

Safe, fast and simple: the DUKTUS pile is load- tested in South Africa

THE DUKTUS DUCTILE CAST IRON PILE SYSTEM

This piling system has been in existence for over 30 years during which time over four million linear metres of ductile cast iron piles have been installed into the ground around the world.

The system comprises 5 m long pre-fabricated pile sections manufactured in the DUKTUS factory in Hall near Innsbruck, Austria. The quality of the prefabricated piles is very high as they are manufactured in a strictly controlled factory environment using advanced technology. This allows a unique specialised jointing system to be formed during manufacture, which, combined with a specialised treatment process applied to the ductile cast iron material itself (DUKTEC), is the key to the success of the system (see Figure 1).

DUKTEC MATERIAL ADVANTAGES

The ductile cast iron pile material is strong and robust, making handling and installation fast and simple and eliminating durability and corrosion concerns.

The unique patented 'Plug and Drive' pile jointing system, in combination with a pile shoe, ensures a watertight core which is easily filled with concrete in a controlled manner to create a high-quality composite pile, with the concrete core surrounded by the high-quality ductile cast iron pile outer shell.

The Eurocodes, now also used in South Africa, recognise these advantages in terms of higher quality control from both the piling methodology and the materials, the combination of which eliminates the risk of pile contamination. The Eurocodes therefore use lower partial factors of safety on the composite pile materials, making the DUKTUS ductile cast iron pile system very efficient in terms of materials. For example, a 170 mm diameter DUKTUS ductile cast iron pile enjoys the same permissible design load capacity as a 520 mm diameter cast-in-situ pile.

As well as being very simple, the unique pile jointing system enables pile installation rates of up to 500 m per day per piling machine. The piling system and methodology require only a standard

Prof SW Jacobsz
Dept Civil Engineering
University of Pretoria
sw.jacobsz@up.ac.za



Dave Rossiter
Chairman
GeoGroup
info@geogroup.co.za



Rob Marsden
Managing Director & CEO
GeoPile Africa
robm@geopileafrika.co.za



Introducing modern technologies into an existing market can be a challenge, but most would agree that the recipe for success must bring together simplicity, technical performance, time savings, high safety and quality standards, and cost savings. Pursuing these goals, piling contractor GeoPile Africa (Pty) Ltd has sourced and introduced into the local market the DUKTUS ductile cast iron pile system under an exclusive licence agreement

30 tonne hydraulic excavator and hydraulic breaker for installation, with a typical piling crew consisting of only four people on site.

Due to the unique DUKTUS 'Plug and Drive' piling system, pile head trimming works are included in the piling scope of works, which brings further time and

cost savings to the activities of the general contractor whose work follows the piling contractor. All of this contributes to deliver a project ahead of schedule and within budget.

In summary – less pile materials, combined with less site resources for installation, with significantly faster piling production rates, plus no pile trimming for the main contractor, plus no spoil or wastage from piling activities all combine into time and cost savings for the client. Smaller diameter piles require smaller pile caps to be constructed by the general contractor, which offers the client further time and cost savings.

A high ground water table and unstable soils constitute problems for most piling systems and result in reduced productivity, requiring more resources such as bentonite and/or the use of temporary casings, all of which increase costs. The DUKTUS piling system is unaffected by these challenges. Regardless of whether the soils are saturated and unstable, this piling system requires no additional resources. High productivity can therefore be maintained. Costs are unaffected and high safety and quality standards remain assured.

PROVING THE PERFORMANCE OF THE PILES

Ductile cast iron piles have already been introduced and used in Africa, the closest location being in Angola. However, because ductile cast iron piles have not yet been introduced into South Africa, it was decided that the technical performance of the piles should first be proved using static load testing. This was achieved with the assistance of the University of Pretoria.

SOILS INVESTIGATION

Initially, three dynamic penetrometer (DPSH) tests were performed and a rotary core borehole was sunk at the university's experimental farm in Lynnwood, Pretoria. Interestingly, the three penetrometers reached refusal at about 16 m depth, giving initial indications that this was the rock head depth. However, this was misleading, because the subsequent borehole proved bedrock to be at 34.5 m depth, with firm to stiff clay overlying the bedrock.

