ADVANCED QUALITY ASSURANCE FOR PILING WORKS FOR THE WICET PROJECT IN GLADSTONE

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ABSTRACT

The “Wiggins Island Coal Export Terminal” (WICET) in Gladstone is one of the largest Greenfield port development projects in Queensland to date. The project will significantly increase the export capacity of the Gladstone Port making it one of the world’s largest coal export facilities. Stage 1 of the port development project commenced in 2011 with completion expected in 2014.

The piled foundations for the overhead gantry stacker and several of the yard conveyors were planned and executed in a design and construction contract by Abigroup Golding Joint Venture and Piling Contractors. WICET agreed to replace the original scheme of driven pre-cast concrete piles with a more efficient, economic and innovative CFA piling solution. This paper will briefly highlight the advantages of the alternative piling method comprising close to 700 CFA piles, approximately 25 m deep, most of them 900 mm in diameter.

The design and approval process included an in depth analysis of the pile group behaviour using numerous pile design software packages including finite element modelling for non-linear analysis.

Verification of conformance with horizontal and vertical design deflection criteria of the piles and pile caps for both ULS and SLS conditions was achieved by testing 3% of all working piles dynamically. Furthermore one vertical and one lateral static load test were carried out to verify the soil parameters used for the design of the deep foundations.

This paper describes the different load test procedures and their execution with respect to compliance with AS2159-2009. The authors will also highlight the advanced quality control systems adopted for the construction process of CFA piles.

The aim of this paper is to increase industry confidence in the use of CFA piles following a detailed review of the data collected during the design, testing and construction of these piles.

1 INTRODUCTION

The “Wiggins Island Coal Export Terminal” (WICET) 12 km North-West of Gladstone is one of the largest Greenfield port development projects in Australia to date. It brings together some of the most experienced bulk commodity ports industry users and operators under one consortium which includes eight owners: Caledon Coal, Yancoal, Northern Energy Corporation, Aquila Resources, Bandanna Energy, Westfarmer Curragh, Cockatoo Coal and Xstrata Coal. The project significantly increases the export capacity of the Gladstone Port making it one of the world’s largest coal export facilities. Stage 1 Civil and Foundation Works of the project started in 2011 and terminal commissioning is expected to be completed by 2014.

1.1 PROJECT SCOPE

This $2.5b project primarily consists of a coal rail receival dump station designed to handle 7,600 tonnes per hour and a 5.5 km long overland conveyor feeding a stockyard area with a capacity of 1.9 million tonnes of coal. A materials handling system then loads the waiting ship from a wharf based ship loader connected by a 2 km long jetty conveyor. The GC10 construction package works are located North of Hanson Road in Gladstone and comprise all civil and structural works associated with the construction of the bulk earthworks, drainage, terminal access road, stockyard tunnel works, stockyard gantry bund rail and trestle piled footings including yard conveyor and transfer tower footings, surge bin conveyor and surge bin complex footings including the coal collection pits. Additional works include the stockyard lighting towers and dust suppression tower footings. An aerial view of the project site during construction is shown in Figure 1.

During the tender phase Abigroup Golding Joint Venture together with Piling Contractors offered an alternate proposal using CFA piles to replace the original scheme which was a combination of driven pre-cast concrete piles and rotary bored piles. The team was awarded the contract and this work was delivered under a design and construct arrangement using close to 700 CFA piles approximately 25 m deep and varying in diameter between 600 mm and 900 mm. The
CFA piles were more suitable for the challenging geotechnical environment. However this piling system had to be taken through a rigorous design and quality control approval process to ensure compliance with project requirements. The CFA piles were installed as per VicRoads specification Section 607 – Continuous Flight Auger Piles.

This paper highlights the advantages of the CFA piling system as an alternative to pre-cast driven piles or rotary bored piles and demonstrates the advances made by the industry to improve the quality control during construction of CFA piles. Given the significant volume of data collected from the piling rig during installation, together with pile load and integrity testing results as well as the detailed pile design/analysis undertaken, a high technical level in both the design and quality assurance (QA) for CFA piles have been demonstrated in this project. These advances in CFA piling design and installation are hereby shared with the industry to further promote their use on major infrastructure and resources projects throughout Australia and particularly in Queensland.

