Augered Cast-in-place Piles for Bridge Foundation Support

W.M. NESMITH, Jr., P.E.
Berkel & Company Contractors, Inc., Atlanta GA USA

KEYWORDS: Deep Foundations, ACIP, Augercast, Augered Cast-in-place, Auger Pressure Grouted, APG

PAPER NUMBER IBC 16-57

ABSTRACT: Although Augered, Cast-in-place (ACIP) piles are commonly used in highway construction for embankment, soundwall and MSE wall support, there remains a reluctance among state agencies to approve the technology for support of bridge foundations. FHWA Geotechnical Circular 8, The Design and Construction of CFA Piles, was developed to provide a framework for the inclusion of these piles in state-level highway foundation support. The author will present three relatively recent case-histories where ACIP piles were used for bridge-approach support, temporary support of a tower-crane for bridge construction, and the direct support of an elevated roadway in an urban area, respectively. Additionally, the author will present recent developments in the areas of automated installation monitoring and non-destructive testing that can provide a level of certainty regarding the integrity of constructed ACIP piles to allow their inclusion as foundation support for all aspects of transportation projects.

ELEVATED MLK DRIVE – ATLANTA GA

ACIP piles were used in conjunction with Drilled Shafts and ground improvement for support of a new stadium in Atlanta GA. In conjunction with this project, the existing elevated portion of Martin Luther King Drive was re-routed and required new foundation support. Due to the performance of 16-in and 18-in piles tested for the stadium, 24-in ACIP piles were selected for support of the new elevated roadway, which required support of 375 tons of compression load per pile.

Atlanta GA is located in the Piedmont Physiographic Province of Georgia. The general geologic profile typically includes residual soils as a result of in-place physical and chemical weathering of the parent bedrock (igneous and metamorphic bedrock). The soils vary from highly-weathered, fine-grained to less-weathered, predominantly coarse-grained (often exhibiting the relic structure of the parent rock).

There is often a transitional intermediate geo-material between residual soil and the parent rock, locally referred to as partially weathered rock (PWR) and defined as residual soil with standard penetration test results (SPT N-value) of at least 100 blows per foot.

Example borings are presented in Figure 1, along with a photo of the drilling platform used for pile installation. They show the typical profile described above with less-weathered soils with depth, the PWR transition zone and the underlying bedrock in one boring.

Test Pile CP-1 was installed to refusal on the underlying bedrock (defined as a drill-rate of less than 12-in per minute using appropriate means and methods for the local geology). The pile was tested in compression by applying load in increments of approximately 37.5 tons to a maximum of 750 tons, at which time the pile was unloaded. The pile was then reloaded to a maximum of 1000 tons without demonstrating any sign of geotechnical failure. A plot of applied load vs. pile-head deflection is included in Figure 2, along with an exposed 24-in ACIP pile at the test site as well as a relatively recent photo of the roadway deck construction.

FIGURE 1 – Example Borings and Installation Platform for MLK Elevated Roadway

FIGURE 2 – Load-Deflection Plot, Exposed ACIP Pile and In-progress MLK Deck Construction

TOWER CRANE FOUNDATION SUPPORT – OHIO RIVER BRIDGE – LOUISVILLE KY

In the second example, Berkel was requested to review the possible application of ACIP piles for the support of the tower crane foundation to be erected for the construction of the Kentucky-side approach of the new Ohio River Bridge connecting Louisville KY to Indiana, again based on nearby performance of heavily loaded ACIP piles.

Example borings near the tower crane pad are presented in Figure 3 and show loose, primarily sandy alluvial deposits over dense to very dense older, over-consolidated sandy deposits and the underlying limestone. It was originally estimated that 16-in ACIP piles installed to 90-ft below boring level, would be suitable to resist an ULTIMATE tension load of 235 tons and a resulting factored load of 140 tons per pile.

Preliminary design parameters are presented in Figure 4 along with the plot of applied load vs. pile-head deflection from the tension test performed at the tower crane location. Some shaft design parameters exceed those from most published design models and are based on recent experience with ACIP piles in similar geologic settings. This is becoming more and more common as drilling equipment and techniques are providing more efficiently installed piles that perform well-better than predicted. The load test result here confirmed the design parameters selected. It is noted that for production, 18-in ACIP piles were installed to accommodate larger lateral loads than originally anticipated by the design team.

