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Internally-jacked pile tests as part of site investigation in problem soils

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ABSTRACT: The mechanics of the internally jacked load test of foundation piles are described, including the parameters measured and the interpretation of the results. The application of the test to three types of problem soil is described: expansive soil; collapsible soil; and soils in dolomitic areas. Particular benefits to pile design in these three soil types are described. Examples of internally jacked pile tests in an expansive soil and a soil in a dolomitic area are described. Conclusions are drawn of the benefits to be derived from early execution of an internally jacked pile test on a site where piled foundations will be used.

KEYWORDS: Pile load test, internal jack loading, site investigation, pile design.

1 INTRODUCTION

Because of low groundwater tables in most of Southern Africa, a common method of site investigation is to use a machine capable of boring 750mm diameter holes, into which a suitably qualified and experienced person descends to record the soil profile. When seeing the profile, if piled foundations are likely to be needed it will be clear to such a person. (It might have been already suspected from preliminary knowledge of the required loads on the foundations.) The information obtained in the site investigation may be sufficient to enable an efficient design of a piled foundation, but the efficiency and reliability of the design will be improved by further information obtained from pile tests.

The time and cost of mobilizing a boring machine and the rest of the equipment and personnel for a conventional pile test are great, and have tended to prevent such pre-design tests from being done. However by using the internally jacked pile test technique, a test pile can be installed while the boring machine is on site for the site investigation, thereby greatly reducing the test pile's cost.

This paper describes how the internally jacked pile test technique can be used to obtain valuable information in problem soils.

2 MECHANICS OF THE INTERNALLY JACKED PILE TEST

A disposable hydraulic jack is cast into the shaft of the pile so that when activated it pushes up and down with equal force. The jack is positioned in the shaft so that the maximum resistance of the pile shaft above the jack is equal to the resistance of the shaft plus the pile base below the jack. (See figure 4.)

The main objective of the test is to determine the load versus displacement characteristics at the pile head. Displacements of the top of the pile at ground surface are measured and also the up and down movements at the jack. The jack movements can be measured by tell-tale rods to its top and bottom. Alternatively a disposable device can be incorporated into the jack to measure the total (up plus down) movement, then from knowledge of the pile top's displacement the separation of the total jack expansion into up and down displacements can be done.

Jong-Sub Lee and Yung-Ho Park (2007) have proposed a method to refine the accuracy of the displacement measurements to take account of elastic compression of the pile shaft, using estimated values of the Young's moduli of the concrete and steel. However it is the opinion of this author that for length (L) to diameter (D) ratios up to 30, such refinement is unnecessary because the compression of the shaft is small compared to its displacement. For larger L/D ratios it is further suggested that instead of estimating moduli to calculate strains, actual strain measurements should be made at intervals along the full length of the shaft. Using measured strains and measurements of the pile top and jack movements, the movements of any part of the pile can be accurately determined.

A further advantage of measuring strains is that loads in the pile shaft can be determined from them. From the differences between shaft load values, the side shear stresses between pile and soil can be determined for different strata in the soil, and also the end-bearing component of the pile's resistance. This knowledge enables the head load v. head displacement graph to be estimated for a variety of choices of pile length and diameter with consequent improvement in economy of design.

Without the strain measurement and for L/D less than 30, the pile shaft can be treated sufficiently accurately as a rigid body, and the head load v. head displacement relationship can be obtained from the internally jacked pile test by simply adding the load v. displacement behaviours of the lengths of the pile above and below the jack.

The internally jacked pile test is sometimes called the Osterberg Cell Test because in 1988 (Osterberg 1998) a particular type of patented disposable jack was used by Prof Jorj Osterberg of Colorado, USA for the first time, and has been used many times since. However the technique was well known before then. For example it was used in a 600mm diameter pile test in the Ventersdorp lava at Wits by two undergraduates for their final year investigation project in 1986.