2 THE STRUCTURES AND STRUCTURAL DESIGN CRITERIA

With the introduction of an alternative proposal using CFA piles, revised design criteria needed to be established and agreed with both WICET (client) and the appointed Structural Engineer for the project. The alternative pile design also required the integration of the original pile cap design with Piling Contractors pile design.

A boundary limit of underside of pile cap was agreed for the pile design. In order to complete the design process, full co-ordination between the pile and the pile cap design was required between the parties involved which included the agreement of pile layouts and load distribution.

The overhead travelling gantry stacker is the most critical structure of the project (Figure 2) and it was designed to withstand cyclonic loading with horizontal and vertical deflection criteria under ultimate limit state (ULS) of 20 mm and serviceability limit state (SLS) of 10 mm displacement of the pile cap.
The remaining structures which required piled foundations were reclaim conveyors 1 and 4, transfer tower 1, overland conveyor 1, surge bin conveyor 1 and the surge bin. The horizontal and vertical pile deflections for those structures under serviceability limit state (SLS) were limited to 10 mm displacement.

Piling Contractors used design software PIGLET and WALLAP for the design of the piles for the overhead gantry stacker. Golder Associates was appointed to carry out independent design checks using finite element code PLAXIS 3D Foundations (non-linear analysis). The pile design was based on AS2159-2009 Piling – Design and Installation, AS1170-2002 Structural Design Actions, AS3600-2009 Concrete Structures, and project specifications (Figure 3).

![Table 1: Typical geological profile and design parameters for the majority of the piles for the overhead gantry stacker](image)

Table 1: Typical geological profile and design parameters for the majority of the piles for the overhead gantry stacker

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Brief Description</th>
<th>( G_{\text{axial}} ) [kN/m²] (G=200 Cu)</th>
<th>( G_{\text{lateral}} ) [kN/m²] (G=200 Cu)</th>
<th>Ultimate Shaft friction ( f_{\text{sa}} ) [kPa]</th>
<th>Ultimate End Bearing ( f_b ) [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>above +7 m AHD</td>
<td>Fill</td>
<td>5,000</td>
<td>5,000</td>
<td>Ignored for pile design</td>
<td>Ignored for pile design</td>
</tr>
<tr>
<td>+7 m to 0 m AHD</td>
<td>firm to very stiff clay</td>
<td>18,000</td>
<td>9,000</td>
<td>35-63</td>
<td>630-1,125</td>
</tr>
<tr>
<td>0 m to -4 m AHD</td>
<td>els/vls mudstone</td>
<td>29,000</td>
<td>14,500</td>
<td>150</td>
<td>2,700</td>
</tr>
<tr>
<td>-4 m to -8 m AHD</td>
<td>els/vls mudstone</td>
<td>90,000</td>
<td>45,000</td>
<td>210</td>
<td>5,400</td>
</tr>
<tr>
<td>-8 m to -14 m AHD</td>
<td>els/vls mudstone</td>
<td>120,000</td>
<td>60,000</td>
<td>150</td>
<td>2,700</td>
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<td>150,000</td>
<td>75,000</td>
<td>150-210</td>
<td>1,350-5,400</td>
</tr>
</tbody>
</table>

3 THE GEOLOGY ON SITE

The ground conditions on site are dominated by mudstone, siltstone, and fine grained sandstone, typically of extremely low and very low strength. Thin bands of medium to very high strength chert can occur locally within the mudstone and siltstone formation. The mudstone and siltstone are typically banded, of extremely low and very low strength, with lesser bands of low strength and continue to at least RL -10 AHD without significant improvement in overall rock strength. In some locations massive or banded chert is found of high to very high strength.

A geotechnical investigation was undertaken prior to the works and used by Piling Contractors for the pile design. Twenty four boreholes were drilled prior to commencement of the project to investigate subsurface conditions underlying the proposed overhead gantry stacker foundations. The boreholes were drilled at each pile cap location and advanced using a combination of solid auger, wash bore and diamond coring.

The assumed components of geotechnical strength, for shaft friction and end bearing, derived from the geotechnical investigation and adopted for the majority of the piles of the overhead gantry stacker are shown in Table 1.

![Figure 3: Project specific deflection limits (left), finite element analysis using PLAXIS 3D Foundations showing theoretical lateral displacements of a typical pile cap of the overhead gantry stacker (right)](image)
A temporary working platform with a total capacity of 400 kPa bearing pressure was provided by the Abigroup Golding Contractors to accommodate the proposed heavy piling equipment. Pile cut-off levels were between 0.5 m to 4.5 m below the working platform level which was typically between RL 5.0 AHD and RL 10.0 AHD.