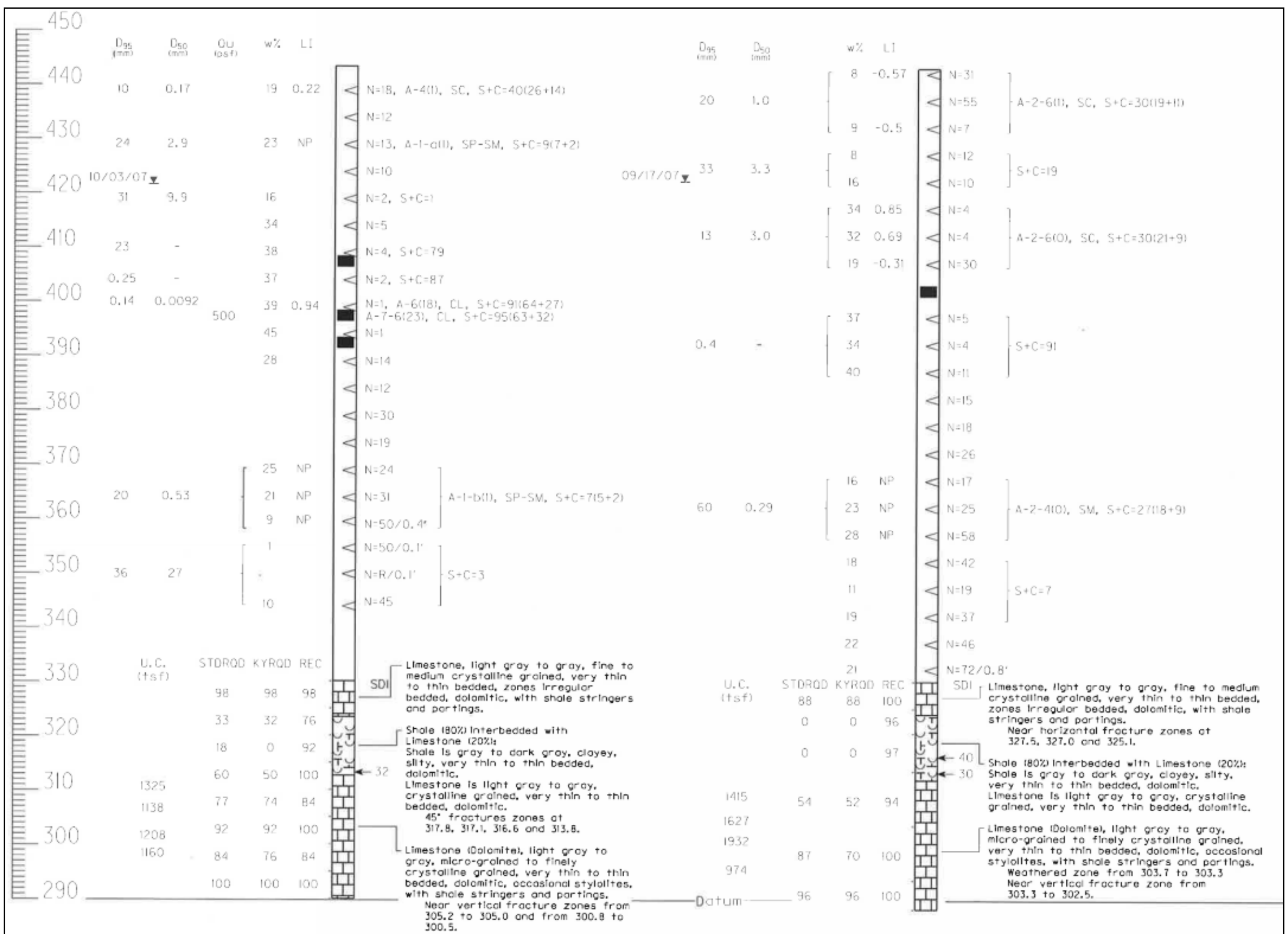

FIGURE 3 – Example Borings for ORB Tower Crane Support

			Berkel APG Pile		Dia	16	in	pile diameter	
						1.33	ft	pile diameter	
					Ultimate	4.19	ft2 / ft	unit side area	
				Soil	unit shaft	1.40	ft2	unit toe area	
EL [ft]	El [ft]	Depth [ft]	Depth [ft]	Type	[tsf]	Shaft [tons]	Total shaft [tons]		
443	438	0	5	Sand	0	0	0		
438	428	5	15	Sand	0.25	10.5	10		
428	385	15	58	Clay	0.45	81.1	92		
385	365	58	78	Sand	1.2	100.5	192		
365	355	78	90	Sand	1.4	70.4	262		
				unit toe [tsf]	25	toe [tons]	35	0.9	Tension factor
						Ult load [toe + total shaft, tons]	297	236	Ult tension load [tons]
						Ult load [toe + total shaft, kips]	**595**	**472**	**Ult tension load [kips]**

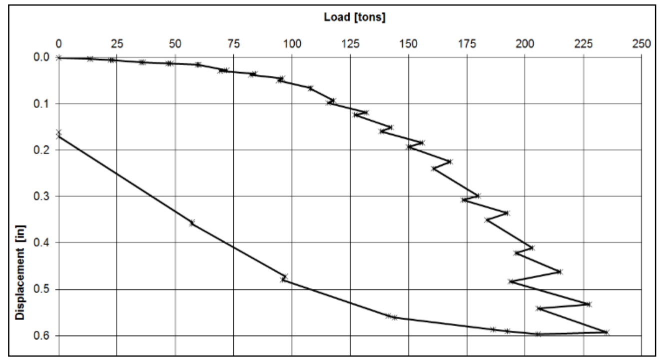

FIGURE 4 – Design Parameters and Tension Load-Deflection Plot at ORB Tower Crane Pad

QUEENS APPROACH – BRONX WHITESTONE BRIDGE – NEW YORK NY

The final example included is a site near the water at a New York City municipal facility in the northern section of Queens. The general stratigraphy is shown in Figure 5. SPT N-values are typically shown at 5-ft intervals with corresponding soil descriptions. Generally, below up to 10-ft of urban fill, typically dense to very dense sandy till was present, however, a portion of the site included significant stiff to very stiff clay till was present. Figure 6 is a photo showing some of the boulders removed in the upper 25-ft to facilitate ACIP pile installation.