3 EXPANSIVE SOILS

A common founding method for structures in a heaving clay area is to support the structure on piles that pass through the potentially heaving strata and are founded in non-expanding strata. The structure is usually supported by beams or slabs that keep it isolated from movements at the ground surface. If the potentially heaving strata expand, upward drag on the pile shaft may exceed the combined weight of the structure and the resistance to uplift of the non-expanding strata. Techniques are available to reduce the upward drag on the shaft but they can be difficult to implement and are of unknown reliability. A common design solution is to estimate the maximum upward dragging shear stress that the expansive soil can develop on the pile shaft, and ensure that the anchorage length in the stable strata is sufficient to hold the pile still. (Blight 1984.)
The internally jacked pile test enables both the maximum shear stress on the shaft in the heaving strata, and the anchorage resistance in the stable strata, to be measured in a single test.
For the simplest form of interpretation of the test measurements, the jack would be positioned at the boundary between potentially heaving and stable strata. Then the upward force-movement behaviour will show the potential heaving pull, and the downward force-movement behaviour will show whether the anchorage is adequate to resist the pull. In this case the end-bearing resistance of the lower length must be nullified by incorporating a soft pad at the bottom of the pile.

However the jack should be positioned so as to show as much as possible of the force v. movement relationships of both upper and lower lengths of the pile. This may cause the jack's position to be away from the boundary between moving and stable strata. In this case the incorporation of strain measurement at sufficiently close points along the length of the pile shaft will give the distribution of shear stress along the shaft and enable the shear stress v. pile displacement behaviour of the heaving and anchoring zones to be distinguished.

4 COLLAPSIBLE SOILS

These most commonly occur near the ground surface, and to avoid relying on them, structural loads are often carried through the collapsible strata into more stable ground by piles. However for any soil the stiffness of shaft shear resistance is much higher than the stiffness of end bearing. I.e. for the same amount of pile downward movement, a much bigger proportion of the shaft shear ultimate stress is developed than the proportion of the end bearing ultimate stress. Consequently unless the toe of the pile rests on rock, at working load on the pile the vast majority of the load is carried by side shear.

A collapsible soil stratum is (by definition) stiff when dry and soft when wet, therefore in piles taken through such a stratum a significant proportion of their total resistance may be derived from it when the structural working-level loads come onto the piles. If local wetting causes some of the piles to lose the side-shear resistance in the collapsible stratum, the pile will redistribute the load by developing higher side shear stress lower down and in end bearing – but it can only do that by moving down. A structure's designer will want to know what this downward movement could be.

An internally jacked pile test with strain measurements along the shaft can give the shaft shear stress v. pile displacement relationship for all strata, and the end bearing v. pile displacement relationship for the stratum on which the pile is founded. The load transfer method of modeling the head load v. head displacement (Coyle and Reese 1966) can then be employed, using these relationships, to predict the settlement of the piles with the collapsible stratum in its dry (as tested) state. If an amended shaft shear stress v. pile displacement relationship is then estimated for the collapsible stratum (e.g. zero shear stress) and substituted into the analysis, a greater pile settlement under the structural load will be predicted.

5 SOILS IN DOLOMITIC AREAS

When the profile of the rock consists of steep-sided pinnacles, piles cannot be reliably founded on them, and the end bearing component of the pile's resistance may have to be ignored. Even if the rock profile is relatively flat the rock level may be very deep, and adequate founding resistance could be obtained from founding piles in the soil strata. (So-called "floating" piles).

As mentioned in the introduction, information determined in the site investigation can be sufficient to do an adequate pile design in terms of reliability and economy. However the addition of an internally jacked pile test to the site investigation could well be useful to confirm the accuracy of the design method(s) used, and if strain measurements for shaft shear stress and end-bearing determination are made, the load transfer method can be used to evaluate different pile diameters and lengths for economic optimisation of the pile design.

6 EXAMPLES

6.1 *Foundations for a rail over road bridge near Ogies*

Figure 1 shows a simplified profile at the site. The soil strata are all either transported or residual materials of the Ecca group of the Karoo sediments, and from foundation indicator tests the geotechnical engineer's report stated that most were of "medium to high heave potential". Although the piles to be installed were 800mm diameter and their holes very stable, the client would not allow anyone to go down to clean the bearing surface of the bottom of the piles, so that the end-bearing capacity of the piles was in doubt.

