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Anatomy of a Data Acquisition System for Drilled Displacement Piles

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Abstract
Automated data acquisition systems are now available for a variety of deep foundation systems including cast-in-place piles. While enhancing the quality of data obtained during the pile casting process, these systems significantly increase the type and amount of data recorded with regard to auger penetration.

This paper presents the full details of a data acquisition, management and presentation system for drilled displacement piles currently in use in North America. Details include recorded parameters, recording methods, field data storage and presentation and permanent data storage and presentation systems. Implications of the availability of this data are presented in the companion paper, "Application of Acquired Drilled Displacement Pile Installation Data".

Introduction

Until recently in North America, the primary method for data collection during the installation of cast-in-place piles has been by manual methods. Typically, this has included visual estimation of penetration rate and depth during drilling and visual observation of grout pressure (usually by observing a dial gauge) along with manual counting of the strokes of a calibrated pump during pile casting.

It is noted that a relatively recent addition to the process is the Pile Installation Recorder (PIR), which utilizes a flow meter to evaluate volume during casting and also optionally measures torque on the motor generating auger rotation (Likins et al, 1998). Nevertheless, the majority of acquired data, and thus the primary focus of an analysis of cast-in-place pile installation, is typically focused on the pile casting process while relatively little data beyond total drilled depth is recorded regarding auger penetration.

However, automated data acquisition systems (DAS), with roots in European deep foundation technology, are now available for a variety of deep foundation systems including cast-in-place pile systems. While enhancing the quality of data obtained during the pile casting process, these systems significantly increase the type and amount of data recorded with regard to auger penetration. This data is proving to be particularly useful for the design and construction of drilled displacement (DD) piles (NeSmith and NeSmith, 2005). The following sections describe the DAS of the DD pile system of Berkel and Co. Contractors Inc (Berkel) highlighting developments during the systems history as well as potential further developments.

Measured Parameters and Instrumentation Details

Figure 1 is a general location diagram of the DAS components included on the installation platforms used for Berkel's DD piles. In general, the system consists of a main control unit which receives signals from a number of instruments installed throughout the drilling platform. This unit consists of a small computer hard-wired with the required software to (a) receive and condition signals from the monitoring instruments and (b) display the data in the appropriate format (Figure 2). The computer also has a minimal amount of data storage capability and includes a touch screen display for data input (project name, pile number, etc.) and selecting data for real-time display (torque, grout pressure, etc.). A data transfer mechanism (PCMCIA port or USB port) is also part of the main control unit.

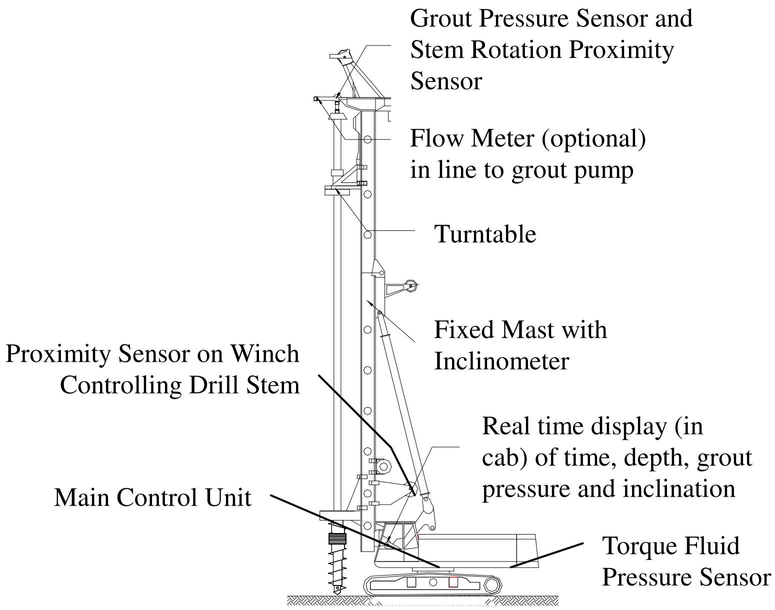
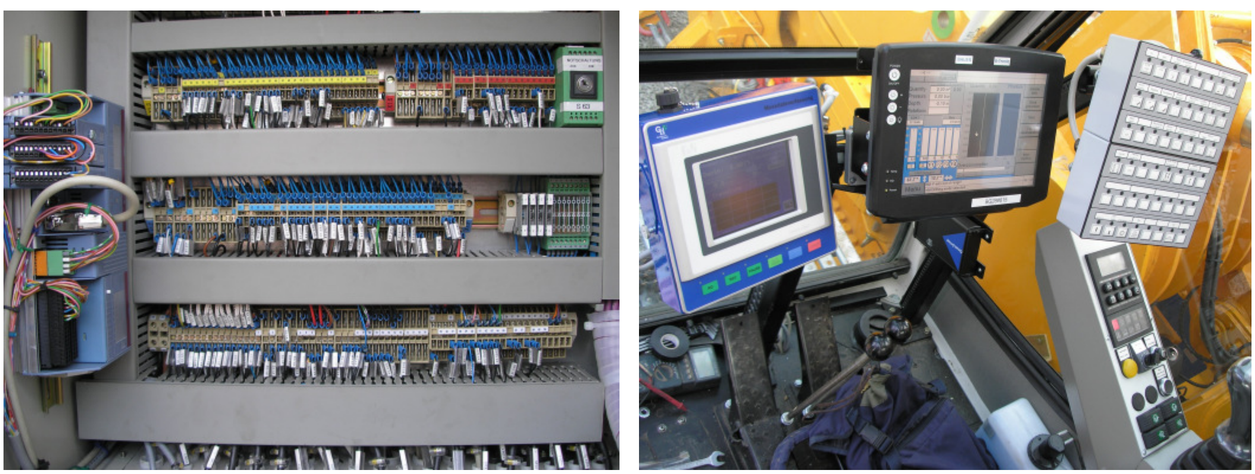


