKED PILE TESTS AT MOUNT EDGECOMBE INTERCHANGE, DURBAN

In 2013 a UK company, which is licensed in the uK to use the name osterberg cell, was the nominated sub-contractor for internally-jacked tests on three bored piles of 900 mm diameter and approximately 30m length at the Mt. Edgecombe interchange. The soil strata were coarse and fine soils of great depth, and the toe of the pile did not reach rock. Most of the lengths of the piles were below the water table so the piles were constructed using the screwed-in cased auger pile technique.

The position of the jack in each pile was approximately 2/3 of the length of the pile from the top, and in all cases the length below the jack reached its maximum capacity first. This meant that the maximum capacity of the upper 2/3 of the shaft was not seen and its force vs. displacement behaviour only seen up to approximately 3 mm. To get the equivalent head load vs. head displacement graph up to a desired mount of displacement, it was therefore necessary to extrapolate the force vs. displacement behaviour of the upper 2/3 of the shaft from approximately 3 mm to 20 mm.

3 INTERNALLY-JACKED PILE TEST AT KING SHAKA AIRPORT, DURBAN

3.1 *General description*

For a deep basement excavation at King Shaka Airport, 900 mm diameter piles were constructed round its perimeter by the continuous flight auger method. Soil strata were mostly coarse sand with some silt, both transported (including fill) and residual, underlain by sandstone of the Karoo geological group. All piles were socketed into material of rock consistency.

The pile tested was a dedicated test pile, shown in Figure 1. The "strain rods" mentioned on the figure are 1m lengths of y12 with electrical resistance strain gauges on them. The reinforcement cage was chosen to be just sufficient for the jack and the strain rods to be attached to it and lowered into the augered hole. Because the cage and jack can be accurately centralised in the hole, very little bending of the pile occurs during an internally-jacked pile test, and the (heavier) working pile reinforcement makes a negligible contribution to the axially loaded behaviour so is unnecessary in a dedicated internally-jacked test. Figure 2 shows

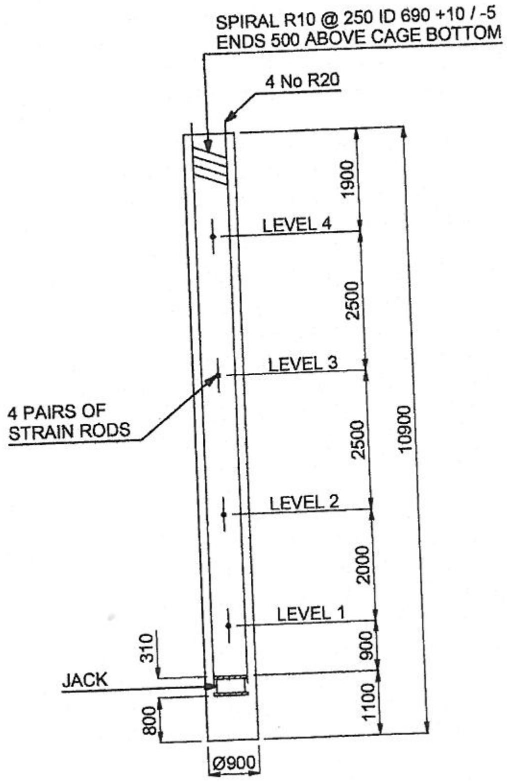

Figure 1. Section through test pile at King Shaka Airport.

Figure 2. Jack ready to be lowered into the pile hole.

the jack attached to the longitudinal reinforcement just prior to its installation in the hole.

Values of force provided by an internal jack during the test are obtained from measurement of the hydraulic pressure applied, multiplied by its internal area. This is checked by calibration before the jack is brought to site. Displacements in this test were measured using tell-tale rods from the bottom and top of the jack, through tubes, to the top of the pile.

Displacement of the top of the pile was also easured.

3.2 *Test procedure*

This was specified by the supervising geotechnical engineer as the "Quick load test method" of AStM d1143 "Standard test Methods for deep Foundations under Static Axial compressive Load". The Quick method description (clause 8.2.2) can be abbreviated as follows.

> Apply the test load in increments of 5% of the anticipated failure load. uring each load interval, keep the load constant for not less than 4 minutes and not more than 15 minutes.
>
> Remove the load in five to ten equal decrements, keeping it constant as for load increasing.

This test method allows the test to be completed in a few hours, compared to the present South African standard (SAnS 1200 Part F 1983) which requires many days, even in freely draining soils.

