JUST-IN-TIME CONTINUOUS FLIGHT AUGER PILES USING AN INSTRUMENTED AUGER.

by

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ABSTRACT:

Continuous flight auger (CFA) piles are constructed by drilling a CFA auger into the ground and, on reaching the required depth, pumping concrete down the hollow stem as the auger is steadily withdrawn. Current practice to predict the bearing capacity of CFA piles is to estimate the undrained shear strength-depth relationship for the overall site, and use a total stress analysis to predict a general pile bearing capacity. This analysis is often based on sparse site data collected from a location remote from the pile. This paper investigates the exploitation of new technology to enable a new improved approach to the procurement, design and validation of (CFA) bored piles. The ultimate target is that the final length of the piles will be determined on site, as they are constructed, and will be optimised to suit the actual local ground conditions.

KEYWORDS: data logging; instrumentation; pile foundations; process optimisation.

1.0 INTRODUCTION:

CFA piles are formed by shearing the soil with a continuous 'corkscrew' like auger, and then replacing the soil with concrete as the auger is withdrawn in a controlled fashion. Finally reinforcement is inserted. They offer a highly efficient and cost-effective solution under certain conditions, however there remains some variation in practice between piling contractors, and in certain situations there is a need for improved confidence in final integrity of the pile. Increased understanding of the data collected on-board during the actual placing of the pile could provide this increased confidence and reduce risk, it would open the way to a radical reform of the business process, with significant changes to the relationships between the bodies involved, and the prospect of economic benefits to all parties [1]. The ultimate target is that the final length of the piles will be determined on site, as they are constructed, and will be optimised to suit the actual local ground conditions.

2.0 CFA PILES:

At face value the installation of a CFA pile seems simple, a hollow stemmed auger is drilled into the soil and concrete is then pumped into the ground through the stem as the auger is slowly withdrawn. However, the action of drilling the pile is a complex one to model and understand. It is not always obvious

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what affect the continuous flight auger has on the ground.

With CFA, the process remains unseen and there is no way of carrying out visual inspections of the bore. We are therefore forced to draw conclusions from past experiences, as to the likely consequences of installing certain piles in certain conditions.

The process of installing a CFA pile comprises of three phases or parts. First there is the boring of the pile, then concrete is pumped into the system pre-charging the lines and auger and finally the pile is concreted. The nature of the rig, the ground conditions and the augers all have an impact on each of these phases.

2.1 Boring the Pile

As the auger is rotated into the ground material from the auger tip is loaded onto the flights. The auger is carrying out three distinct actions - cutting, displacement and transportation of soil.

Figure 1 demonstrates the auger being screwed into the ground. As the auger moves downwards the surrounding soil has to be displaced by the volume of the auger. This is typically 15-20% of the volume of the bore.

As the ground is excavated at the cutting head it bulks and a ribbon of spoil moves up the auger. Because of this bulking there is always sufficient material available to fill the flights. The full flights now support the bore, over the length of the auger.

It would be ideal if CFA piles could be completely installed in this way, with the auger being continually screwed into the ground. However, even the largest rigs do not have sufficient power to overcome the frictional forces that are generated by displacing the auger volume into the surrounding soil.

Instead, it is necessary to restrain the auger during the boring process. This allows some soil to travel up the flights (transportation) with no further material being loaded onto the auger at the bottom. If the flights were allowed to empty in this way then the auger could start to load from the sides of the pile bore, a phenomenon known as side loading.

Side loading would loosen the surrounding soils which is detrimental to the skin friction of the finished pile. In fact many CFA piles have been observed to have lower skin friction than expected from calculation. In addition on some sites skin friction has been observed to vary from one pile to another by as much as 100%, which illustrates just how critical the boring of the pile is to its performance.

2.2 Pre-charging

This refers to the practice of pumping sufficient concrete into the auger stem in order to fill it before extraction of the auger begins. Typically the required pre-charge volume is between 150 and 300 litres.

After boring and while pre-charging it is important that the auger is not excessively rotated. In granular soils this action can have a detrimental affect not only on the shaft friction because of side loading, but also on the end bearing capacity of the pile due to the material at the base being loosened.

Prior to pre-charging it is common practice to lift the auger slightly off the bottom of the bore in order to allow the bung or "clack" at the auger tip to open (to allow the concrete to flow through). Experience shows that this lift should be kept to a minimum of 100mm.