Figure 1. Generalization of DAS for Berkel's DD pile drilling platform



(a) **(b)**

Figure 2. Main Control Unit including (a) motherboard (vertical on photo on left) and signal conditioning and (b) real-time viewing and control panels in Operator's cabin

The control unit records the signals received from these instruments at a rate of 1 recording per second. Primary recorded parameters are as follows:

Time: Time is recorded by an internal counter in the main control unit. Initial dates and times are input by the operator at the start of a project and from then time is measured in seconds from these initial values by the counter.

Depth: Depth is monitored through the use of a proximity sensor which measures the rotations of the main winch, which supports the drilling stem (Figure 3).

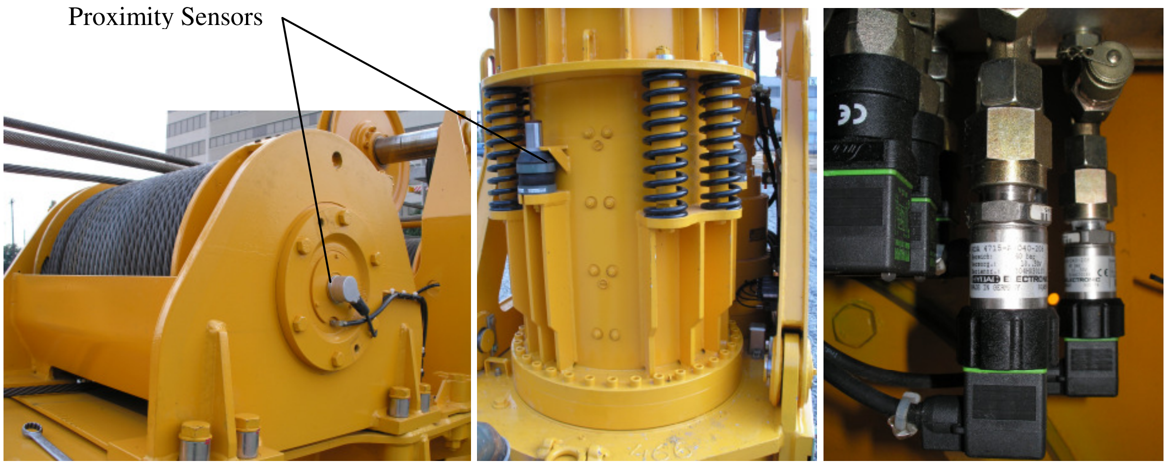
Mast Inclination: Inclination of the mast of the drilling platform is monitored to the nearest 0.1° by an inclinometer attached to the mast

Torque*: While torque is not directly measured, a pressure transducer is used to monitor the hydraulic fluid pressure applied to the motor driving the rotation of the stem of the DD pile system (Figure 3). Hydraulic pressure is measured to the nearest 0.1 bar.