During pile installation, unexpected underground obstructions were encountered in some locations along the overhead gantry stacker foundation. In those areas the ground conditions were very abrasive and consequently wear and tear on the heavy duty piling augers was extremely high as shown in Figure 4.

![Figure 4: Heavy duty CFA rock auger (left), heavily worn bullet teeth compared with a new tooth (right)](image)

### 4 PROPOSED PILING METHODS

#### 4.1 THE ORIGINAL PROPOSAL: SQUARE PRE-CAST DRIVEN CONCRETE PILES

The original proposal for piling works for the yard conveyors and about half the overhead gantry stacker was based on the installation of square pre-cast concrete driven piles sized 350 mm x 350 mm. For the remaining piles of the overhead gantry stacker conventional rotary bored piles 900 mm in diameter were proposed. The precast piling solution was developed by the Structural Engineer in the early stages of the project with input from various piling specialists (including contractors) and due consideration was made of potential issues with respect to pile type, spacing and heave. Heave was not seen as an insurmountable problem for the driven piles. Based on geotechnical advice a rotary bored pile solution was adopted in discrete sections of the gantry stacker assuming potential pile driving issues in these areas.

Pre-cast driven concrete piles can be an effective and economical piling solution if ground conditions are suitable. This pile type is very effective in soft to firm cohesive or loose to medium dense granular ground conditions. Obstructions or hard layers cannot be penetrated readily by this pile type and the usage in stiff clay and soft rocks is limited.

For two thirds of the pile caps of the overhead gantry stacker pile centre to centre spacings for the proposed pre-cast driven concrete piles were one metre and there was a concern of potentially creating heave and damage to adjacent piles as eighty one piles were required per standard pile cap within the cap dimension of 9 m x 9 m. Due to the displacement effect of the driven piles, driving conditions would be expected to become more difficult with every pile installed. This effect could have been controlled via site installation measures but would have added time to the construction phase. Furthermore, hard driving conditions were expected in a few areas and the risk of damage to the driven piles or not being able to drive them to design depth was considered to be too high by Piling Contractors.

#### 4.2 THE ALTERNATIVE: CONTINUOUS FLIGHT AUGER (CFA) PILES

As a result Piling Contractors submitted an alternative proposal using Continuous Flight Auger (CFA) piles. CFA piles are a non displacement piling system which was used first in the United States of America in the early 1940’s (Gupte 1989). CFA piles were implemented in Europe and Australia about 40 years later in the early 1980’s with the development of equipment that allowed the use of concrete rather than sand-cement grouts.

Contrary to conventional rotary bored piles (where an open excavation is created prior pouring to the pile) CFA piling applications do not rely on Kelly bars for transferring the installation forces transmitted by the piling rig to the ground to install the pile. CFA augers are directly attached to the drill head of the piling rig. The most significant distinction to conventional bored piles using Kelly bars is that the CFA pile does not create an open excavation. The auger and the soil inside the auger flights support the borehole walls. CFA piles must be poured while the auger is extracted, concrete will fill the potential cavity created by the extracted auger.

The CFA auger consists of a hollow stem with constant auger flight pitches and flights with a constant outer diameter (Figure 5). The tip of the auger is sealed with a temporary end cap to prevent soil or water ingress into the hollow stem of the auger during installation. The most common auger diameters range from 450 mm to 1200 mm and drilling depths
in excess of 40 m can be achieved with modern piling rigs. For the WICET project 600 mm and 900 mm piles were installed with depths up to 25 m below working platform level.

The installation procedure for CFA piles is described in Figure 5 after Peiffer et al. (1993). The auger is rotated through the soil and auger rotation continues in the same direction throughout the whole auger penetration. Soil is cut and transported upwards out of the borehole and at the same time the auger (the flights of which are filled with soil) maintains the integrity of the borehole and prevents it from collapsing. The penetration rate must be selected carefully to ensure that the same volume of soil that is transported by the rotating auger flights is cut and loosened by the auger tip simultaneously. This is important to avoid soil decompression and over excavation in granular soils when penetration is too slow (Viggiani, 1993; Thornburn et al., 1993).