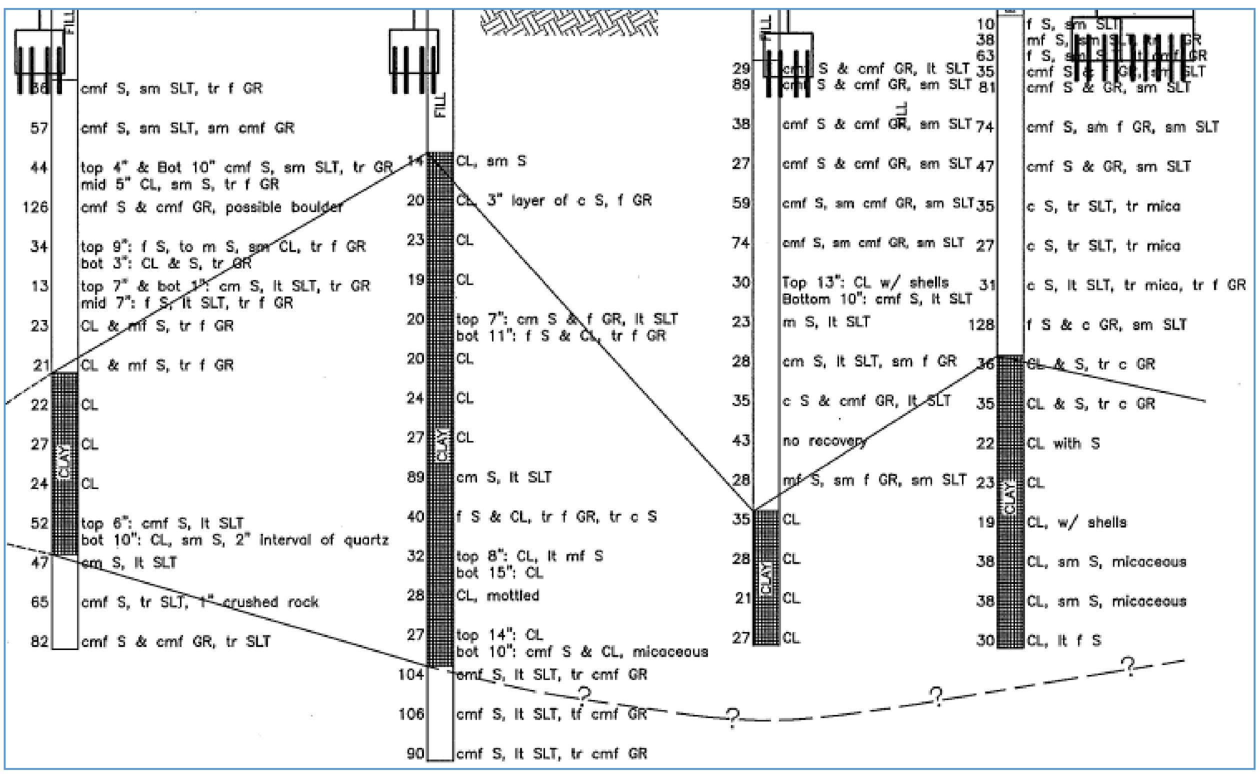

Figure 5 – N-values and Soil Descriptions of Glacial Till in Queens NY

ACIP piles, 16-in in diameter, were proposed to resist 150-ton to 160-ton design compression loads, depending on location within the project extents. Figure 7 shows the applied load vs. pile-head deflection for the test pile installed in the predominantly clay till portion of the site (2nd boring profile from right in Figure 5) while Figure 8 shows the same results for the test pile installed in a predominately coarse-grained till portion of the site (in this case, near the boring profile shown on the far right of Figure 5).

Figure 6 – Boulders Removed in the Upper 25-ft of Queens NY Site to Facilitate ACIP Pile Installation