Drilling Stem Rotation: The rotation of the drill stem is monitored through the use of a proximity sensor which directly records stem rotation (Figure 3).

Grout Pressure: A fluid pressure sensor is located at the top of the turn table where the grout enters the hollow drilling stem. Grout pressure *at the top of the drilling stem* is measured to the nearest 0.1 psi.

Grout Flow: Grout flow may be measured by means of a 3-in (inside diameter) magnetic flow meter with a Teflon liner inserted in the grout line between the pump and entry-point of the hollow drilling stem. It is noted that this is not a standard feature of the Berkel DD pile system, as Berkel DD piles are typically cast by grout pressure as opposed to volume. However, the feature is available where local codes (e.g. Los Angeles County CA) dictate the use of this equipment for cast-in-place systems. Grout flow is recorded to the nearest 01 ft^3.



(a) **(b)** **(c)**

Figure 3. (a) proximity sensor on main winch to monitor drill stem depth through main winch rotation
(b) proximity sensor on turntable to monitor drill stem rotation
(c) hydraulic pressure transducer to measure fluid pressure driving rotation of drill stem

Temporary (field) Data Storage and Manipulation

Data Storage and Transfer

Recorded Data is first stored in the main control unit. In the first generation of systems, data was immediately converted for storage into a database format for use with the database program PXU01. While efficient in its organization for permanent storage, this method does not allow for individual pile installation data to be accessed in the field until the data is downloaded and processed through PXU01 on a stand-alone computer. Additionally, data is transferred in database form; i.e. one file that grows in size as the project continues.

In the past two years, the on-board data storage format has been changed to a system where the data for individual piles is stored in individual text-delimited files (i.e. one pile per date file). Individual files can be accessed on-board from the main control unit and transferred one-by-one or all together, allowing for much quicker access of data for individual piles when required.

The first generation systems include PCMCIA ports for data transfer requiring PCMCIA cards to read the data from the main control unit and, more importantly, PCMCIA ports on the computer on which the data will be permanently stored (and which are very rarely included on desktop PCs). Berkel's newer systems incorporate USB ports for data storage which has eased the transfer to the permanent storage facility.

Data can be transferred from the main control unit at any rate required. Typically, data is transferred at rates between once daily to twice weekly. Transferred data is not permanently removed from the main control unit at the time of transfer. Rather this data must be manually removed upon verification that the data has been successfully transferred to the permanent storage facility.

Calculated Parameters
As discussed previously, it is only the systems that have been installed in the past two years or so that have included the ability to record drilling stem rotation. In these systems, torque is calculated based on the drilling platform's relationship between hydraulic fluid pressure on the motor driving the stem rotation and the recorded stem rotation rate and applied torque. In the first generation systems, this was not possible and the applied fluid pressure was typically used as the best estimate of torque. In the newer systems, either the fluid pressure or the calculated actual torque can be displayed.

Field Data Presentation
All recorded data is displayed in real time on the main control unit in the operator's cabin (Figure 4). Additionally, the drilling platforms are equipped with remote display units which are connected via a long cable to the main control unit and may be viewed at some distance outside (but within a few feet of) the operator's cabin (Figure 4). These remote display units present depth and either torque or grout pressure (based on the phase of installation as selected by the operator in the control cabin). Torque is presented as either the fluid pressure applied to the motor that drives stem rotation or the calculated actual torque as described above.

Another recent system addition regarding data presentation is the inclusion of a small wireless signal router. By adding a small router to the main control unit and mounting an antenna on the roof of the operator's cabin, a signal can be broadcast over a small area (the project site for example). The data being displayed in the operator's cabin can then be received and displayed by any computer within the broadcast range that has wireless capabilities.