2.3 Concreting

Once the auger has been pre-charged and the bung is blown, extraction can begin. It is good practice to rotate the auger during the initial stages of concreting in order to carry concrete and debris up onto the auger. Once this has been done and concrete pressure is observed at the swan-neck then the auger can be withdrawn, balancing the rate of extraction with the amount of concrete pumped through it.

The concrete supply pressure is usually measured at the top of the auger stem at the swan neck. This means that for pressure to be measured the auger string has to be full of concrete. With a stem of 25m in length this translates to a pressure of about 500kN/m2 or 5 atmospheres at the auger tip.

Given that measuring pressure is not always possible, concrete flow rate versus auger extraction becomes the best guide to producing sound piles. Over-break is that concrete used over and above the net volume of the bore. Oversupply should always be positive including towards the pile top where the ground is loosest, to ensure that concrete always flows up the flights. Otherwise contamination is possible, particularly in wet soils.

Over-break targets are critical for the correct construction of a CFA pile. In stiff soils pulling to high targets, say of 25% or more, may be impossible as the bore cannot yield to take the oversupply. In this case concrete will eventually escape to the ground surface or, more likely, the high pressure will lead to a blockage in the auger. Conversely, low targets in loose or soft ground could lead to defective piles, as the concrete will slump and leave the bottom of the auger tip exposed. It is therefore important that the over-break target is set for each contract and modified throughout the job as necessary.

3.0 STENT INTEGRATED RIG INSTRUMENTATION SYSTEM (SIRIS):

SIRIS is first and foremost a system for monitoring the construction of continuous-flight-auger (CFA) piles. SIRIS has been developed entirely by Stent and has been in service since about 1998. It is currently being used on all rigs in the CFA fleet [2].

The purpose of SIRIS is to assist the rig driver with constructing piles by providing him with a detailed picture of various parameters during the construction process. These parameters include auger depth, rotation, concrete pressure, concrete flow and over-supply.

In addition, SIRIS produces a complete record of the construction process for each pile, including the occurrence and cause of any delays. This record or "pile log" is then used for project management purposes and to produce a graphical record of each pile for presentation to the client. These client plots can be provided on paper or in the form of an electronic record along with the software necessary to view them.

SIRIS is effectively made up of three parts:

1. A computer on each of the CFA piling rigs and a number of sensors.
2. A database for storing, reviewing and managing pile logs.
3. A viewer for use by engineers or clients to review pile logs.

3.1 Rig Computer

Each piling rig is fitted with an industrial IBM compatible PC running the Windows NT operating system. This PC is connected to a full-colour, touch-sensitive high-brightness screen through which the driver controls the whole system. The screen is bright enough to be used in direct sunlight and the system is controlled via a user-friendly system of coloured buttons.

This PC is also connected to a number of sensors distributed about the piling rig as shown in Figure 2.

3.1.1 Concrete Pressure

A pressure sensor at the top of the auger, attached to what is referred to as the swan-neck, is used to measure the pressure of concrete pumped through the auger during the concreting phase of piling.

3.1.2 Depth

Two sensors on the rotary table or at the cat-head (the top of the mast) are used to measure vertical movement of the rotary table in order to calculate auger depth.

3.1.3 Rotation

Another two sensors on the rotary table are used to measure the number of revolutions of the auger and the direction in which it is rotating.

3.1.4 Concrete Flow

This is measured by a sensor in the line that detects the strokes of the concrete pump and therefore allows the volume of concrete to be calculated.

3.1.5 Torque

The pressure of the hydraulic fluid delivered to the rotary table is measured in order to give a rough indication of the torque being delivered by the auger during boring.

During the piling process SIRIS interrogates these sensors fifty times per second and uses the data to present the driver with a clear picture of what is happening. The sensor values are also used to create a detailed log of the whole process. Information is recorded for every 0.1 metres of the pile during both boring and extraction. In addition delays are also recorded, along with the cause of the delay as indicated by the driver from a pre-defined list.

3.2 The SIRIS Database

The pile logs recorded on the CFA rig computers are downloaded on a daily basis, either by floppy disk or (increasingly often) by GSM modem. They are then copied onto the SIRIS database which resides on a server on the Stent internal network

As well as providing a mechanism for storing, retrieving and reviewing pile logs the database generates a number of statistics which are used to assist the management of piling contracts - such as rates of production and a breakdown of the cause of delays. It also generates statistics on a historical basis which can then be used to improve the estimates for future jobs. It is because of this use of data for other internal processes that SIRIS is referred to as an integrated rig instrumentation system.

