INSPECTION AND QUALITY CONTROL OF AUGERCAST PILES

George Piscsalko[1], Benjamin White[2]

ABSTRACT

Augered cast-in-place piles (ACIP) have in recent years become increasingly popular due to their relatively low cost. However, the quality of ACIP is greatly dependent on experience and the installation process. During installation, the grout volume pumped versus depth is the single most important parameter for proper installation control. In practice, quality control has been traditionally accomplished by visual observations of pump strokes. This practice may result in inaccurate determination of the incremental grout volume, often with only a single total volume measurement for the entire pile with no detail as a function of depth. This practice has led some engineers to question the quality and performance of ACIP and therefore limiting the use of this pile type.

The use of automated monitoring equipment to electronically measure and record incremental grout volume versus depth has become common during the installation of ACIP piles. Accurate measurements of incremental grout volume versus depth during grout placement allows for corrections to be made during installation. In addition, non-destructive test methods such as Pile Integrity Testing (PIT) have been widely used to effectively evaluate shaft integrity. PIT uses one-dimensional sonic wave propagation theory and can be efficiently and economically applied to a portion of piles or to every pile on a project. PIT has been proven to be a valuable tool in integrity evaluation and quality control of ACIP. Utilizing automated grout volume monitoring equipment during installation and subsequent sonic wave propagation test methods have led to higher quality assurance for ACIP.

This paper compares installation with traditional inspection methods to the improved automated monitoring methods. Example cases demonstrate some problems encountered during ACIP installation with traditional methods, and the benefits and proper use of automated monitoring equipment. Example cases from integrity testing are presented and correlated to measured grout volumes during installation.

Keywords: Auger-cast piles, Integrity Testing, automated monitoring equipment

1. INTRODUCTION

The installation of ACIP piles is highly variable due to several factors including the skill and experience of the operator, contractor, and inspector, condition and maintenance of the grout pump and rig, proper depth markings on the leads, accuracy of the pump calibration under installation type conditions (not just a simple barrel test), and pump size versus nominal pile diameter. Traditional inspection in the United States usually results in at best a total grout volume per pile based on counting the total number of pump strokes. This provides little to no assurance that the volume along the shaft is uniformly distributed, or if there are serious defects.

[1] Engineer, Pile Dynamics, Inc., 4535 Renaissance Parkway, Cleveland, OH 44128
[2] Engineer, GRL Engineers, Inc., 4535 Renaissance Parkway, Cleveland, OH 44128

The traditional approach to approving ACIP piles is to perform static load tests on a very small percentage of piles. Unfortunately, the static test pile locations are chosen before installation and are generally installed with relatively more care than non-tested piles. The resulting "grout ratio" (installed volume versus theoretical volume of the hole) is often larger for this pile than for any subsequent pile on the project.

The use of automated monitoring equipment during the installation of ACIP piles improves the installation quality and provides far greater accuracy of incremental volume versus depth than can be achieved with traditional inspection methods. The automated monitoring equipment also provides real time drilling and incremental grouting information to the operator. Potential installation problems can be immediately detected and corrected while the grout is still fluid.

The increased accuracy of automated equipment allows for greater detail in documentation of the installation. Consistent documentation allows for a direct comparison between static load test piles and other piles. Ultimately, the use of automated monitoring equipment guides the contractor to quality construction of each production pile. The output from automated monitoring equipment reassures the engineer that his or her design is being constructed to the standards required by the specifications.

2. CURRENT PROBLEMS WITH TRADITIONAL INSPECTION CONTROL OF ACIP PILES

According to section 1.3 of the Deep Foundation Institute's (DFI) "Augered Cast-In-Place Manual" (2003), "The grout volume placed for each increment of depth is the single most important installation control used during ACIP pile construction. The pile contractor's grout pump and auger equipment operators and the inspector need to continually monitor the incremental grout volume being placed." Although some projects record total volume placed per pile, many do not record the incremental grout volume. When attempted, such manual inspection of incremental volume is very difficult to achieve with reasonable accuracy. The inspector must reliably detect that a true pump stroke has occurred. This pump stroke is then given some estimated volume based on a "calibration" of the pump. The pump calibration using the traditional barrel test is insufficient, as it typically has only a very small number of strokes involved (and the grout flow is actually "continuous" so obtaining an "integer" number of strokes is very difficult at best), there is no confining pressure for the grout (as compared to when the auger is in the ground, and the barrel must be "under filled" with the missing volume accurately determined.