(a) **(b)**

Figure 4. (a) real-time graphical display of drilling and grouting parameters in control cabin
(b) real-time numerical display of same parameters on display unit outside of control cabin

Permanent Data Storage and Presentation
Data is typically permanently stored on a PC-based, desk-top type computer. With the first-generation systems, data must be stored using the free-ware program data management program PXU01. Berkel has designed specific applications within PXU01 for data manipulation and presentation. Raw installation data from individual piles may be exported as a text or excel. Plots of installation data, as shown in Figure 5, may be printed directly or exported by copying and pasting to another application (e.g. Excel, Word, PowerPoint etc.).

When changes were made to the on-board data storage and transfer mechanisms (as described previously), a change was made to the permanent storage system as well. Berkel uses the proprietary data management program FlexPro by Weisang GmbH & Co. to store, manage and present DD pile data acquired with their newer systems. Raw pile installation data is stored as individual text files; one pile per file as they are recorded to the on-board computer. This raw data is then processed using a number of functions specifically designed for Berkel to use in FlexPro for data presentation. Figure 6 is an example plot of this later version of pile installation data. One significant advantage of using FlexPro is the ease with which it allows for large numbers of calculations to be performed at the same time. For example, with the first-generation system the calculation of Installation Effort (IE, as discussed in NeSmith and NeSmith, 2006) requires data for piles to be exported individually (once per pile) for processing through an Excel-based system to calculate IE. With FlexPro, the calculation of IE (along with the generation of the resulting plots of IE vs. depth for example)) can be performed on any number of piles at the same time.

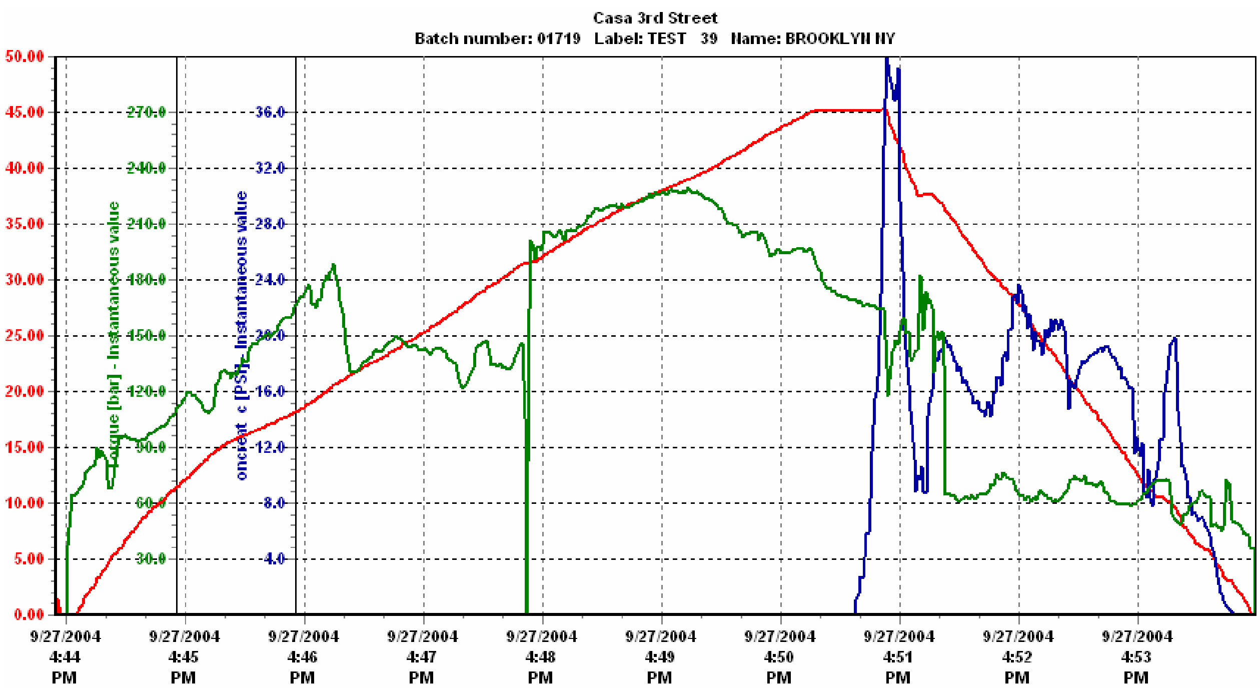


Figure 5. Example Plot of DD Pile Installation Data

Data Usage

The DD pile installation data described herein is currently being used in both the final design and quality control phases of projects where DD piles are installed. Additionally there is still a great deal of further potential for the use of this installation data. Specific use of DD pile installation data is discussed in the companion paper, Application of Acquired Drilled Displacement Pile Installation Data (NeSmith and NeSmith, 2006)