When the proposed toe level is reached auger rotation is stopped and the first batch of pumped concrete is discharged through the hollow auger stem into the pile excavation. Concrete pressure of up to 5 bars (depending on ground conditions) blows off the end cap at the auger tip. The auger is rotated one or two turns inside the fresh concrete to fill the auger flights with concrete and to take up any debris from the pile base. The auger is then lifted at a constant rate without any rotation. Further rotation would transport the fresh concrete through the auger stems towards the surface. This might cause excessive concrete overconsumption and a risk that the required positive concrete pressure cannot be maintained which might cause bore wall collapses. Concrete is continuously pumped through the hollow auger stem and a positive concrete pressure has to be maintained at all times during auger extraction.

The extraction rate of the auger depends on the concrete pressure and supply rate and the auger tip must remain embedded in the fresh concrete at least half a meter to ensure shaft integrity. After the concrete has reached working platform level a reinforcement cage can be installed in the fresh concrete. With modern concrete technology, concrete mixes should achieve a sufficient workability that the use of a cage vibrator can be avoided (cage vibrators present a risk of causing concrete segregation).

One of the main advantages of CFA piles is the high production rate which can be achieved with the system. This can make CFA piles very economical. Their installation is vibration free and lateral stress relief associated with bored piles (Viggiani, 1993) can be reduced notably if construction is carried out correctly. Pile diameters and pile lengths are limited compared to rotary piling applications.

The construction of CFA piles in water saturated or unstable soils is possible without any additional measures like casings or drilling fluid to keep the excavation stable, as long as installation parameters are monitored and controlled correctly.

Compared with conventional bored piles the visual verification of the pile excavation is not possible as concrete is poured whilst the auger is extracted. CFA piling is a “blind process” and advanced quality assurance is critical to construct a conforming pile.
5 QUALITY ASSURANCE OF CFA PILES

5.1 PILE MONITORING RECORDS

Despite the introduction of CFA piles in Australia about 30 years ago, the pile type has not yet been fully accepted throughout the industry. CFA piling is a blind process and construction problems with CFA piles must be identified as soon as possible after pile construction to discover and rectify potential problems without delays. Scott et al. (2006) point out that rig instrumentation can assist the rig operator to construct the required pile. Construction records must be checked as soon as possible after pile execution. This task should be carried out by an experienced engineer as a sound knowledge of design, pile loads and ground conditions is required to interpret installation parameters.

Potential problems with respect to the pile construction have to be identified quickly in order to avoid identical issues for the remaining piles on site. Modern piling rigs are fitted with electronic and mechanical sensors and measurement devices to monitor construction parameters during the execution of CFA piles. A typical construction record used at WICET is displayed in Figure 6.

Construction records are taken for every single pile on site and they are electronically documented during pile execution. This data can be accessed at any time and downloaded in the office by the engineer using remote transmission technology. During pile installation pile depth, penetration rate, torque, rotations of auger stem, extraction rate, concrete pressure and concrete flow are monitored on a computer screen in the cabin of the piling rig and observed by the operator. All of these installation parameters are related to each other and they must be analysed together.

5.1.1 Depth and Penetration Rate

The progression and depth of the auger tip in the ground is measured by depth in metres. Depth sensors are checked daily before the start of the shift to ensure that measurements are correct. The measurement of penetration and extraction rates is of great importance as penetration should be in a constant range in order to achieve continuous auger cutting and soil transport action.

Penetration rates are sometimes used as an indicator of dense/hard soil strata. Despite a statement by Derbyshire et al. (1989) that the penetration rate is a more reliable indicator of drilling conditions than the torque measurement, the rate of auger penetration should always be analysed in combination with torque readings.

5.1.2 Torque

Torque is an indicator for auger resistance in the soil. Bustamante and Gianeselli (1998) point out that torque capacities are of greatest importance for CFA piles to maintain constant penetration rates. He also points out that the shape of the auger head and the ground conditions are the most important factors influencing how much penetration energy must be applied by the piling rig to install the auger with constant penetration rates. Even if torque increases operators should keep penetration rates constant to ensure constant cutting and transport action of the auger. An increasing torque usually gives an indication that a dense or stiff soil layer is being penetrated.

It is important for CFA piles that rigs with sufficient torque capacities are used for pile installation. Van Weele (1988) emphasized those rigs are necessary to keep the penetration rate in a constant range and to avoid over excavation in granular soils.

