ON SITE PILE INSTRUMENTATION AND ITS INTEGRATION INTO THE MANAGEMENT PROCESS

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Abstract: The paper describes how modern computer and telecommunications technology has enabled the creation of a piling instrumentation system that integrates seamlessly with the rest of the site and project management processes. The system, called SIRIS, consists of an industrial computer and sensors on the piling rig, a notebook computer used by the site foreman and a database system located back at the office - all of which are linked by GSM (Global System for Mobile Communications) modems.

Keywords: Pile foundations, instrumentation, automation, sensors, GSM modem, user interface, site information control.

1 INTRODUCTION

Stent Foundations are a major international foundation contractor specialising in medium to heavy piling and diaphragm wall construction. They are very conscious that automation and IT have a vital role to play in improving the service that they can provide to customers, and providing them with a commercial edge over their competitors.

Figure 1. CFA Piling Rig.

In November 1994 the Stent Automatic Pile Positioning and Recording system (SAPPAR) was launched using a differential satellite global positioning system (GPS) to assist rig drivers in accurately positioning the rig over a pile position. Following on from the success of GPS, the system was further developed to include automation of the final positioning(1). Realising that the benefits of automation only accrue when it is fully integrated within a comprehensive IT environment, Stent started work towards integrating the site automation with the business process through the use of object technology(2). Stent Integrated Rig Instrumentation System (SIRIS) is a major contribution towards this.

2 THE FOUNDATION INDUSTRY IT ENVIRONMENT

A foundation contractor generally takes on the role of a specialist sub-contractor within a construction project. Their role is to provide a relatively restricted range of products (compared to a main contractor), and they are normally technically answerable to the structural consultant appointed by the client. They generally employ their own specialist labour and plant, although materials such as concrete are usually acquired locally.

The foundation contractor is usually one of the first organisations on site, and this is often before the installation of fixed telecommunications. The contract may be of very short duration - ranging from a few days upwards. This means that the communications media adopted must be self-contained, mobile and easily established. Once developed, the IT infrastructure must require minimal support and maintenance.

The development of SIRIS has constantly been aligned with current working practices and developed with feedback from its operatives and clients alike. Although this might not produce the most efficient IT system, it has provided one that integrates with working practices on site and is usable by workers who have no previous knowledge or experience in IT systems. This change in culture from a production based site to one where IT and quality assurance are of high importance is a huge step forward, and one that is often overlooked when implementing an IT system.

SIRIS development has so far been concentrated on the continuous flight auger (CFA) process. CFA differs from other piling techniques in that there is greater uncertainty as to the size and integrity of pile produced. Driven piles are precast, and as such the major dimensions and integrity can be verified before they are driven into the ground. Bored piles can have the excavated shaft inspected before the filling of concrete, including the soil conditions at the pile toe, and it is possible to witness the concreteing process as the pile is constructed. CFA is a blind process (a full description follows), where instrumentation data becomes an increasing necessity to ensure pile integrity and conformance to specification.

3. SIRIS DESCRIPTION

Figure 1 shows the system process and how workflow is managed between the office and site. Although the rig can link directly with the office and have a pile schedule produced from there, it is still under the control of the foreman, and as a result the work flows from the office via the foreman, equipped with a laptop and GSM modem, to the rig. There are several reasons for this:

1) Information flow links in seamlessly with current working practice
2) The foreman can schedule work more accurately and account for breakdowns and delays more easily than someone based back at the office.