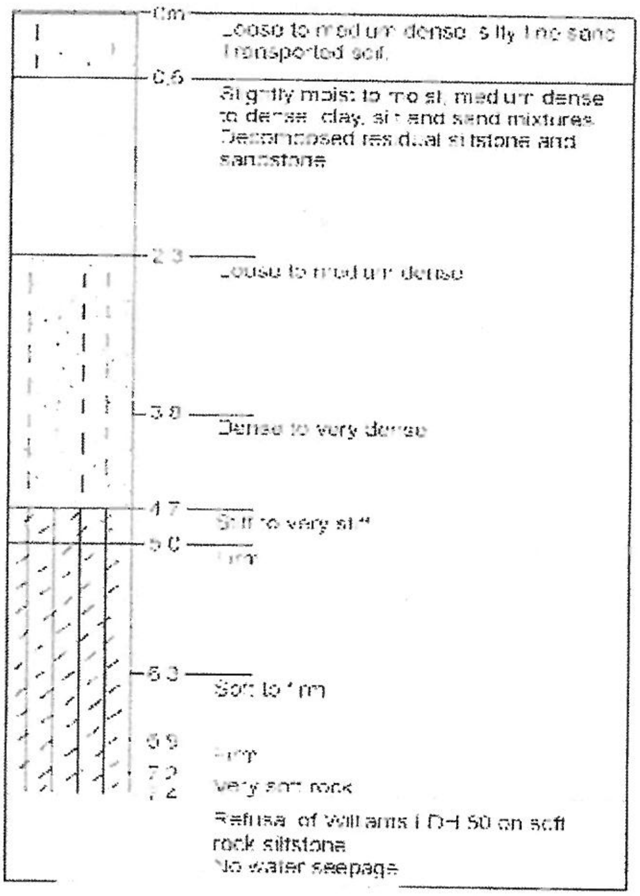

Figure 1. Simplified soil profile at site of rail over road bridge on the Ecca series of the Karoo sediments.

There were, therefore, two reasons for doing a test that would give the shaft capacity of the pile separate from the end-bearing:

1. If loose material were left at the base of a working pile, its capacity could possibly be only side shear on the shaft. (Day, 2006)
2. The uplift force from heaving strata and the anchorage resistance per metre length of shaft in the stable strata needed to be known.

From consideration of the probable strength of the strata, the position of the jack was chosen to be at 7,4m below the ground level shown on figure 1, with a further 2m drilled into the (probably non heaving) siltstone with a tungsten tipped coring tool.

Before putting any concrete into the hole, a soft foam pad was lowered to the bottom of the hole to eliminate any end bearing resistance. Concrete was then poured to the level of 7,5m below ground level, and the jack lowered down onto it. The rest of the pile was then filled up with concrete. No reinforcing was needed for this test.

After the concrete had cured, the jack was loaded and measurements made of top-of-pile displacement and total displacement (up plus down) of the jack. The test was carried out in three stages: 1. loaded to 100% of working load; 2. loaded to 150% of working load, (following SANS1200F); 3. loaded to the capacity of the jack. Working load on the piles was 1800kN, therefore because the jack is loading both lengths of shaft above and below it, the jack load for "working load" was 900kN.
For present purposes, only the results from the third stage of the test are shown, in figure 2. It can be seen that the lower (2m) length of the pile was weaker than the upper length, with the result that a maximum movement of 2mm of the upper length was seen. However the following can be determined from figure 2:

1. The maximum load carried by the 2m lower length, and hence its anchorage capacity, was 690 kN/m^2 in side shear.
2. The maximum average shear stress over the upper length was not mobilised. In figure 2 the load is still rising at the maximum load of 3450 kN applied, which was the jack's capacity. However not all the strata through which the upper shaft length passed were, in fact, expected to heave, so that strain measurements in the shaft to show the shear stress v. movement relationships for the different strata could have been valuable.
3. The total downward load capacity of the pile shaft was shown to be at least [illegible] kN (2 x 3450kN) without any contribution from the toe of the pile.

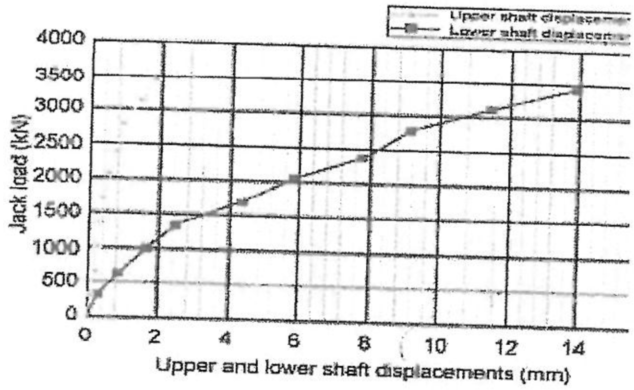

Figure 2. Rail over road bridge, graph of jack load against displacement of the lengths of pile shaft above and below the jack.