5.1.3 Pull down forces

If torque capacities together with auger self weight are insufficient to establish or maintain constant penetration, additional pull down forces can be activated by the rig operator. These extra forces should only be used to establish constant penetration rates. Pull down forces are usually measured by comparing the hydraulic pressure required for pull down actions expressed as a percentage of the total pull down capacity.

5.1.4 Concrete volume

Concrete volume is usually measured by flowmeters attached to the concrete supply line of the rig. It is important to calibrate the flowmeter from time to time in order to ensure that concrete volume measurements are correct. This can be done by counting the strokes of the concrete pump knowing the volume of concrete that is pumped per stroke and comparing this value with the measured volume of the flow meter.

5.1.5 Concrete pressure

There are two different requirements for concrete pressures for CFA piling applications. Firstly, the concrete must be pumped from the concrete pump to the drill head of the rig at the top of the mast. Usually pressures of 20-25 bars are required for this task. Secondly, and more important for the pile construction, is the additional concrete pressure which
is necessary for the construction of the pile shaft and which is measured as an installation parameter. This pressure is usually in the range of 1-5 bars. Concrete pressure cells are usually located close to the drill head on top of the auger on the “U-shaped” concrete supply line. The cell will register positive concrete pressure whilst concrete is pumped through the stem.

Concrete pressure is an important indicator during the auger extraction and pouring process of the pile. Concrete pressure inside the stem must be positive at all times in order to maintain the integrity of the pile shaft. A positive concrete pressure usually indicates that the auger tip is embedded in the fresh concrete and that the concrete pressure inside the bore is equal to the horizontal stresses at the bore wall. Negative concrete pressure might indicate that the auger tip is not embedded into the fresh concrete and that wall collapse might occur in the gap between auger tip and surface of the concrete column inside the pile excavation. This condition must be avoided as it will cause defective piles.

5.1.6 Common errors with computer monitoring

Engineers should not solely rely on the construction monitoring data but they should also control and challenge data. There are some common errors in rig monitoring systems which the authors want to highlight in this section:

The print out of the pile shape on the construction record often shows necking or bulging of a particular pile section. This plot is based on concrete delivery related to auger extraction rate. However, concrete delivery rate is not measured at the auger tip and these plots can provide misleading information.

Negative, zero or very small positive concrete pressure at the swan neck does not indicate that the concrete pressure at the auger tip is close to zero or negative as well. The hollow stem could be partially filled with concrete causing positive concrete pressure at the auger tip. In this case the monitoring program would indicate zero or very small positive concrete pressure and a possible faulty pile necking in the area of the auger tip. This issue can be minimized if concrete has excellent workability criteria and is pumped continuously through the supply lines without air pockets.
5.2 CONCRETE PROPERTIES FOR CFA PILES AT WICET

Piling Contractors used 450 kg/m³ cementitious material, 10 mm aggregate and a retarder to ensure workability was maintained for four hours. For this project a self compacting high slump mix (S40-10-250) was used for the CFA piles, designed in accordance with VicRoads specification Section 610 – Structural Concrete. Fresh and hardened concrete tests were taken as per VicRoads 610. The CFA piles were constructed under Vic Road specification 607 – Continuous Flight Auger Piles as no regional specification for Queensland is currently available for this piling method.

Besides the characteristic compressive concrete strength, workability and resistance against bleeding are the main requirements for a suitable CFA piling concrete mix. With modern concrete technology, high slump mixes with excellent workability can be designed without difficulty. Piling Contractors used the “Recommended Practice: Tremie concrete for Deep Foundations” (2012) as a guideline for the workability and stability requirements and a slump of 250 mm and a slump flow between 400-450 mm was targeted. Slump flow is defined as the average of two measurements, namely, the largest diameter of the slump flow of the concrete and the diameter of the slump flow at right angles to it.

Prior to commencement of works on site, laboratory tests were carried out to ensure sufficient flowability of the mix using the L-box (Figure 7). The L-box results were verified by the slump (250 mm) and slump flow (450 mm) tests and could be correlated back to the pre-production tests when taken on site throughout the project. When slump or slump flow values on site varied more than the allowed tolerances, the concrete was rejected.