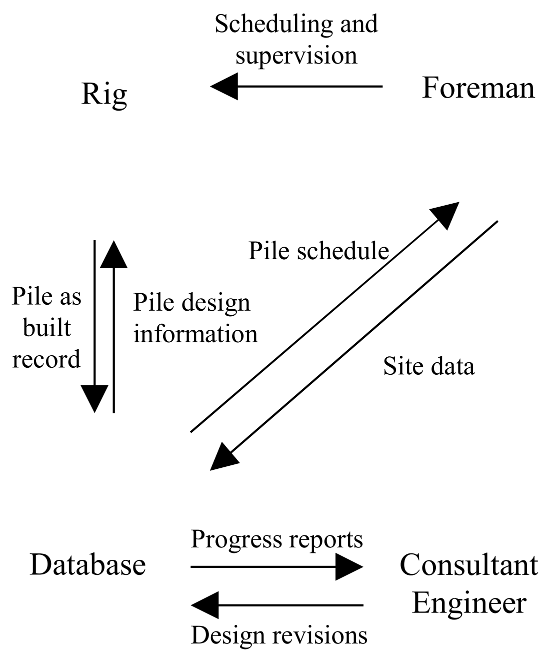

Figure 2. Information Flow To And From The Rigs

3) With multiple rig sites there is someone obvious directing what happens where.
4) Foremen are likely to remain longer with Stent, hence be familiar with operating the system.
5) Rig drivers are driving large and heavy machinery. Concentrating on other tasks can slow production, or could easily lead to an accident.

CFA pile construction can be broken down into three main areas.

3.1. Positioning

The instrumentation system provides the driver with a list of piles (the rig schedule) which has been created by the foreman from the pile schedule and transferred to the rig - either by radio modem or floppy disk. When the driver has selected the pile from the list that he is going to construct, he must first move the rig onto the required position. Currently this is achieved with the assistance of a "banksman" using traditional techniques. The instrumentation system records the time taken for the rig to get onto position and allows the driver to indicate the cause of any delays during this process - such as waiting for the pile position to be set out or for the route to the pile position to be clear.

3.2. Boring

Once on position the driver can begin to bore the pile. During this process the instrumentation system continually displays the current depth of the auger and the required depth of the pile (figure 3). It also displays the auger torque, average boring rate and indicates the degree to which the auger may be "flighting" - that is, transporting soil from the sides of the bore up the flights to the surface. This is a condition which is to be avoided since it makes the hole larger than necessary and disturbs the soil around the auger which can reduce the integrity of the final pile. Flighting is a function of the pitch, rate of rotation and rate of penetration of the auger. It is more of a problem in some ground conditions than in others - particularly in soft ground or where the auger passes through strata consisting of loose, granular material. The instrumentation system also displays the pressure in the auger stem as an aid to detecting the rare occasion when the stem becomes blocked while boring.

As with positioning, the driver can indicate the cause of various delays during boring such as rig breakdown, obstructions or, more commonly, the time taken to fit additional sections to the auger string. Such delays are recorded by the instrumentation system along with the auger depth, torque and rate of rotation, at regular intervals.

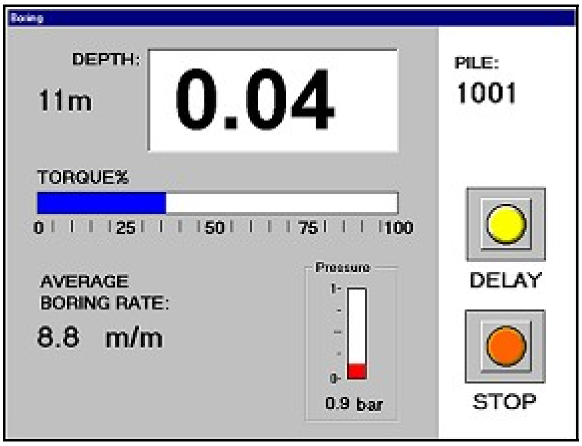

Figure 3. Screen Display During Boring

3.3. Concreting

Once the auger is at the required depth the driver can move onto the concreting phase (figure 4). During this phase concrete is delivered to the rig through a flexible line by a concrete pump, which may be located some distance away (tens of meters). The concrete is pumped down the hollow stem of the auger to the auger tip. The driver must extract the auger at a rate which balances the rate of delivery of the concrete - thus ensuring that the bore is completely filled. During pumping the driver must ensure as far as possible that the tip of the auger is always below the level of the concrete in the bore and that the pressure is sufficient to prevent the walls of the bore from collapsing inwards. In practice the volume of concrete placed in the pile should always be greater than the theoretical volume of the bore.

