Automated Inspection Control of Augercast Piles

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Abstract.

Augered cast-in-place (ACIP) piles have become increasingly popular. However, the quality of this pile is highly dependent upon the installation process. The Deep Foundations Institute (DFI) ACIP Manual gives guidance for proper installation and inspection. During the installation of ACIP piles, this manual stresses that incremental grout volume pumped versus depth is the single most important parameter for proper installation control. Unfortunately, traditional quality control is accomplished by visual observation and manual documentation methods. In practice, this results in inaccurate determination or documentation of the incremental grout volume, often with only a single total volume measurement for the entire pile with no detail of grout distribution as a function of depth. The use of automated monitoring equipment to electronically measure and record this incremental grout volume versus depth with high precision has become quite common during the installation of ACIP piles.

This paper compares installation with traditional inspection methods to improved practice following the DFI manual guidelines. Example cases demonstrate some problems encountered during ACIP installation with traditional methods, and the benefits and proper use of automated monitoring equipment during the installation of ACIP piles.

Automated Inspection Control of Augercast Piles

INTRODUCTION

There are many factors that determine the quality of installation for an augered cast-in-place (ACIP) pile. Several of these factors include the skill and experience of the operator, condition and maintenance of the grout pump and rig, skill and experience of the inspector, proper depth markings on the leads, skill and experience of the contractor, 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 USA 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. The rotation and penetration rate during augering can cause over-excavation of soils and the resulting problems on adjacent structures, and reduction of pile capacity for all piles on site due to loosening of the soils (*1*).

The usual "proof" of ACIP installations is a static test on one pile, or at most a very small percentage of piles. Unfortunately, the static test pile location is chosen before installation and usually great care is taken by the contractor during this pile's installation so that the load test passes. As a result, the "grout ratio" (installed volume versus theoretical volume of the hole) is often larger for this pile than for any subsequent pile on the project. Even so, there are numerous instances of structural failures during the static test, with several such examples shown in reference (*2*). Because production piles with lower grout ratios would fail structurally at even lower loads, and with a trend to higher ACIP loads and less redundancy, it is therefore imperative that production piles attain at least the same grout volumes as the test pile.

The use of automated monitoring equipment during the installation of ACIP piles improves the installation quality by eliminating reliance of many of the factors listed above, and provides far greater accuracy of incremental volume versus depth than can be achieved with traditional inspection methods. In addition to greater detail in the installation records of incremental volume versus depth, the automated monitoring equipment also provides real time drilling as well as incremental grouting information to the operator so any potential installation problems can be immediately detected and corrected while the grout is still fluid. The drilling depth and torque are presented to the operator numerically and the incremental grout volume is presented both numerically as well as graphically for ease of use. The graphical presentation alerts the operator if any depth increment has insufficient volume so this potential defect can be immediately corrected while the grout is still fluid.

This greater accuracy allows for greater detail in documentation of the installation. This documentation also allows more direct comparison with the load test pile installation, and guides (and perhaps inspires) the contractor into a more careful construction of each production pile. The capabilities of automated monitoring equipment can help the engineer to completely understand in detail the installation of the ACIP piles.

CURRENT PROBLEMS WITH TRADITIONAL INSPECTION CONTROL OF ACIP PILES

According to the Deep Foundation Institute (DFI) "Augered Cast-In-Place Manual" (*3*), section 1.3 states "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." While some inspection companies make such recordings and some regions of the country are better than others in compliance, most ACIP inspections in the United States record only the total volume pumped per pile. Even when measured, such manual inspection of incremental volume is very difficult to achieve with reasonable accuracy.

First the inspector must reliably detect that a true pump stroke has occurred. This pump stroke is then given some estimated volume based on some "calibration" of the pump. The pump calibration using the traditional barrel test is not sufficient, 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 highly variable in some cases, often even missing strokes due to valve problems. The pressure measured in the grout line can reveal surprising information about the performance of the grout pump. For example, Figure 1 shows a real pump operating normally, while Figure 2 shows the same pump later on the same pile behaving erratically (and missing pump strokes). The authors' experience (based on numerous such measurements) has shown at such times that no volume actually flows, although the inspector usually counts "pump strokes" during this time, and thus indicating more volume than actually pumped. To compound this problem, the missing strokes are often clustered so that a section of the pile depth increment 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 5 feet. Thus depth resolution is at best poor.