Figure 7: Advanced concrete testing using filtration press (left), L-box (centre) and slump/slump flow (right)

The filtration test has been carried out prior to commencement on site as well. With this test, pressure is applied to a fresh concrete sample (Figure 7) to simulate conditions at the pile base. The amount of water which can be squeezed out of the sample within 5 minutes (applying 5 bars pressure) is measured and gives an indication of the resistance against bleeding of the mix. The approved mix for WICET showed excellent results and was below the recommended limits of the “Recommend Practice” guideline. The authors strongly recommend use of the “Recommended Practice Tremie Concrete for Deep Foundations” for the design and verification of suitable CFA piling mixes.

5.3 PILE LOAD TESTS

As part of their design and construction contract, Piling Contractors carried out load tests to verify the pile capacity and the assumptions made in the pile design. 3% of all working piles were tested using dynamic load tests. Furthermore one vertical static load test and one lateral static load test were carried out. All tests were carried out in accordance with AS2159-2009 and project specifications.

5.3.1 Static vertical load test

For the static load test four reaction piles (each 900 mm in diameter and 18 m long) were required to anchor the test frame arrangement. The reinforcement cage of the reaction piles was fitted with anchor rods which were bolted to the frame. Three 50 ton hydraulic jacks and three 40 ton load cells were placed on top of the test pile (Figure 8) to apply and quantify the test loads. A reference beam with dial gauges was used to measure the vertical and horizontal movements of the test pile and the reaction piles during the test.

The static load test (in accordance with AS2159-2009) was carried out to verify the vertical load capacity of a sacrificial test pile of 18 m length and 900 mm in diameter. The sacrificial test pile was installed to similar depth as the working piles and the load steps and cycles were applied as shown in Figure 9.
For the assessment of the pile serviceability load $P_s$ (2759 kN), a load of 3000 kN was applied to the pile head and held for four hours; at this load the total pile head deflection was 0.98 mm or 0.19 mm corrected for creep. This result is well below the project specification acceptant criteria of 10 mm (SLS).

For the assessment of the design geotechnical strength $P_g$ (7801 kN), a load of 7800 kN was applied to the pile head to verify the ultimate geotechnical load and held for one hour, at this load the total pile head deflection was 10.29 mm or 6.02 mm corrected for creep. This result is well below the project specification acceptant criteria of 20 mm (ULS). During the last load cycle a maximum test load of 10,000 kN (capacity of the frame) was applied to the pile head. The deflection under this load was 25.75 mm or 13.13 mm corrected for creep. All results are displayed in Figure 10.
5.3.2 PDA tests
For 3% of all working piles dynamic load tests were carried out. The PDA data was analysed using the computer software CAPWAP to generate load settlement curves for each test. A typical CAPWAP curve is displayed in Figure 11.

Figure 11: Certified PDA testing frame with 10 ton drop weight (left), typical CAPWAP load displacement curve for a working pile of the overhead gantry stacker foundation (right)

For the whole project twenty four working piles (each 900 mm in diameter and typically between 15 m to 22 m long) were tested dynamically using the Pile Driving Analyzer (PDA). Typically four strain gauges and four accelerometers were installed about one meter below the pile head and the tests were carried out at least fourteen days after installation to ensure sufficient concrete strength. Piling Contractors used a 10 ton drop weight which operated inside a structurally
certified steel frame (Figure 11) to re-strike the piles using one meter drop height. One representative blow was selected for each pile and analysed using the computer program CAPWAP.

For all dynamic load tests the ultimate geotechnical strength $P_g$ (7801 kN) of the piles was achieved, in all cases with less than the specified maximum settlements of 20 mm (ULS). The typical load distribution analysis shows that, typically, the shaft contributed about 90% of the total activated pile resistance and that the full pile resistance was not activated during testing. Consequently, the load test results could be interpreted as being conservative. A typical CAPWAP load settlement curve for a working pile of the overhead gantry stacker is shown in Figure 11 and the load-settlement data show adequate agreement with the static load test results (after creep correction) displayed in Figure 10.

### 5.3.3 Static horizontal load test

One static lateral load test was carried out in accordance with AS2159-2009 to verify the lateral displacements of a test pile (900 mm in diameter and 18 m long) under a specified lateral load of 450 kN (ULS). The pile was installed to similar depth as the working piles and the load steps and cycles were applied as shown in Figure 13.

For the lateral static load test two reaction piles were required to transfer the reaction loads from the test into the ground. The test piles and the reaction piles were connected with a steel frame (see arrangement in Figure 12) and all piles were fitted with two inclinometers per pile to measure the lateral deflections. The load was applied using one 100 ton hydraulic jack. Similarly, the applied load was measured using one 50 ton canister compression load cell. The load was applied one metre below the pile head.