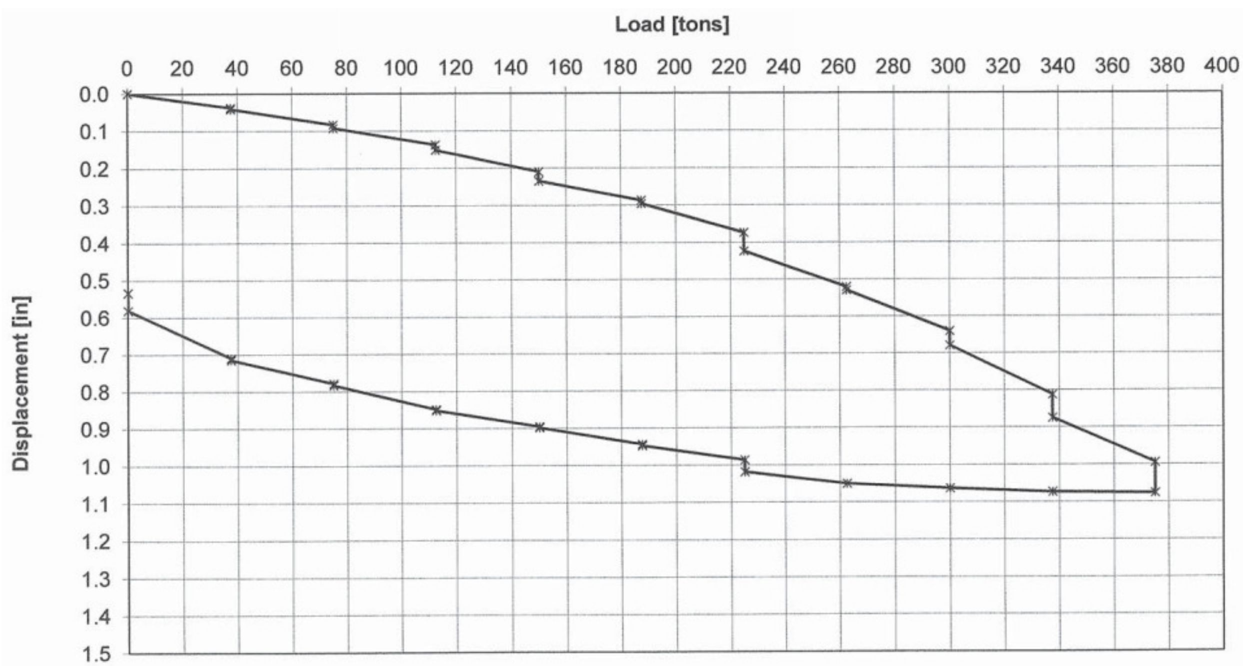

FIGURE 7 – 16-in ACIP Pile x 82-ft in Predominantly Clay Profile

The test pile in Figure 7 is probably about at its interpreted ultimate load according to the Butler-Hoy method (Studlein et al, 2013) at its maximum applied load of about 375 tons. The test pile in Figure 8 did not have enough pile-head deflection to estimate ultimate load, however, it should be obvious that the ultimate load is well in excess of the maximum applied load of 300 tons. In both cases, the ultimate load of the test piles was in excess of that which would be predicted by currently available design methods.

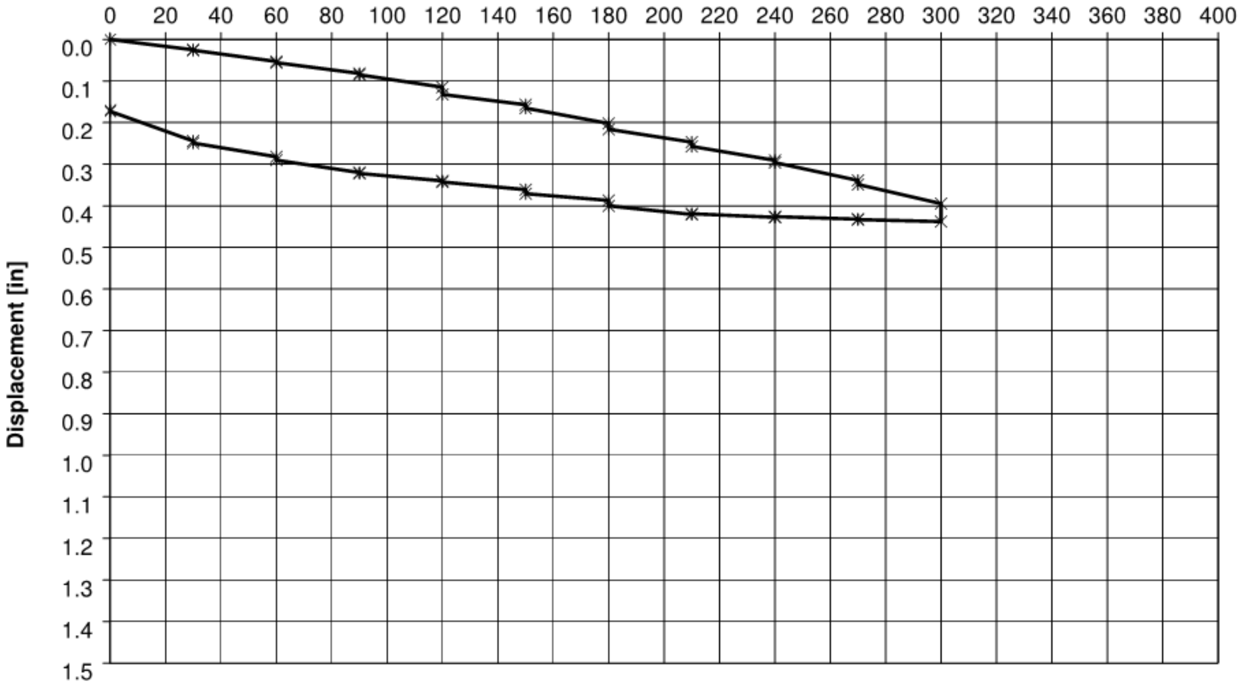

FIGURE 8 – 16-in ACIP Pile x 77-ft in Predominantly Sand Profile

INSTALLATION MONITORING

There are now a significant number of automated monitoring equipment (AME) systems available to augment manual installation monitoring. It should always be noted that AME cannot replace manual inspection but provides supplemental information to the pile installer and Inspector during pile installation. Typical AME for the piles discussed in this paper may consist of the following:

- A Display Unit to display numerically and/or graphically the collected information from various sensors. This unit should be mounted in the cab to provide immediate feedback to the crane operator. All AME data should be stored in electronic format and available for download for processing and/or possible further evaluation/final reporting.
- A real time clock should be included in the display unit that shows time to the nearest second.
- A depth sensor consisting of a rotary encoder on self-retracting cable spool attached to drill top or gear box or a spring loaded rotary encoder mounted on the gear box and in constant contact with the leads to monitor auger tip depth at all times during installation OR a proximity sensor mounted on the main winch calibrated to convert winch rotation to tool depth. Pile depth should be viewable on the Display Unit along with penetration and withdrawal rate, calculated from depth vs. time measurements.
- Rotary Head Pressure Sensor to monitor the hydraulic pressure provided to the gearbox. This pressure can then be approximately converted to torque on some equipment. On other equipment, this relationship is more complex including both pressure and rotational speed.

Rotation Sensors consisting of a proximity switch on the rotary head/gearbox OR a measurement of the flow of hydraulic fluid pressure applied to the rotary head, calibrated with rotation rate so that rotation rate can be viewed on the Display Unit.

A Magnetic Flow Meter may be installed in the grout line near the drilling platform to measure grout volume pumped. Note that flowmeters typically have exposed electrodes that must be in contact with the conductive fluid (grout). If non-conductive sand particles take up space on the surface of the electrode, this interferes with the flow of electrical current. If the amount of electrode in contact with the fluid is variable, calibration with pump strokes, and accurate flow measurement with the meter, is not possible. Some installers have noted difficulty in maintaining calibration in various geographic areas where cast in place piles are commonly installed.

Where this is apparent, one should revert to counting strokes of the grout pump if there is difficulty in maintaining flowmeter calibration. In the author's experience, grout volume from flowmeter data, should be calculated for depth increments of not less than 5-ft.

Grout Pressure Sensor (not typical) to monitor maximum and minimum grout pressure in the grout line. Although this not useful for volume versus depth measurement, this sensor can possibly be used to estimate pump strokes in some systems and depending on grout/concrete viscosity, so the flowmeter volume can be converted into approximate volume per pump stroke to evaluate grout pump performance.

Real Time Remote Display to display numerically and/or graphically the collected information from various sensors, for real-time review by the Inspector or other designated representative of the owner. Alternatively, a Field Printer to make a hard copy of results for each pile once completed.

Most AME systems have software that allow for producing installation records for each pile. An example record is shown on Figure 9. General project and pile parameters are presented on the upper portion of the record. The parameter versus time graph shows auger tip depth, grout flow rate, and KDK pressure. Grout pressure versus time is optional. The parameter versus depth graph shows (from left to right), tool penetration rate while drilling (black line) and withdrawal rate while grouting (brown dashed line), KDK pressure, Grout Flow Rate, Auger Rotation Speed and Incremental Grout Factor. For DD piles, grout pressure is measured at the top of the tooling instead measuring grout volume. This grout pressure would be displayed on the bottom right in lieu of the incremental grout volumes. Partial DD piles may be cast from either volume or pressure at the top of the tooling depending on local soil subsurface conditions.

NON-DESTRUCTIVE TESTING (NDT)

General

The integrity of production piles may be evaluated by one of a number of NDT methods to confirm final system acceptance. Any NDT method has pile types and subsurface conditions for which it may or may not be well suited. This should be considered on a project specific basis. A much more detailed discussion of NDT methods can be found in the, "Guideline for the Interpretation of Nondestructive Integrity Testing of Augered Cast-in-place Piles" prepared by the ACIP Pile Committee of the Deep Foundations Institute. It is noted that ALL NDT results should be used as a guide for additional detailed evaluation of pile quality and NEVER as a stand-alone reason to reject a pile.

Impulse Echo (Sonic Echo) Method for low strain integrity testing

ASTM standard D5882-07 is applicable to low strain integrity testing. The impulse echo test consists of producing a compression wave at the top of the pile and measuring the return of the wave which is reflected off of the pile toe, assuming the pile is uniform. The wave can also be partially reflected by changes in impedance within the pile shaft. It is considered that a change of impedance might be indicative of a change in pile diameter or grout quality. Typically, the wave is generated by using a hammer to strike the pile top and an accelerometer to measure the response. An example of the striking procedure and results obtained from the data collected are shown in Figure 10.