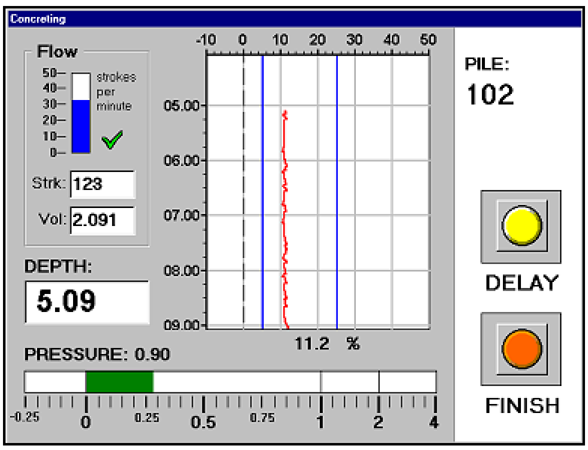

Figure 4. Screen Display During Concreting

This is because some of the concrete will inevitably force its way into the disturbed ground around the auger - particularly in soft strata. This additional concrete is referred to as "overbreak" and is expressed as a percentage increase of the theoretical volume. The overbreak may typically be 20% but can vary greatly depending upon the ground conditions.

The concreting phase of CFA piling is the most critical for ensuring the production of a sound pile and instrumentation is essential. The system provides the driver with a continuous indication of the concrete pressure at the top of the auger stem. By keeping this pressure slightly positive the driver can ensure that the auger stem is always full of concrete - thus ensuring that there is always a head of concrete above the auger tip. The instrumentation system also provides an indication of concrete flow and a trend graph, showing the overbreak as the auger is extracted. Together with the concrete pressure, this graph helps to ensure that a sound pile is always produced.

3.4. Pile logs

All information from the CFA process is recorded in a pile log (itself broken down into positioning, boring, and concreting logs). The pile logs have been developed using a text readable format, hence the log itself can be printed and interpreted without the use of further software. Each item of information in the log has an assigned tag, thus software decoding is straightforward and it also allows the log to be expanded at a later date without having to worry about format changes or further decoding. This format has been chosen over object models from STEP or similar for several reasons.

1) Simplicity and human readability which maximises flexibility as an open standard.
2) No suitable STEP standard currently exists(2), and probably will not do so for the foreseeable future. Once created the standard will take time to be adopted by other contractors and clients, hence it is thought to be sufficiently far off to consider at this stage (given that rig hardware will require upgrades on a five year lifecycle, and software approximately every three years).
3) This low-level information is not intended for use by clients or consultants, if they do require it, they can read the files manually.

At the end of each day, pile logs are compressed, and copied to a transmit directory and sent via GSM modem back to the office. A soft copy remains with the rig as a backup until the end of the contract. The foreman has access to the files on a more regular basis if required.

3.5. Client reports

Back in the office the as-built pile logs are expanded, and run through some extrapolation format, utilising Microsoft Word can be printed and sent as hard copy or emailed directly to the client or consultant.

An example SIRIS pile log is shown in figure 5. It consists of some summary information in the top left hand corner identifying the contract name, pile number, diameter, length, and nominal concrete volume, as well as the actual concrete volumes used and the average oversupply. Start and finish times for boring and concreteing are also displayed.

The remainder of the top of the report is graphically based, showing information relating to the boring phase of pile construction. System pressure (bar), boring rotation (rev/0,5m), boring rate (m/min) are all displayed with respect to pile depth. The lower half of the report contains data logged during the concreting process. Swan-neck pressure, volume, extraction rotation, and extraction rate are all plotted again with respect to pile depth. The concrete volume software which interprets all the raw data into graphical format for easy readability. This graphical graph also has a line plotted, indicating the required level of overbreak, thus making it very easy to spot any under filling of the pile should extraction occur to rapidly.