AS2159-2009 does not specifically nominate acceptance criteria for lateral pile performance, the criteria must be specified prior to the test. The effects of pile head fixity are to be considered when establishing the acceptable limits. Pile head fixity during the test is usually free compared to pile head fixity for the working piles which is usually fixed or at least partially fixed and pile deflections can be significantly lower in the fixed case. It was agreed to apply a lateral load of 360 kN, 480 kN and 600 kN to test the pile beyond ULS design conditions. The expected displacement from the finite element analysis was calculated to be 15 mm, 20 mm and 25 mm respectively. The lateral ULS load of 600 kN was applied resulting in an ultimate limit state moment of 1350 kNm located 3.75 m below the point of load application resulting in 25 mm of predicted lateral displacement. The ULS moment value, location and predicted displacement was calculated with the FE code PLAXIS 3D.

The test results showed that the applied force of 360 kN caused a total lateral deflection at the pile head of 4.92 mm and a creep corrected deflection of 2.59 mm. At an applied force of 480 kN the total deflection at the pile head was 7.46 mm and the creep corrected deflection was 5.24 mm. At an applied force of 600 kN the total deflection at the pile head was 11.47 mm and the creep corrected deflection was 9.28 mm. The test results are displayed in Figure 14 and the parameter selection for the Plaxis input seem to be conservative as the tests results are more than 50% below the design predictions.
5.4 PILE INTEGRITY TESTS

The pile integrity tester (PIT) can be utilized to detect construction defects such as major cracks, necking, soil inclusions or voids in the pile shaft. In AS2159-2009 it is recommended that piles should have been cured for at least one week or have achieved a characteristic strength of at least 25 MPa prior to testing. The smooth and hard surface of the pile top is impacted with a hand held hammer and the resulting pile top motion is measured with an accelerometer attached to the pile top (White et al., 2008). The hammer impact creates a low strain compression stress wave that travels down the pile. The wave is reflected when a change in impedance is encountered. Impedance is related to a pile’s cross sectional area, elastic modulus, and the velocity of the stress wave. In general, a region of impedance reduction exhibits a positive reflection while an impedance increase causes a negative reflection. No significant irregularities suggest the pile shaft is generally homogeneous and free of cracks. 15% of all working piles at WICET were PIT tested, all of them showed good integrity as shown in Figure 15.

The graphical results obtained are plotted over a length scale although they are really functions of time. If a defect is present, its size can be estimated from the magnitude of the early reflection, and its location from the time of that reflection. The PIT provides graphical displays of the velocity records with time in the field. The signals from a minimum of three impacts are typically averaged to produce one characteristic response.
CONCLUSION

The CFA piling proposal by Abigroup Golding Joint Venture and Piling Contractors replaced the original scheme using pre-cast driven concrete piles and rotary bored piles. The main advantages of CFA piles for the WICET project was the reduced construction program compared to driven pre-cast concrete piles, as well as the ability of CFA piles to penetrate hard layers and thus avoid potential pile heave problems associated with driving. Despite heavy wear and tear on the augers, the design toe levels were reached for almost all 700 piles.

The execution of CFA piles is a “blind” process and an experienced piling contractor using advanced quality assurance is required to ensure the piles are of sufficient quality. Full construction monitoring of the installation process and the concrete placement process is required to control penetration rates, concrete pressure and concrete volume. Sufficient torque and pull down force of the piling rig is crucial in order to ensure constant penetration rates and to avoid over excavation in granular soil conditions. Special performance based requirements are necessary for concrete to be used in CFA piles; particularly the workability and resistance against bleeding must be excellent to ensure the reinforcement cages can be installed effortlessly and without use of external vibrators.

More than 3% of the working piles were dynamically load tested and all pile displacements were within the specified load settlement criteria. Furthermore one vertical static load test was carried out successfully to verify the dynamic load tests results. The lateral pile capacity could be successfully demonstrated by one lateral static load test. In summary it could be demonstrated that the pile design parameters were suitable. All integrity tests (15% of the working piles) demonstrated no damage to the pile shafts.

For the WICET project the client has approved the use of this versatile piling technique and it has been demonstrated that advanced quality assurance can ensure a proper execution and quality of the end product. CFA piling can be a very attractive solution if construction and product control will be carried out adequately.

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