The soil profile comprised a firm, silty clay from reworked residual shale to a depth of 15 m. This was followed by sandy



Figure 1 The lengthening of the pile is achieved quickly, safely and securely by means of a tapered frictional socket joint



Figure 2 A DUKTUS pile being installed using a standard excavator fitted with a breaker hammer

clay from reworked residual andesite to 29 m. The consistency of this material varied fairly randomly between firm to stiff, with occasional soft inclusions. Below 29 m the residual andesite became intact and weathering reduced with depth. Intact highly weathered soft rock andesite was encountered at 34.5 m.

The soils investigation revealed the soil profile to be much deeper than anticipated. However, this meant a conservative profile in which to test the piling system, as longer piles would tend to be more prone to problems like lateral deflection and buckling under load than shorter piles. Results from pile tests in such a profile should therefore be conservative.

INSTALLATION OF TEST PILES AND ANCHOR PILES

Two test piles and eight reaction anchor piles were installed. The total installed pile length amounted to 200 linear metres and was accomplished within only one and a half day's work in early November 2011. The time spent installing the DUKTUS ductile cast iron piles in-

cluded four hours for the installation of strain gauges inside hollow test pile TP2. The local excavator operator had never been introduced to this piling method before. The test piles are respectively referred to as TP1 and TP2 in this article. A DUKTUS pile being installed using a standard excavator fitted with a breaker hammer is illustrated in Figure 2.

During installation, it was decided to terminate TP1 into the stiff clay at a pile toe depth of 30 m, some 4.5 m above the rock head level determined from the adjacent borehole. TP2 was driven to 27.5 m depth, terminating about 7 m above the expected rock head level. It is uncertain by how much the depth to bedrock varies on the test site, as only one borehole was drilled.

Both test piles were instrumented with four levels of weldable strain gauges to measure the axial load distribution in the piles during the load tests. The load was applied to a 300 ton load cell located on top of each pile, and was electronically recorded to provide a continuous load record for each test. Pile displacements

were recorded using dial gauges, complemented in the final test by electronic displacement transducers.

Each of the eight anchor piles was driven using a special oversize shoe to 15 m depth into clayey material (residual shale). During driving, the annular space between the pile and soil was filled with 10 MPa mortar in order to improve the shaft capacity of the piles. GEWI bars of 50 mm diameter were placed into the core of the eight anchor piles and these were filled with 10 MPa mortar. The central core of TP1 was also filled with mortar while TP2 was not filled. The pile plan layout is presented schematically in Figure 3.

Two decisions were deliberately taken in order to obtain 'worst case' static load test results. First, the test piles were terminated several metres above the expected rock head. Second, a relatively weak 10 MPa hand-mixed mortar was deliberately selected for all pile filling.

It was decided to perform a static load test based on aiming for a permissible

design load capacity of 1 200 kN on the mortar-filled TP1. In the case of TP2, the central core was left hollow and it was decided to aim to perform a static load test on this test pile to prove a permissible design load capacity of 900 kN.

METHOD OF INSTALLATION OF DUKTUS PILES

DUKTUS piles were supplied in standard 5 m prefabricated lengths. A 30 tonne excavator with hydraulic booms and hammer, capable of reaching the necessary height required to drive each 5 m pile section, was used. The installation methodology is described below:

1. The first pile section was lifted from a horizontal storage position on the ground into a vertical position by the excavator operator using a standard sling.
2. The tapered spigot toe of the first section of the pile was then lowered to fit snugly onto the pile shoe, which had been placed at the pile position as surveyed.

3. The excavator operator then guided the hydraulic hammer and pile adaptor pin into the socket at the top of the pile section.
4. The banksman checked the pile verticality using a spirit level, and the excavator operator then activated the hydraulic hammer (breaker hammer) to drive the pile section into the soil.
5. After the first pile section had been driven to ground level, the excavator operator lifted a second pile section and lowered the tapered spigot toe into the socket at the top of the first pile section.
6. The unique design of the patented DUKTUS 'Plug and Drive' jointing system ensures (i) that a pile section aligns with the preceding pile section, and (ii) that the structural rigid connection joint between the two pile sections is completed after ongoing pile driving, forming a cold weld to fuse together the two pile sections, and (iii) that the joint between the pile sections is as strong as

the individual pile sections themselves.