6.2 *Building foundation piles in the Centurion dolomitic area*

Figure 3 shows the profile logged from percussion drilling. The piles were designed to be 400mm diameter and founded within the soil strata, so that the contribution of end bearing to the piles' working load capacity would be very small. A test pile was required to check the load capacity of the piles as designed, and strain gauging was also done along the length of the pile to get profiles of side shear stress distribution.

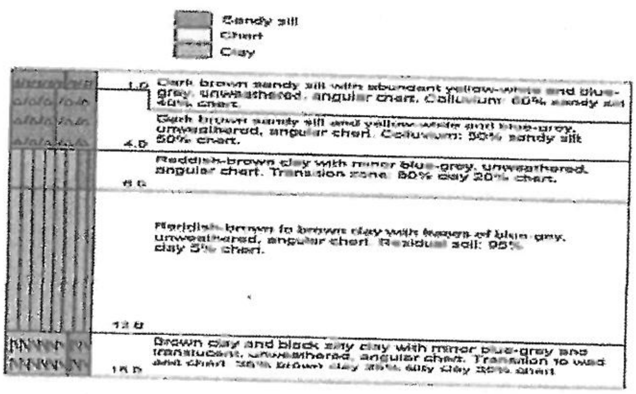

Figure 3. Soil profile from investigative percussion drilling for building foundations in a dolomitic area.

Figure 4 shows the arrangement of the jack and the strain gauge positions within the 12m total length of the pile. Figure 5 shows the graph of jack load v. movement of the lengths of the shaft above and below the jack. The position of the jack, to equalize the ultimate resistance from the lengths above and below it, could have been better chosen. In this case the increase in shear resistance with depth from the increasing chert content was offset by the greater decrease in shear resistance with depth as the clayey matrix became wetter.

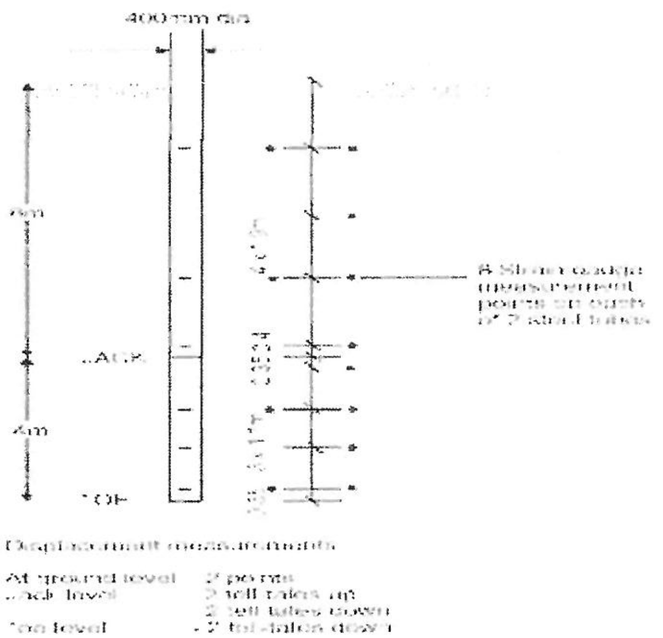

Figure 4. Internally jacked pile test in a dolomite area, positions of jack and strain gauges.