3.3 Pile Log Viewers

As well as the SIRIS database which is only accessible on Stent's network, there are also two other "stand alone" software packages that can be used for reviewing pile logs. One of these is used by Stent's engineers when they do not have access to the network. The other is a simplified version of this software that is intended for use by clients for reviewing and printing pile logs that have been passed to them electronically.

4.0 JUST-IN-TIME PILING:

In his 1984 Rankine lecture Wroth discussed different in-situ tests in which the parameter Undrained Shear Strength (τ_u) is measured. He showed how the tests were fundamentally different and compared them to the unconsolidated undrained triaxial test. Differences such as the directions and freedom of rotation of the three principal stresses were highlighted. He described the different test results as a hierarchy of τ_u. He concluded, "it is imperative for a designer to recognise this hierarchy, and to select a strength which is appropriate to the analysis or the design procedure being used" [3]. For the specific case of Continuous Flight Auger (CFA) piles the industry relies mostly on the unconsolidated undrained triaxial and/or standard penetration test to obtain a general view of the τ_u with depth over a site. This is then used to predict the performance of all the piles on a site using an undrained analysis. The problems associated with this process are well known in the field of geotechnical engineering and will not be discussed in this paper. The results of an Imperial college investigation showing the inadequacy of current pile design practices are not surprising given the current design methods. Sixteen entries from seven countries were received for the prediction of load capacity and displacement of a jet grouted and a control pile. The predictions for the load bearing capacity of both piles differed by almost an order of magnitude [4].

4.1 "Smart" Auger

Sensors on the piling rig vehicle could obtain much of the information required for JIT-pile, such as auger torque, and this is the obvious approach. However there are significant problems:

- Large piling rigs tend to be custom manufactured and vary in details such as hydraulic pump performance. This means that each individual rig would require independent setting-up and calibration.
- Time taken for setting-up, calibration and maintenance of the sensors would reduce the availability of a high-cost asset.
- The use of variable displacement hydraulic pumps and motors means that the relationship between system pressure and torque may not be that straightforward.
- Moving JIT-pile equipment from one rig to another becomes a major task.

The solution is to concentrate as much sensing as possible on the auger itself. Augers contain a short link that can be engineered into a focus for data collection and communication. A link has been prepared by the addition of strain gauges to measure both torque and axial force in the auger. Calibration has been carried out in the laboratory at Lancaster (Figure 3). The information is then relayed to the rig instrumentation system by radio link telemetry. This is the so-called "Smart Auger" concept and represents an important commercial spin-off from the research. Such systems can be easily moved between rigs and serviced independently of the expensive plant.

The adding of additional instrumentation and sensors to the auger itself allows direct measurement of torque and vertical load information during the boring stage of pile production. These readings can then be interpreted and used to estimate the undrained shear strength (τ_u) of the surrounding soil.

4.2 Method

The auger is advanced one pitch every revolution or "corkscrewed" into the soil for a certain distance, to ensure the least possible disturbance to the soil. The auger can do this under its own weight. The winch is then applied to pull back on the auger stopping penetration, while the auger is allowed to rotate at a specified rate. The cylinder of soil penetrated by the auger is sheared. The torque as well as the pullback force on the auger is measured and the shear stresses imposed by these on the cylinder of soil being sheared is calculated. The resultant maximum shear stress is then assumed to be related to the undrained shear strength of the soil. Model tests at Southampton University have been used to test this theory.

4.3 Results

Work is continuing to validate the lab based model tests with the production of a full sized auger section equipped with the necessary sensors and instrumentation. A test rig capable of applying the large forces has been constructed to permit full calibration and testing of the auger section with field trials due to commence shortly.

5.0 CONCLUSIONS:

If the information gathered proves not to be accurate enough for design purposes it still provides a useful amount of information for validating every pile on site and picking up anomalies in subsurface conditions. Furthermore it could lead to the automation of the drilling process, eliminating the influence of the operator on performance of the pile.

To date, all the indications are that an appropriate relationship between drilling resistance and pile strength has been established. Current testing work is underway at Southampton to verify the results and the work will shortly progress to site testing and verification.

The effective exploitation of 'difficult ground' will increase in importance as old sites are redeveloped for new uses. This means that the demand for piled foundations will increase, and it is therefore timely to address the issue of how new technology can improve the process.