7. Steps 5 and 6 were repeated until the pile was driven down to reach the chosen founding level where the pile was driven to a predetermined set.
8. The pile was then marked at the final cut-off level and cut off using a simple angle grinder.
9. The off-cut pile section was then used as the starter pile section on the next pile installed (see step 1 above), thereby avoiding any material wastage.

After completion of driving, the inner core of the DUKTUS pile remains dry, due to the DUKTUS design of the watertight pile joint and shoe. This permits physical measurement of the depth of every pile installed, giving added quality assurance and peace of mind to all parties concerned. After final inspection and measurements, the installed piles can easily be filled with concrete. A 170 mm external diameter DUKTUS pile requires only 18 litres of concrete per linear metre. Therefore, 300 m of pile installation per day (for example, 20 piles to 15 m depth) will only require a single ready-mixed concrete truck to be delivered per day towards the end of the day's piling work.

The next day the general contractor has no pile trimming to carry out, and minimal cleaning up is required, enabling immediate commencement of steel fixing and shuttering for pile cap works.

STATIC LOAD TESTS

Compression Test

The jack and reaction beams and load testing equipment were set up on site and the relevant zero readings were taken.

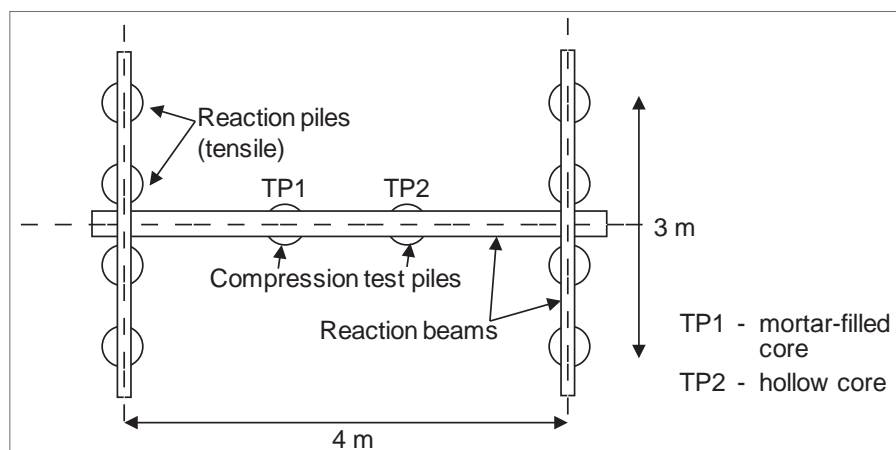


Figure 3 Pile test arrangement

Table 1 Static load test summary table for DUKTUS test piles TP1 – 170 mm diameter x 9 mm wall thickness x 30 m depth – core filled with 10 MPa mortar

Test pile reference	Test pile details	Load (kN)	% of Permissible design working load	Gross settlement (mm)	Residual settlement after unloading (mm)
TP1	30 m depth (4.5 m above rock head)	1 200 kN	100%	18.43	4.12
TP1	core filled with 10 MPa mortar	1 500 kN	125%	25.46	5.99

Table 2 Static load test summary table for DUKTUS test piles TP2 – 170 mm diameter x 9 mm wall thickness x 27.5 m depth – hollow core

Test pile reference	Test pile details	Load (kN)	% of Permissible design working load	Gross settlement (mm)	Residual settlement after unloading (mm)
TP2	27.5 m depth (7 m above rock head)	900 kN	100%	9.61	3.76
TP2	hollow core	1 350 kN	150%	17.27	2.27
TP2		1 800 kN	200%	32.25	8.75

The 30 m deep mortar-filled test pile TP1 was statically load-tested in two cycles, first up to 1 200 kN (the idealised permissible design-safe working load) and then up to 1 500 kN (125% of the idealised permissible design-safe working load). A further load cycle was not carried out due to a problem with the reaction system.