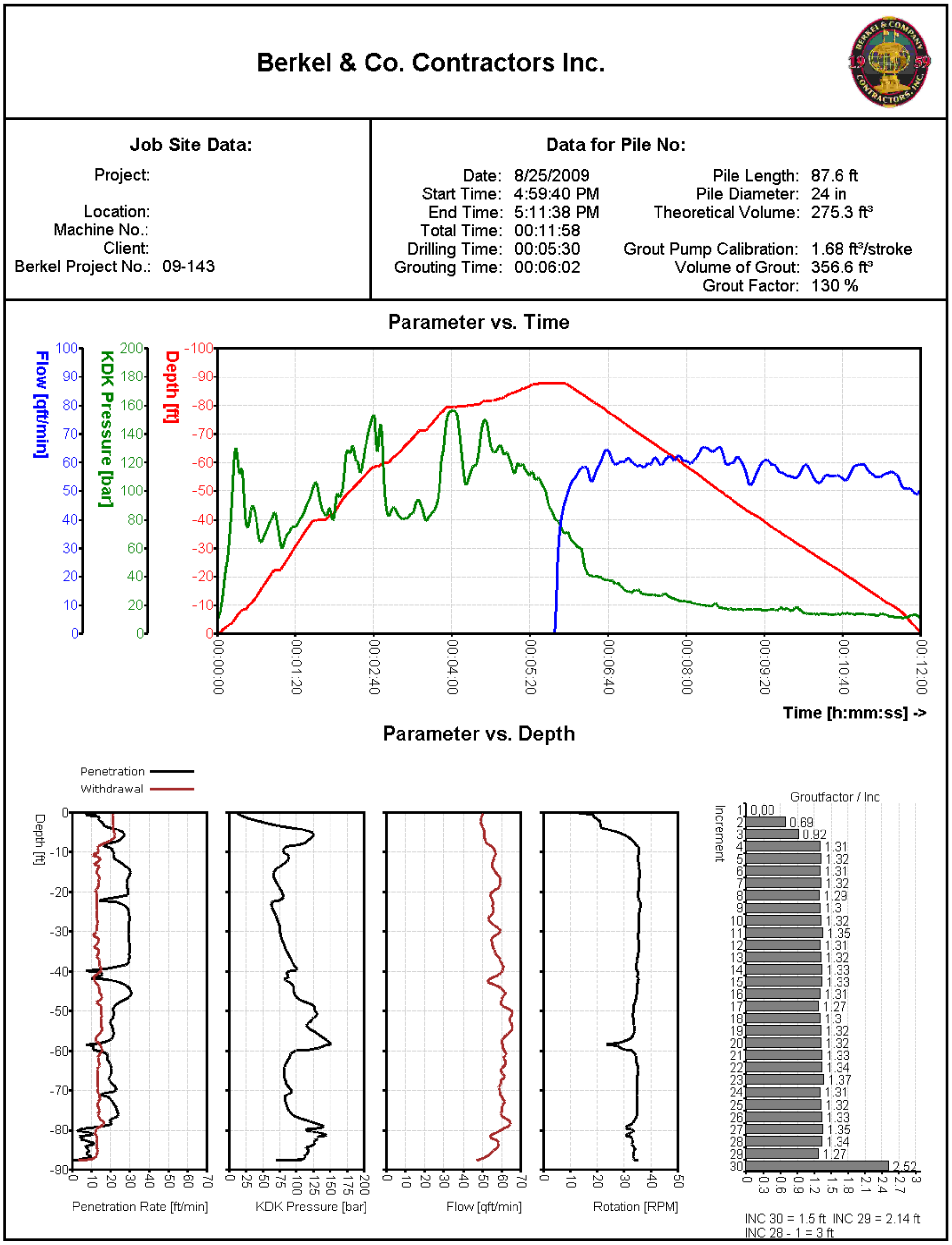

Figure 9 - Example AME installation record for ACIP and CFA piles

The test is limited in effectiveness at depths greater than 30 times the pile diameter which limits the effectiveness in long ACIP piles. More importantly, variations in pile diameter can limit the quality of the data obtained. For example, cast-in-place piles installed in soil profiles with soft upper soils will typically have nominal diameters greater than the plan diameter. As the diameter of the pile decreases back closer to plan in stiffer lower soils, reflections will occur and data beyond this point is often meaningless or worse, useless. This misreading of a return to nominal diameter as a potential reduction to less than plan is one of the most common errors in the use of this testing method. It cannot be overstressed that results from this type of NDT procedure would NEVER constitute rejection of a pile, only an indication that pile records and local stratigraphy be examined more carefully. While the technology behind the method is sound, the experience of the author has been that this is one of the most misunderstood and misused methods of NDT and, considering the limitations noted above, is not suitable for ACIP piles unless performed by very competent practitioners with a thorough understanding of procedure and the meaningfulness of the results.

Readers are strongly encouraged to refer to the referenced DFI document for a more compressive presentation of the method and its limitations as well as the Impulse Response (Sonic Mobility) Method Impedance Log/Profile Analysis which are potential enhancements to the method described here.