During pile installation, the pump does not always maintain a repeatable volume per pump stroke, and is often highly variable. The actual volume pumped per stroke is variable due to changing confining pressures related to soil strength with depth, variable height of the gear box (thus concrete head during grouting), maintenance changes during the project, pump speed, hose condition, grout consistency, and a variety of other factors that can change throughout the project. Pump malfunctions produce essentially zero volume for some pump strokes. Disturbances on the grout hose from sources such as construction equipment driving over the lines cause errors when counting pump strokes from the grout line pressure. Therefore, monitoring devices that only count pump strokes to determine grout volume suffer from inaccuracies as they assume a constant volume per pump stroke. During times when the pump is running inconsistently, the inspector often counts "missed pump strokes" and thus indicates more volume than actually pumped. To compound this problem, the missing strokes are often clustered so that a section of the pile may be seriously under pumped.

Finally the inspector must determine the exact depth of the auger where this pump stroke has occurred and then manually record this stroke at the appropriate depth. Often the leads are poorly marked and are typically only marked every 1.5 m, thus depth resolution at best poor.

Alternate methods for more accurately determining the incremental grout volume as well as grout line pressure and lift height are needed.

3. USING AUTOMATED MONITORING EQUIPMENT FOR THE INSTALLATION OF ACIP PILES

Proper inspection control of ACIP piles will evaluate that the drill does not over excavate the soil, that the incremental grout volume be accurately measured and recorded, that the grout line pressure be continuously measured and recorded, and that the auger movement be accurately measured. Automated monitoring equipment can assist the inspector and design engineer in assuring accurate incremental grout volume. Automated monitoring equipment also provides real time information to the operator so any grout deficiencies can be corrected while the grout is still fluid.

The Pile Installation Recorder for ACIP piles (PIR-A) consists of the following components:

- The PIR-A main control unit provides signal conditioning for all sensors, processes the measured data, and displays the drilling and grouting information in real time for the operator.
- The depth sensor is a tensioned steel cable attached to the gearbox that is routed over a rotary encoder, allowing the depth sensor to monitor the movement of the auger. The actual depth sensor resolution is 0.6mm, although recording is made only to one inch.
- The grout line pressure sensor continually measures the grout line pressure. The minimum, maximum, and average grout line pressures are recorded.
- The magnetic flow meter is installed in the grout line to measure grout volume.
- The torque pressure sensor installed in the hydraulic line measures the auger torque during drilling.

Automated monitoring equipment records both the drilling phase as well as the grouting phase for ACIP piles. During drilling, auger tip depth, torque, and drilling speed are recorded. Over rotation of the auger, which can cause over-excavation of soils, can be easily observed by the time required to drill each increment and the displayed drill rate, and therefore measures are taken to minimize this occurrence. When the auger tip reaches the design depth, the operator initiates the grouting mode. In the grouting mode, the automated monitoring equipment measures and displays the grout volume for every increment of depth both graphically and numerically. The operator can adjust his withdrawal rate to produce a pile satisfying the incremental grout volume requirements. The grouting depth increments are user selectable as per the specifications given by the design engineer (600 mm increments are recommended by the manufacturer). Since the operator observes the incremental grout volumes on the PIR-A in real time, the auger withdrawal rate can be adjusted to ensure that sufficient grout is pumped into each increment. If the operator observes an increment with insufficient grout, he can simply immediately stop the auger withdrawal process, re-drill to below the deficiency and re-grout the pile while the grout is still fluid.

Upon completion of the pile grouting, a detailed record is printed for both the drilling and grouting phases of the pile. The printout for each pile includes maximum drilling depth with the associated time and torque for each depth increment, incremental grout volume and grout ratio for each depth increment, and summary volumes including total volume pumped for the pile. This printed summary can be immediately reviewed by the inspector upon completion of the pile. Any detected problems can be corrected before moving the rig to the next pile location. All data for each pile is stored on a memory card, allowing it to be reviewed in greater detail if necessary.

4. PILE INTEGRITY TESTING

In addition to monitoring incremental grout volume during drilling, Pile Integrity Testing (PIT) can also assure quality in augercast pile construction. After a sufficient curing period, typically a minimum of 7 days, each pile can be tested quickly and economically. PIT uses a handheld hammer to impact the pile top and generate a compressive stress wave which propagates along the pile. Stress wave inputs and reflections (from non-uniformities or the pile toe) are measured as a function of time by an accelerometer attached to the pile top. The acceleration is integrated to velocity for interpretation by the test engineer.