Figure 3 shows the graph of jack force vs. time that actually occurred in this test. Planned increments were 250 kN, but the first one was accidentally 400 kn. When applying the increment to 3500 kn, the electric pump was initially unable to hold the required pressure, which fell, but then rose to 4200 kn. This was because a leak had developed somewhere below ground, the pump's reservoir

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nearly emptied and the supply of fluid to the pump had become intermittent. While the load was being held at 4200 kn, large movements were seen at the top of the pile and on the tell-tale from the top of the jack, indicating that the maximum capacity of the length of the pile above the jack had been reached.

Because of the leak and the irregular behaviour of the pump caused by it intermittently sucking air, the unloading of the pile was not as smooth as was specified, as can be seen in Figure 3.

3.3 *Test results*

Figure 4 shows the force applied by the jack plotted against: (i) displacement of the top of the pile; (ii) displacement of the top of the jack; (iii) displacement of the bottom of the jack. no serious irregularities in the graphs were caused by the less than optimum load vs. time record.

3.4 *Interpretation of measurements into the equivalent head load vs. head displacement behaviour*

When a pile is loaded at its top, and if the elastic compression of the pile is ignored, the top and bottom of the pile will displace by the same amount. Hence

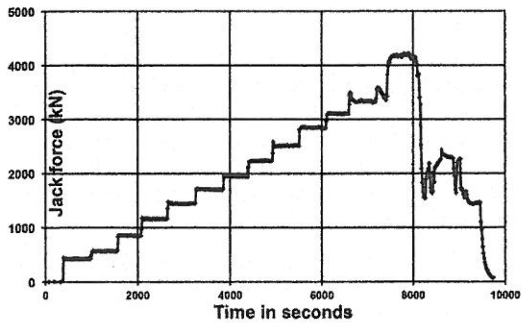

Figure 3. Jack force vs. time.

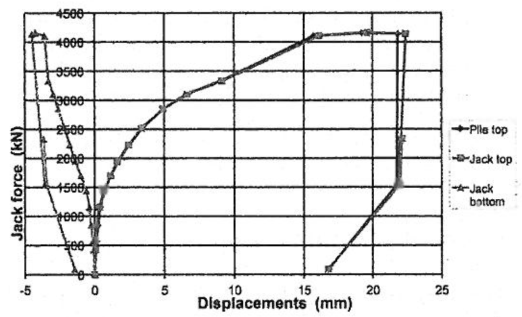

Figure 4. Jack force vs. displacements at three places.

the basic procedure (ignoring pile compression) for interpreting the internally jacked test is:

i. choose intervals of displacement of the part of the pile that displaced the lesser;
ii. for each displacement value, see from Figure 4 what forces on the pile parts above and below the jack produced the same displacement value;
iii. add the forces together to get a point on the head load vs. head displacement graph.

This has been done and is shown on Figure 5. the maximum force seen on this graph is 6900 kn, which is less than the maximum total applied force in the test of $2 \times 4160 = 8320$ kn seen on Figure 3. This is because the maximum displacement of the lower part of the pile is 4.5 mm, and at this displacement the upper part of the pile has reached a force of only 2740 kn.

To synthesise a longer head force vs. head displacement graph, the force displacement behaviour of the lower part of the pile (in this test) must be extrapolated to a displacement closer to that for which the behaviour of the upper part of the pile is known. However, because the toe of the pile is socketed into rock, this is difficult to do. In this case, because 6900 kn was a satisfactory test value for this pile, such an extrapolation was not done. For a "floating" pile, founded above rock, such as those at Mt edgecombe, the extrapolation can be easily done, because the side shear stress does not change much in the vicinity of the jack.

Note that a further refinement of the procedure to synthesise the head load vs. head displacement graph is to include the effect of elastic shortening of the pile shaft. The effect of this shortening can be seen on Figure 4, where the measured displacements at the top of the jack are slightly greater than those at the top of the pile. However the differences are small and so this refinement was not done.

3.5 *Interpretation of the strain rod measurements*

The mean of the two measured strains at each strain rod level is plotted along the length of the pile,

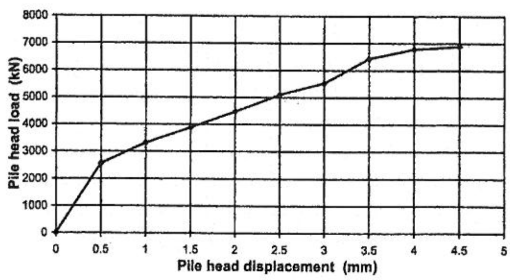

Figure 5. Equivalent head load vs. head displacement.

for chosen intervals of the jack load increments, as shown in Figure 6. the strains that occurred at the level of the bottom of the jack (where the jack opened) are extrapolated from the strains at rod level 1 using the same slope as from level 1 to level 2. This is shown on Figure 6 by dotted lines. In fact the ground will probably be stiffer from level 1 to the jack, meaning that the extrapolation lines ought to be flatter, but it is difficult to estimate this increase in stiffness.