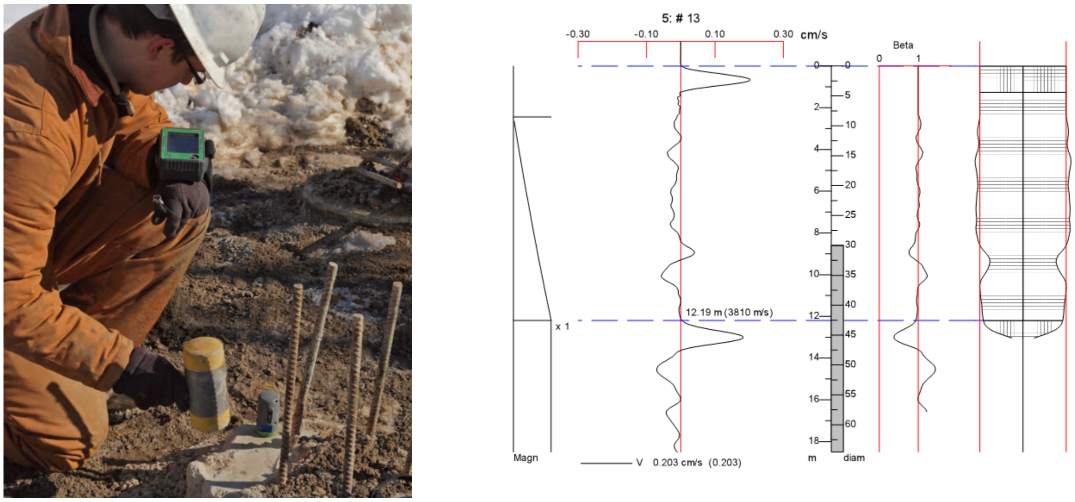

Figure 10 - Photo of Impulse Echo Test and Example Output (from GRL, Inc.)

Sonic Logging

Because of the generally small diameter of ACIP piles compared to drilled shafts, sonic logging of the piles typically consists of single-hole (or downhole) sonic logging (SSL). The method consists of inserting a sonic probe into a water-filled PVC pipe attached to, and installed with, the pile's full-length center bar. The tube should be immediately filled with water upon placement into the pile.

The single-hole probe has both a sonic source and a receiver (Figure 11) which are fixed at a known distance from each other. The speed of the generated wave from the source to the receiver is recorded as the probe is inserted through the length of the tube and the results plotted vs. depth to assess changes in wave speed which might be indicative of changes in pile diameter or grout quality (Figure 11).

Debonding of the PVC from the grout is possible and if it occurs, no meaningful data can be collected as the sonic wave will not travel to the grout surrounding the PVC pipe. Tests must typically be performed within two to three days and water must be placed in the PVC pipe before meaningful hydration begins to minimize the debonding risk.

Due to typical source and receiver spacing, the lateral range of the probes is generally considered to be 12-in to 18-in. Readers are strongly encouraged to refer to the aforementioned DFI document for additional details about the quality and limitations of data obtained through sonic logging.