The 27.5 m deep hollow core test pile TP2 was then statically load-tested in three cycles of 900 kN (100% of idealised permissible design-safe working load), 1 350 kN (150% of idealised permissible design-safe working load) and then up to 1 800 kN (200% of the idealised permissible design-safe working load).

The results of the load tests are summarised in Tables 1 and 2 and the load-displacement curves for the first load cycle on each pile are shown in Figure 4. Most of the pile head settlement could be attributed to elastic deformation of the piles as illustrated by the small residual settlement values upon unloading. The

maximum settlement under working load amounted to 18 mm and 10 mm for the grouted and hollow piles respectively, while the residual settlement after removal of the working loads amounted to only about 4 mm for both the grouted and hollow piles.

Tension Test

Following the compression tests, tension tests were carried out on two of the 15 m long anchor piles by jacking the reaction beam using pile TP2 as reaction. A maximum tensile load of 600 kN was applied to each of the reaction piles, mobilising on average 51 kPa of shaft friction (based on a 15 m pile length and pile diameter of 170 mm with a 40 mm wide grouted annulus around the pile). This was accompanied by only between 1 mm and 2 mm upward displacement at pile head level, which was nearly fully recovered upon unloading, leaving a residual upward displacement of only approximately 0.5 mm. It was not possible to exert larger tensile loads given the rated capacity of the GEWI bars connecting

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the reaction system to the piles. The tensile test clearly illustrates excellent shaft capacity around the mortar-filled perimeter of the piles, confirming that the DUKTUS system has potential to also perform well in soil conditions where sound end-bearing capacity is not guaranteed.

SUMMARY

Two pile load tests, carried out on approximately 30 m long DUKTUS piles in a firm clayey soil profile underlain by competent bedrock, illustrated excellent load bearing characteristic with settlements of only 19 mm and 10 mm respectively under working load. Between 70% and 80% of this settlement resulted from elastic compression of the piles, as illustrated by the small residual settlement upon unloading.

The soil profile in which the piles were tested is deeper and softer than what would typically be encountered in South African conditions. It is approximately twice the depth in which the DUKTUS piles would typically be recommended. The results obtained are therefore deemed to be conservative. The relatively soft clay provided adequate lateral support to ensure a high axial capacity, not only arising from end-bearing, but also very good shaft resistance.

Due to its simplicity and efficiency, the DUKTUS piling system has numerous advantages:

Piles are rapidly and easily installed using locally available resources – a standard hydraulic excavator and hammer, as well as local excavator operators who may have no prior piling experience.

The system offers a high standard of safety and quality. Very few site personnel and very little equipment are required on site for piling works to be carried out. This dramatically reduces site congestion and conflict with other activities on site. Piles are prefabricated in the quality-controlled environment of the DUKTUS factory and each pile is supplied with quality certification in compliance with European Standards.

Pile installation is rapid, generally averaging 250 to 300 linear metres per excavator per day. The DUKTUS pile, being a driven displacement pile, is a direct replacement for the driven cast-in-situ pile, for which a typical production per piling rig is generally around 50 linear metres per day.

As an example, a small piling site such as a three-storey low-rise office or apartment block or car park might require, say, 100 piles to 15 m depth. Piling would take a single driven cast-in-situ piling rig approximately five weeks to install, after which the general contractor would be unable to commence pilecap construction until around week seven of the construction programme.

He would first have to trim the piles to the final cut-off level and tidy up the site after the piling contractor has left. In comparison, the DUKTUS piling system would require just over one week to complete the entire piling installation, inclusive of the pile trimming, with minimal site disturbance and no wastage of piling materials whatsoever. This enables the general contractor to commence pilecap construction immediately after the piling works in week two of the construction programme. On larger projects, that five week time saving would be further amplified due to the use of multiple piling machines.