3.6. Rig hardware

With CFA piling there are five process parameters which the instrumentation system monitors, records and displays to the driver. These are:

- Auger depth
- Auger rotation
- Auger torque
- Concrete pressure
- Concrete flow

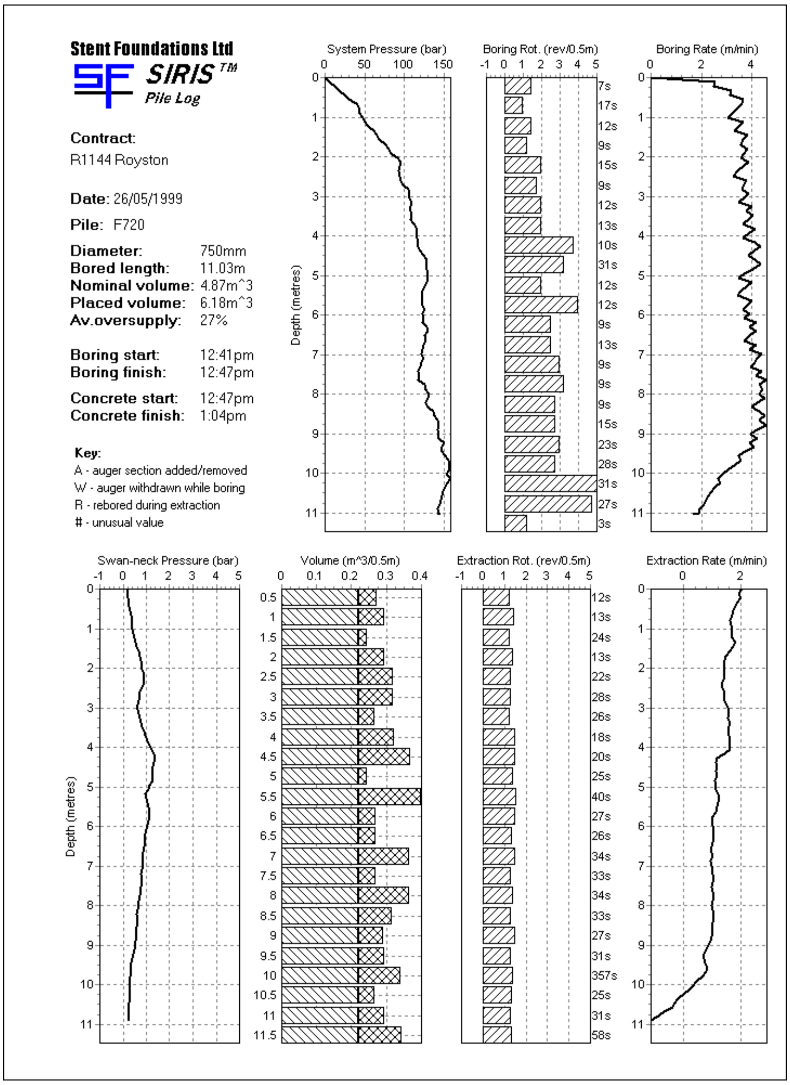

Figure 5. Example SIRIS Pile Log.