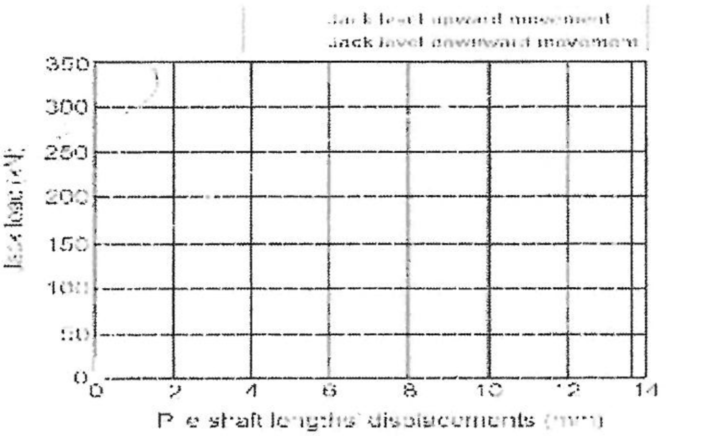

Figure 5. Internally jacked pile test in a dolomite area, graph of jack load against displacement of the lengths of pile shaft above and below the jack.

Forces in the pile shaft were derived from the strain measurements. The mean shear stresses for four lengths of the shaft above, and four below, the jack were then derived from the forces. From the displacement measurements at the jack and ground surface, and the measured strains, the displacements of each of these eight lengths of shaft as they developed stress was calculated, enabling graphs of shear stress v. shaft displacement for each of the eight lengths to be drawn. These are shown in figure 6. Using these relationships with the load transfer method gave the head load v. head displacement graph, figure 7.

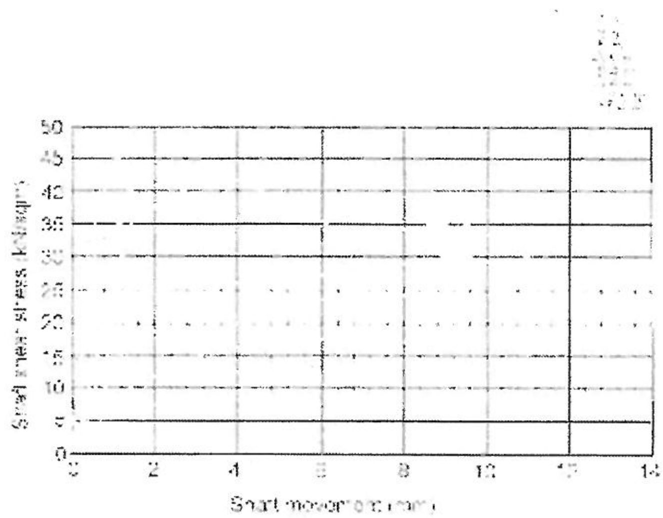

Figure 6. Internally jacked pile test in a dolomite area, graph of shaft side shear stress against shaft displacement for eight separate lengths of the shaft.

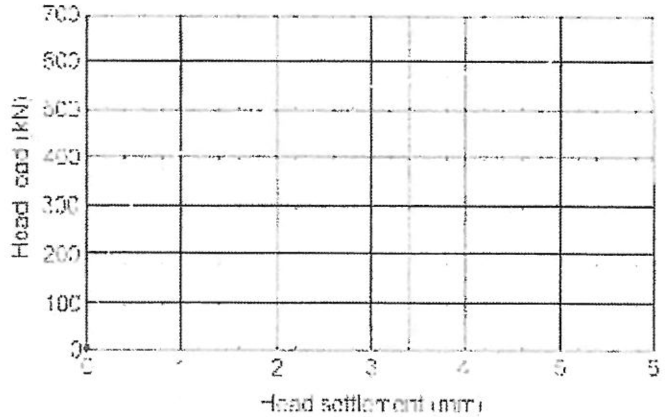

Figure 7. Internally jacked pile test in a dolomite area, simulated head load against head displacement graph.

The performance of the test pile was judged to be satisfactory by the responsible engineers, but it was only done late in the construction programme so there was no opportunity left for economic optimisation of the production piles' length. If the test had been done at site investigation stage in the highly variable soils on dolomite, greater benefit would have been derived from it.

7 CONCLUSIONS

1. The internally jacked pile test can be quickly carried out.
2. With load and movement measurements only, it can satisfy the SANS 1200F requirements for the application of 150% of working load to a test pile.
3. With careful choice of the jack position, the head load v. head displacement graph can be determined sufficiently far towards the absolute maximum capacity of the pile for practical purposes.
4. With strain measurements along the shaft, the pattern of load transfer from the pile into the soil can be seen, enabling improvements to the pile design to be made.
5. If pile tests are done early, ideally at site investigation stage, economic benefits are more likely to be realized.

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