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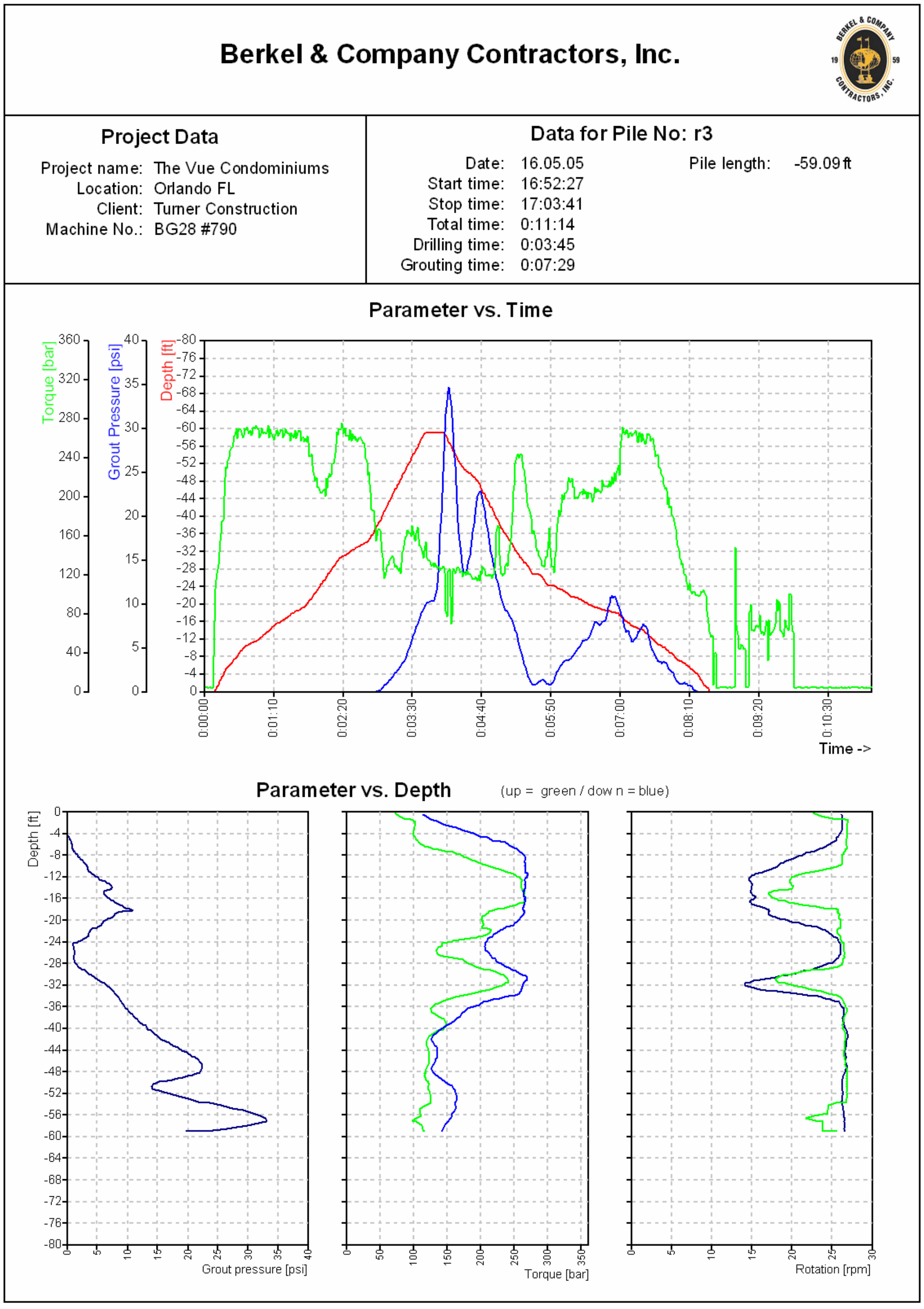

Figure 6. Example Plot of DD Pile Installation Data