PIT results include a velocity versus time curve from which the engineer can determine if the shaft has defects or cracks. Defects are often a decrease in cross-sectional area (necking), which is typically caused by too little grout being placed in a pile increment. Correlation can be made between PIT records and PIR-A records to verify possible necking. If necking occurs in a shaft, PIT records can show a tension reflection in the velocity record prior to the toe reflection (if observed), while the PIR-A record may show a low grout volume for the corresponding segment.

5. CASE HISTORY USING LARGE PUMPS WITH SMALL DIAMETER HOLES

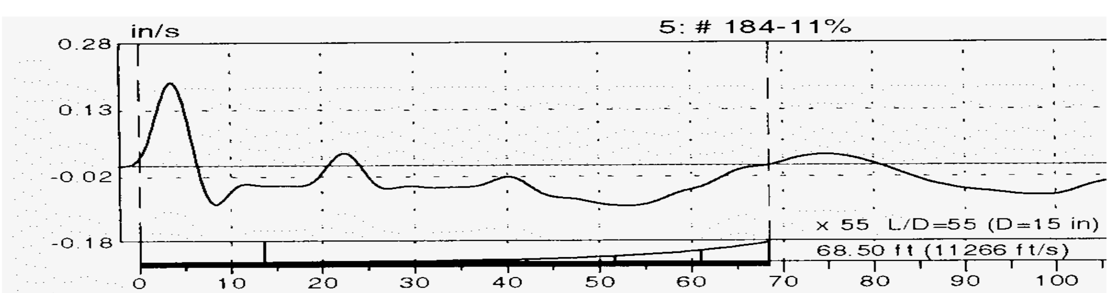
Automated monitoring equipment recorded 38 cm diameter ACIP piles drilled to a depth of 19 to 21 m (Piscsalko & Likins 2004). All piles were installed with a 76.5m^3/hour pump with a field calibration of 0.026 m^3/stroke. For a 38 cm hole with a nominal area of 1.13 m^3, each stroke would fill about 0.23 linear meters. Although the recommended output increment is 600 mm, the contractor initially selected output increments of 1.5 m.

Due to a large pump relative to the pile diameter, the operator was required to withdraw the auger at a very rapid rate to avoid large amounts of excess grout. High withdrawal rates can increase the potential for under grouting. If the pump misses one or more strokes, a substantial distance receives little or no grout, thus creating a potential major structural deficiency. If the operator experienced missed strokes in the 1.5 m increment, the auger withdrawal can be slowed at the end of the increment to compensate. Thus, the 1.5 m section may look “filled”, although not uniformly. For this reason the 1.5m increments chosen had insufficient resolution to see any relatively short grout deficiencies.

The project specifications also required that each pile be tested with low strain pile integrity testing (Piscsalko & Likins 2004). The PIT velocity output for this pile is shown in Figure 1 and reveals a reduction in cross section at approximately 6 m depth. The reduction can be observed by the strong relative increase in signal starting at that depth (relative to the start of the curve at depth zero), indicating a tensile reflection from a cross section reduction.

When the data for this shaft was reprocessed using 600 mm intervals (Figure 2), a grout volume ratio of 82 and 76% of theoretical (which is 66 and 61% of the specified 125% grout ratio required for this project) at 7.9 to 7.3 m and 7.3 to 6.7 m, respectively, was observed. The low volume indicators (**) on the printout make it very easy for the inspector to quickly evaluate a shaft immediately upon completion and recommend any corrective action while the grout in the shaft is still not set.

The PIT test results correlated well with automated monitoring records using the recommended 600 mm output increments. The minor difference in depth of the reduction is due to an assumed wave speed for PIT (from which the depth is calculated), or change in pile top elevations in completing the pile. After testing several shafts on this project in a similar manner, the contractor and inspector changed the output report increment to 600 mm. This provided the operator and inspector with the accuracy needed to install a uniform shaft while still allowing the operator to withdraw at a very rapid rate due to the very large pump (relative to the hole size) used on this project.