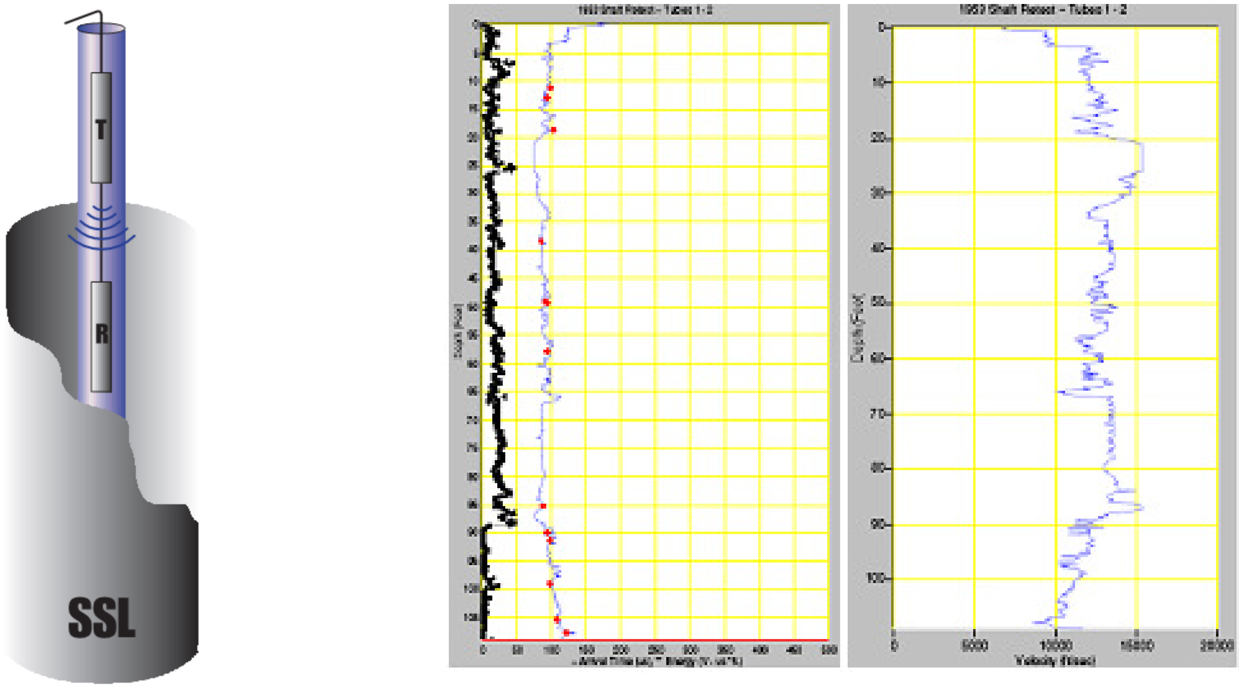

Figure 11 – Schematic of Single-hole Sonic Logging and Example Output (from GRL, Inc.)

Thermal Integrity Profiling (TIP)

The TIP process involves monitoring the temperature of the curing grout of a cast-in-place pile at or near the peak heat of hydration. This may be done by means of a thermal probe inserted into a PVC pipe attached to the center-bar of the pile or a thermal wire attached to, and embedded with, the center bar (Figure 12). The wire has thermistors every 1-ft and readings may be taken continuously at predetermined intervals. The general concept is that a uniform pile will have a uniform temperature profile. Variations in temperature might indicate increased or decreased diameter or variable grout quality. Example output from test results is shown on Figure 13. The downhole tests typically need to be run within 24 hours of pile casting. The embedded wire is typically logged between 24 and 36 hours to capture data from the maximum heat of hydration. While perhaps more flexible in this regard, the wire method is less flexible in choosing which piles to monitor as they must be selected beforehand. This allows the same thermal wire to be reused, reducing cost. While relatively new, the author's experience with TIP results has been very positive.

Figure 12 – Photos of downhole probe and wire-attached Thermal Integrity Profilers

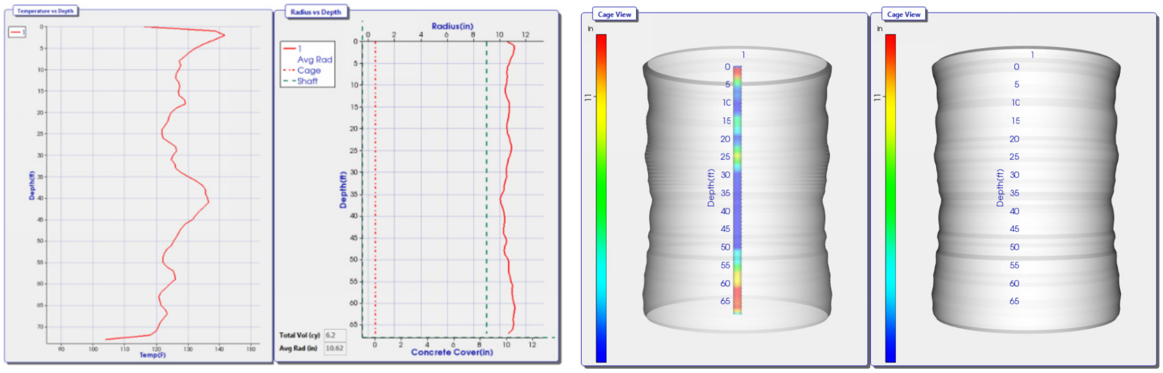

Figure 13 – Example output from Thermal Integrity Profiling (from GRL, Inc and Berkel)

ACKNOWLEDGEMENTS AND REFERENCES

The author and colleagues co-authored the article, "The Evolution of Cast in Place Piles" for the November/December 2013 DFI Magazine. This was the basis for the majority of the information presented herein regarding the history and early development of ACIP piles.

Additional references are as follows:

Brettmann, T., Hertlein, B., Piscsalko, G., Whitmire, B., Meyer, M. (2011), "Guideline for the Interpretation of Nondestructive Integrity Testing of Augered Cast-in-place Piles" prepared by the ACIP and DD Pile Committee of the Deep Foundations Institute.

Butler, H.D., and H.E. Hoy (1977) "The Texas Quick-Load Method for Foundation Load Testing," User's Manual. Report No. FHWA-IP-77-8, 1977.

NeSmith, W.M. (2015). "Recent developments in ACIP and DD piling". Proceedings of the Annual Conference of the Minnesota Geotechnical Society. February 2015

Studlein, A.W., Reddy, S.C., Evans, T.M. (2014). "Interpretation of Augered Cast in Place Pile Capacity Using Static Loading Tests". The Journal of the Deep Foundations Institute. Vol 8, No. 1, pp. 39 – 47. 09 June 2014

Waisnor, Bryan M.; Ducote-Price, Angelle; Jarosz, Ben; Duncan, Michael J., Smith, Charles J. (2001). "Geotechnical Engineering within the Piedmont Physiographic Province". Report of a study performed by the Virginia Tech Center for Geotechnical Practice and Research. August 2001