Although the contractor usually controls the withdrawal rate based on his counting of strokes, the inspector is busy with other tasks such as observing the completion of previous piles, and thus the inspector in most cases does not document the incremental volume but rather records only the total pump stroke count and thus total volume per pile. The distribution of this volume along the shaft is then often undocumented and thus unknown (in the authors' experience of reviewing installation records of ACIP tests in relation to low strain integrity testing, more records lack incremental volume than have it). The combination of these effects may result in undocumented grout deficiencies along the pile shaft. Even in cases where incremental volume is documented, the accuracy is poor due to inaccuracies in volume measurement (e.g. calibration, pump performance, maintenance) and also due to depth resolution and parallax errors.

The DFI "Augered Cast-In-Place Manual" (*3*) section 1.3 further states "It is important that sufficient pressure be maintained to assure a constant flow of grout to the auger. Only in this way can adequate grout quantities be built up on and around the auger flighting." However, it is impractical for the inspector to watch the analog pressure gage located on the pump, while also watching the auger location, while counting and recording the pump strokes. In most cases it is not even possible for the inspector to have his foot on the hose for pump stroke counting and still be in position to see the pressure gage on the pump. These pressure measurements are typically not monitored, nor recorded on most manual inspection log sheets.

In the USA practice, according to the DFI "Augered Cast-In-Place Manual" (*3*) section 3.4.9, "The auger may be either withdrawn continuously or in small increments. These discrete lift increments should be limited to at most 12 inches (300mm).” The International Building Code (*4*) also notes that “The auger shall be withdrawn in a continuous manner in increments of about 12 inches (305 mm) each.” However, most leads are not marked every 12 inches, making it nearly impossible for the inspector to visually determine the lift heights. Typical practice of pumping a specific number of strokes per lift (calculated from pump stroke volume to satisfy the required volume) can result in under pumping if the lift height is inadvertently too large, or when the pump malfunctions as in the case shown by Figure 2. In case of pump malfunction, some grout will be supplied from the auger stem although it would take many seconds to naturally empty, but if the lift increment is too high and too fast, suction forces may cause a cave-in even if the stem had full grout.

Section 3.4.7 of the DFI ACIP Manual (*3*) states “The most desirable precautions that are available in the construction of ACIP piles are to: pump the specified initial grout head prior to withdrawal of the auger, maintain grout pumping while installing the required incremental grout volume as the auger is being withdrawn, and observing grout return when the auger’s depth below the ground surface is equal to or greater than the specified initial grout head. The observation of these three conditions are the most useful quality control tools that can be utilized in ACIP pile construction.” The requirement for grout return observation assures the pile has not encountered an adverse local ground condition such as a cavity.

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

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 to insure when applicable that no lifts exceed 12 inches (300mm). Automated monitoring equipment can assist the inspector and design engineer in assuring accurate incremental grout volume, grout line pressure, and lift height when applicable. Automated monitoring equipment also provides real time information to the operator so any grout deficiencies can be corrected while the grout is still fluid.

Monitoring devices that only count pump strokes to determine grout volume suffer from inaccuracies as they assume a constant volume per pump stroke. The actual volume pumped per stroke is variable due to variable confining pressures related to changing soil strength with depth, variable height of the gear box and 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 during the day. Pump malfunctions as in Figure 2 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. A magnetic flow meter is a much more accurate system of measuring grout volume, and is required by specification in England (*5*) because they concluded that volume determination by any other means was inaccurate.