6.0 ACKNOWLEDGEMENTS:

Throughout the grant period Stent Foundations Limited, under their own resource, developed their own rig instrumentation system known as SIRIS, and it was decided that both the collection of additional data and the final JIT-pile system should be compatible with this. The JIT-Pile funding has been through the UK's EPSRC - grant GR/M90450.

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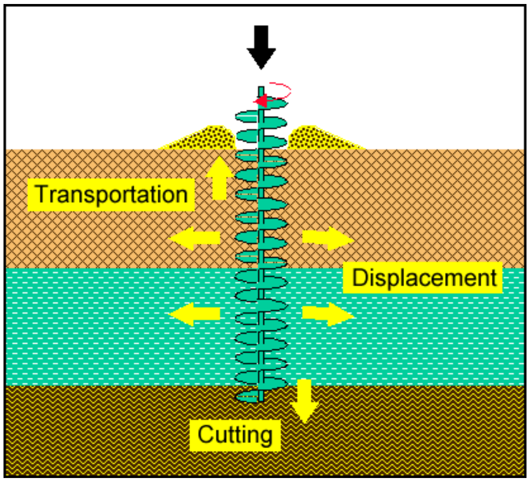

Figure 1 – CFA processes during the boring phase.

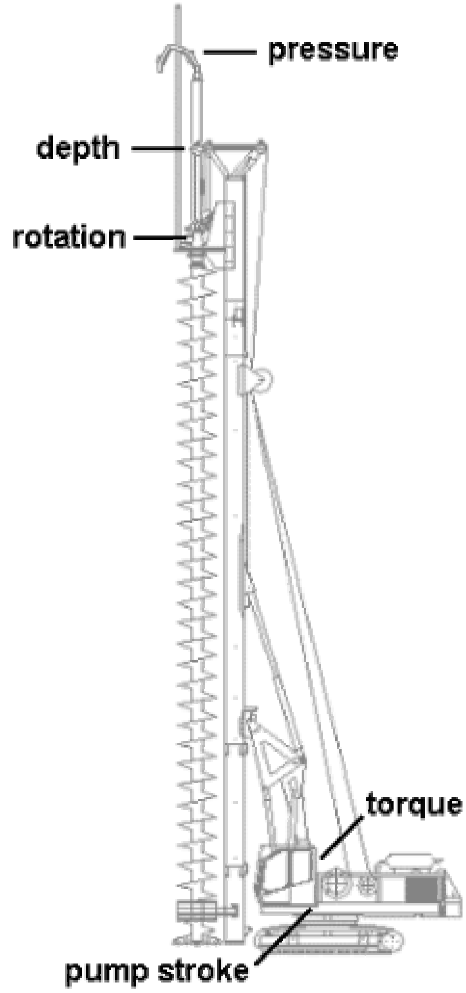

Figure 2 – CFA rig based sensors

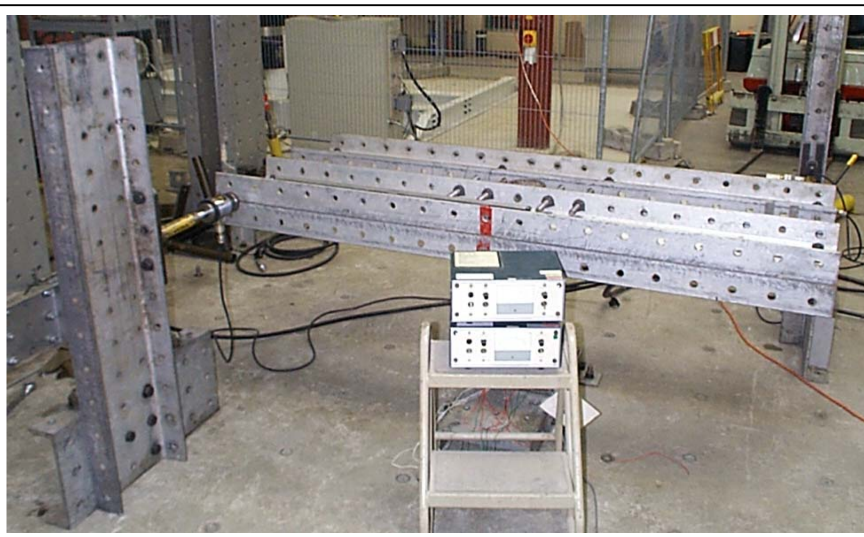

Figure 3 – Auger instrumentation testing at Lancaster University.