Withdrawal Data [start 14:06]

depth (ft)	pumped volume (ft3)	ratio (%)	line_pres min (PSI)	line_pres max (PSI)
69.0		(max depth)		
67.6	10.28		(Stem+Head vol)	
66.0	5.79	236	4	279
64.0	3.00	122	164	279
62.0	4.63	188	171	254
60.0	3.21	131	171	269
58.0	3.35	137	203	268
56.0	2.61*	106	199	268
54.0	2.51*	102	189	268
52.0	3.28	134	200	259
50.0	4.56	186	200	272
48.0	3.99	163	212	267
46.0	3.67	150	212	268
44.0	2.72*	111	206	268
42.0	4.73	193	206	272
40.0	3.28	134	206	274
38.0	2.79*	114	203	259
36.0	3.18	129	203	259
34.0	4.63	188	203	273
32.0	3.53	144	208	265
30.0	3.43	140	204	265
28.0	2.30**	94	200	252
26.0	5.01	204	198	268
24.0	1.87**	76	198	268
22.0	2.01**	82	194	252
20.0	6.18	252	194	263
18.7	<-- return depth			
18.0	1.66**	68	198	252
16.0	6.07	247	198	283
14.0	3.28	134	198	283
12.0	3.64	148	201	261
10.0	4.45	181	201	261
8.0	3.85	157	205	260
6.0	3.53	144	205	260
4.0	2.68*	109	203	260
2.0	3.39	138	203	260
0.0	3.85	157	69	269
	0.04		(spill vol)	

[stop 14:11 (00:04:21)]

Nominal Inc Vol: 2.45 ft3 (2.0 ft)
Target Inc Vol: 2.82 ft3 (2.0 ft)
Nominal Vol: 84.65 ft3 (15.0 in dia)
Min Target Vol: 97.35 ft3 (115%)
Pile Vol: 122.68 ft3 (145%)
Stem+Head Vol: 10.28 ft3 (8.4 ft)
Spill Vol: 0.04 ft3
Total Vol: 133.00 ft3

* pumped volume < target volume
** pumped volume < nominal volume

Figure 2. Pile Installation Recorder Results

6. CONCLUSIONS

The traditional manual inspection process for ACIP pile installation often results in inaccurate and incomplete documentation. The DFI ACIP Manual guidelines are desirable goals, but even when incremental depths are recorded manually, it is practically impossible to achieve sufficient incremental grout volume accuracy. Undocumented defects can result through this traditional inspection process.

The use of automated monitoring equipment on ACIP pile installations provides the operator with real time incremental grout volume, which is the most critical information needed for proper quality control as identified by DFI. The PIR-A measurements follow the DFI ACIP manual recommendations. The use of a magnetic flow meter is essential to obtain accurate incremental grout volumes since volume from counting pump strokes can be misleading, especially in the case that the pump malfunctions. Volumes from the magnetic flow meter are determined within 2%, and the actual depth resolution is 0.58 mm (although recording is made only to one inch). Thus, automated monitoring equipment is capable of extremely accurate determination of incremental grout volume placed.

ACIP contractors and operators are given guidance by the automated monitoring equipment to improve the quality of ACIP piles. If the monitoring equipment detects a low grout volume for any depth increment, the auger withdrawal can be immediately halted, the pile can be immediately re-drilled past the deficiency, and the pile re-grouted while the grout is still fluid to correct the problem. The availability of more accurate ACIP pile information will provide the design engineer with a greater degree of confidence when specifying ACIP piles.

It is shown that recording incremental grout volume for 1.5 m increments, as recommended by DFI guidelines for manual inspection, is not sufficient. There is a possibility that a large section within a 1.5 m increment will be under-pumped, while the remainder of the increment has been over-pumped. This incorrectly makes the increment appear to be filled properly, when there could be significant defects. Automated monitoring equipment can very easily provide incremental grout volume for 600 mm (or finer) increments, thus significantly decreasing the possibility of under grouting.

REFERENCES

Augered Cast-In-Place Manual., Deep Foundation Institute (Hawthorne NJ), 56 pages, 2003.

Piscsalko, G., Likins, G., "Automatic Inspection Control of Augercast Piles." *TRB Conference*, Washington, DC, January 11-16, 2004.

Likins, G., Beim, G., Morgano, M., Piscsalko, G., and Goble, G., "Construction Control for Augercast Piling." *Proc. of Geo-Denver Conference, American Society of Civil Engineers Geo-Institute*, Denver, Colorado, August 5-8, 2000.