Figure 7 shows the jack force plotted against the extrapolated strains. The slope of this graph is the conversion factor from strain to force in the shaft.

The shear stress values in Figure 8 are the means over the lengths between strain rod levels. They are obtained from the difference in the forces in the pile at sequential strain rod levels, divided by the shaft area between those levels.

In Figure 9, graphs of shaft shear stress vs. shaft displacement are plotted using the mean of the measured values of displacement of the top of the jack and the top of the pile. As already mentioned, there is a negligible difference between these two.

The strain rod positions are usually chosen to be at the boundaries between the distinguishable soil strata. then Figure 9 would give the shear stress v. displacement for each of the strata. However in the

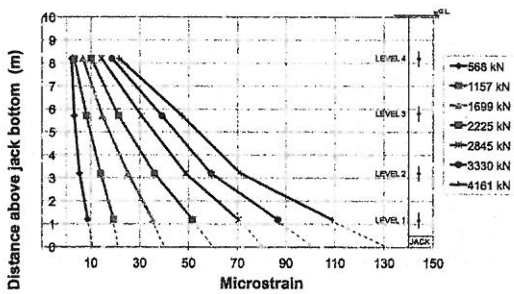

Figure 6. Mean strains at strain rod levels for 7 stages of loading.

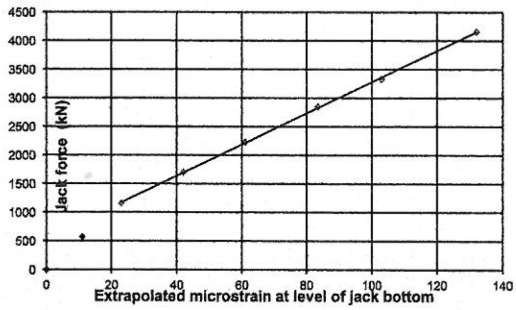

Figure 7. Jack force vs. extrapolated strain at level of jack bottom.

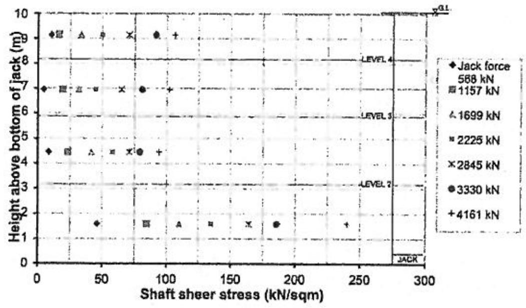

Figure 8. Mean shaft shear stresses for 7 stages of loading.

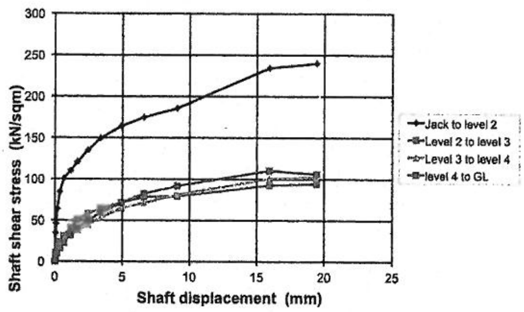

Figure 9. Shaft shear stress vs. shaft displacement.

present case, the depth to rock was found to be 30% less than expected, causing the pile cage to protrude a long way above ground and consequently the strain Rod positions did not correspond to strata boundaries as well as could be wished.

The advantages from strain rod measurements are as follow.

i. The distribution of shear stress along the pile can be seen and compared to what the pile designer predicted.
ii. The proportions of load carried in end bearing and shaft side shear can be seen.
iii. The graphs of shaft shear stress vs. shaft displacement and end bearing stress vs. displacement can be used with the load transfer method of modelling pile mechanics (Everett, 1991) to optimise the pile design.

Items (i) and (ii) may be reassuring or alert the designer to a need for a change in design.

4 CONCLUSIONS

The comparative economy of the tests can be seen from the fact that the cost to the piling contractor of using the UK testing contractor at Mt edgecombe was more than r600 000 per test, and the cost for the King Shaka test was r78 000. The latter could have been less, but the piling contractor Wepex generously paid what had already been allowed for a conventional test, to help finance further research into other methods of pile testing.

Although no changes to the pile design were done at King Shaka Airport as a result of this particular test, the potential for improvements in pile design has been shown. this potential can be realised providing: i. strain rods are incorporated; (ii) the pile test is done early in the project programme.

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