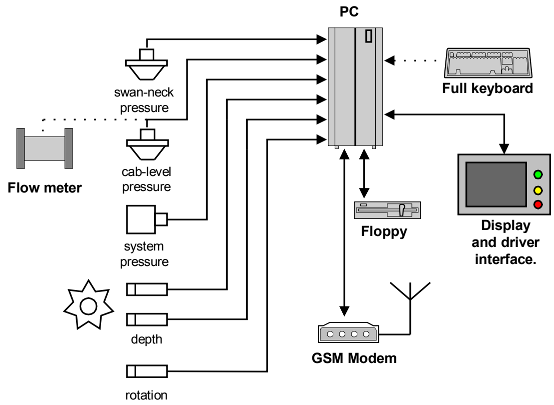

Figure 6. Rig Hardware Connection

These parameters are measured by six separate sensors on the rig. The concrete pressure is measured by a pressure transducer fitted close to the top of the auger. The auger depth is measured using two proximity sensors and a toothed wheel which rotates as the auger is lowered or raised. A third proximity sensor is used to sense auger rotation. The auger torque is measured indirectly by measuring the hydraulic system pressure and the concrete flow by either an electromagnetic flow-meter in the line, or by counting pump strokes using a second pressure transducer. An interface box connects the sensors into a rugged industrial PC mounted behind the driver in the cab. The PC operates with Windows NT operating system, offering added security and compatibility with office based machines. A floppy drive is mounted to provide simple data transfer on magnetic media, or the files can be transferred by GSM modem. Hardware connections are represented in figure 6.

3.7. Driver interface

The original user interface consisted of a colour LCD screen mounted alongside several highly coloured control buttons. A system of menus was used to toggle between options and selection was made via an enter button. Although this system worked well it was inflexible with a limited number of options available. New users required higher levels of training and it was quite easy to select the wrong option as the buttons are quite small relative to a gloved hand. These problems coupled with a supplier problem forced Stent into looking at other alternatives.

SIRIS now uses a sunlight-visible, colour, high resolution LCD screen equipped with a touch-sensitive membrane. This eliminates the need for a keyboard and allows the system to be controlled in a very intuitive manner. A great deal of time and effort was spent in collaboration with drivers, designing the user-friendly and highly visible interface, and menu choices are now software dependent rather than hardware. Figure 7 shows the LCD screen mounted in the cab at eye level. The driver has full control of the positioning of the screen should it block visibility.

Figure 7. Driver LCD Display

Not having a keyboard available in the cab is an unusual option, but offers many advantages. The onboard PC instantly becomes a rugged box unattractive to thieves, there is no facility for operators to accidentally delete or remove files, or to add games software as a distraction. When software upgrades are required they can be downloaded externally by modem, or updated by a qualified maintenance team which brings along a standard keyboard rather than require an expensive sealed type keyboard.

4. CONCLUSIONS AND FUTURE DEVELOPMENT

The SIRIS system has been running in a development capacity on two CFA rigs for twelve months. The entire CFA fleet is currently undergoing an instrumentation upgrade to the SIRIS, and should be up and running in two months time.

Benefits from SIRIS include:

- Fast, detailed pile conformance information for the client
- Better control of on-site processes through improved production records
- A reduction in paperwork on site
- Detailed productivity information for more accurate estimating

There have been some practical issues which still require resolving. One of the most common failures in the system is damage to wiring, particularly to the external sensors. This damage tends to occur during rigging and de-rigging hence more time is required in operator education and training to ensure that they understand the importance of the instrumentation system. A detailed Drivers Manual(3) has been developed for this, explaining the instrumentation and software operation fully. There is a page in the back of the manual to be used as a driver feedback form for suggestions, or improvements to the system.

Another disadvantage is the bandwidth available over the GSM network. At present, log files take three to five minutes to be sent back to the office, partly due to a thirty second security connection time, and partly due to the 9600 baud bandwidth available. The SIRIS system has been designed with the foresight that this bandwidth will rapidly increase as the GSM technology develops, hence in the near future it should not prove a restriction on working practices allowing file transfers to take place quicker and more frequently.

Future additions and upgrades to the system are relatively straightforward, since all the software follows an object-oriented approach. Current thinking is to add additional sensors to the rig to understand the CFA process in more depth, and to have some sort of real time agent running in the background flagging any log files which appear too far from specification.

Eventually SIRIS will provide the platform for other site data to be recorded, such as concrete type, slump, and delivery time, the cage type and size, and other non-pile related information such as workers hours. The intention is to move towards a paperless site, but this will only arrive with the collaboration of others and a widespread set of standards for data exchange.

5. ACKNOWLEDGMENTS

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