Less equipment and manpower resources on site, in combination with a rapid production rate of pile installation, result in a clean and safer construction site with less congestion. More working space is freed up for the general contractor to proceed more effectively. Furthermore, due to the simplicity of the segmental installation process, the DUKTUS piling system is versatile and flexible in terms of variable pile depth requirements.

The results of the strain gauge measurements installed by the University of Pretoria at different levels along the length of the test pile shafts, as well as the data from other instrumentation used in the test arrangement will be presented in a future technical paper. □

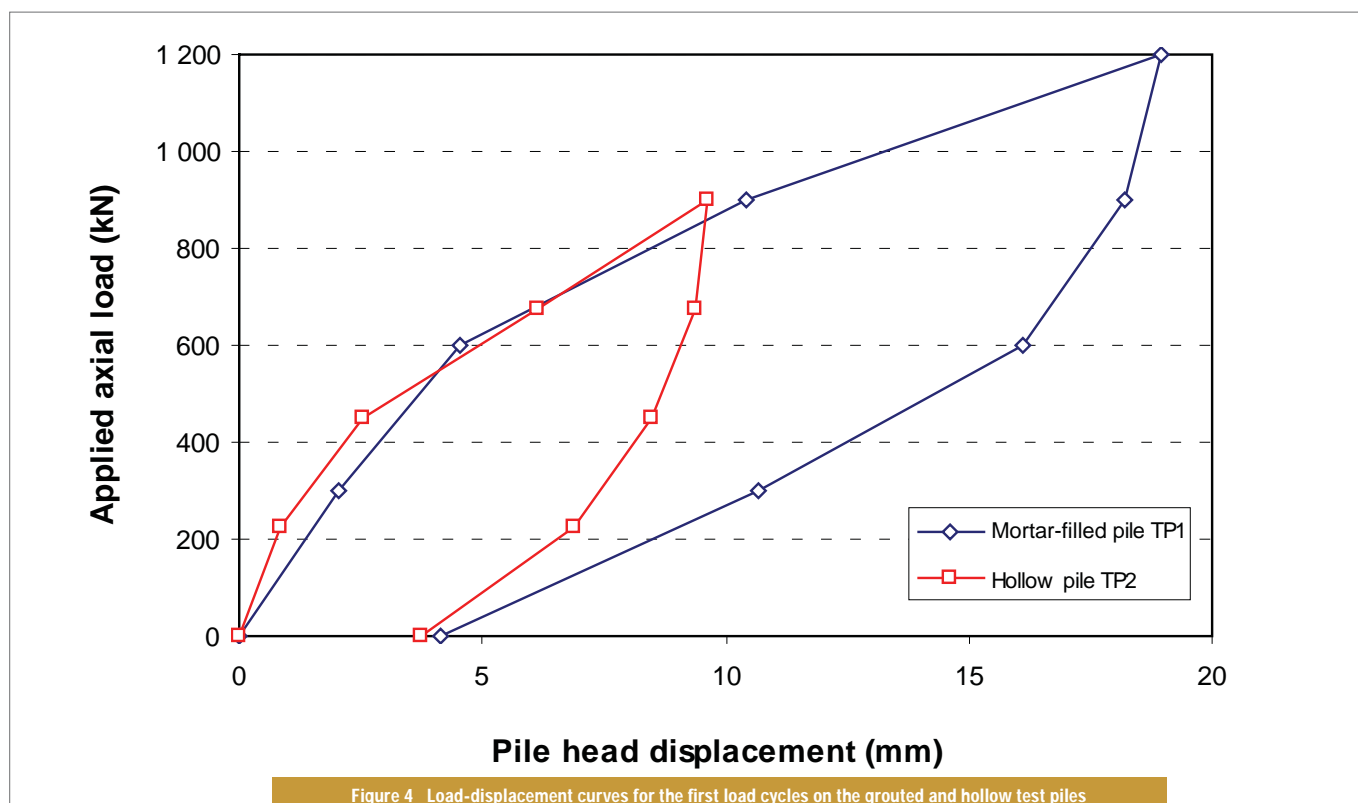


Figure 4 Load-displacement curves for the first load cycles on the grouted and hollow test piles