The drawing in Figure 3 shows the overall configuration of an automated monitoring equipment system called the Pile Installation Recorder for Augercast piles (PIR-A). The PIR-A main control unit [#1] 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

[#2] 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 0.025 inch (0.6 mm), although recording is made only to one inch. The grout line pressure sensor [#3] continually measures the grout line pressure. The minimum, maximum, and average grout line pressures are recorded. The magnetic flow meter [#4] is installed in the grout line and works on the principal of Faraday's Law of Induction, which states that a conductor (e.g. grout or concrete are about 3 orders of magnitude more conductive than the minimum required) that passes through a magnetic field will cause a voltage to be induced which is proportional to the velocity at which the conductor is moving. Knowing the cross sectional area of the flow tube and the velocity of grout movement, the flow volume is easily determined to an accuracy within 2%, as proven by the authors in numerous laboratory and full scale field tests under pulsed pumping conditions. The manufacturer of the particular flow meter used actually quotes 0.25% accuracy at the typical flow rates achieved for ACIP pumping, and 1.5% accuracy at near static flow rates, both of which are far more accurate than the application requires. This grout volume measurement is completely independent of pump stroke counting (dividing the total volume from the flow meter by counted pump strokes gives a true volume per pump stroke, useful to evaluate pump consistency or maintenance needs). The magnetic flow meter has a ceramic liner that has shown no appreciable wear after several years of continuous service. The calibration is always checked prior to field application; flow meters which have been returned following long periods of use have always shown stable calibration. The torque pressure sensor [#5] 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 it records the auger tip depth, torque, and drilling speed. 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 taken to minimize this occurrence. When the auger tip reaches the design depth, the operator presses a key to initiate 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, which is compared to the required volume based on an input target incremental grout ratio specified for the pile. 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, but 2 foot or less increments (500 mm) give sufficiently detailed information and minimize the possibility of local defects. Since the operator observes the automated monitoring equipment incremental grout volumes in real time, the auger withdrawal rate can be adjusted to insure that sufficient grout is pumped into each increment. If the operator sees 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. It should be mentioned that the inspector is not eliminated, but rather the automated monitoring equipment supplements the various observations that the inspector must perform for which the automated equipment is incapable.

ACIP contractors find that their operators appreciate the guidance given by the automated monitoring equipment during grouting, and find it helpful to assure quality control, and assist when entering new markets where quality concerns have limited ACIP pile use (*6*). The equipment is mounted to the installation crane near the crane operator to minimize cable lengths and their exposure to harm. Because the only moving part is the depth sensor cable attached to the gearbox, it therefore has proven very durable with minimal down time, with the vast majority of such systems reporting no problems. Occasional problems occur, generally due to either the power source (e.g. rigs hit by lightening, or weak crane batteries) or the lacing of the cable for the depth sensor in the boom, but are generally resolved within one day in the USA practice. Very little maintenance is required other than the periodic greasing of the (optional) pressure sensor fitting.

CASE HISTORY WITH LARGE LIFT HEIGHTS

The automated monitoring equipment monitored the 18 inch (450 mm) ACIP piles which ranged in depth from 47 to 56 feet (14 to 17 m). The data for all piles was initially logged with uniform 2 ft (600 mm) depth increments. However, while installing these piles, the operator used discrete lifts and then pumped the required grout for this increment before continuing to pull the auger in lifts out of the hole. Because the operator purposely chose to make only one lift per selected depth increment, the average lift height of 2 foot (600 mm) was double the recommended 1 foot (300 mm) lift height recommended in the DFI “Augered Cast-in-Place Manual” (*3*) and the International Building Code (*4*).

The volume pumped by the discrete lift method as a function of depth shows (Figure 4) that the grout was pumped primarily at one depth for each large lift height, with some grout pumped during the transition pull for each lift. The actual lift heights varied from 15 inches (375 mm) to a maximum of 32 inches (800 mm). The printed record for this pile is shown in Figure 5. At each ‘Auger (tip) Depth’ the ‘dD’ lift height, the ‘pumped volume’ in ft^3 for the entire increment listed (integral of the volume versus depth between successive lifts), and the ‘volume ratio’ (percentage of grout pumped per lift increment compared to the nominal hole volume for that lift increment) are listed. When a lift height greater than 15 inches (or 20 inches) is measured, a special indicator (# or ##) is printed to alert the operator and inspector of excessive lift heights. Printing this data as if it had been taken with the lift mode reveals that almost every lift height increment is in violation of the recommended maximum lift height. Although the grout will distribute itself within the lift increment and some grout will drain from the hollow auger stem acting as an accumulator, excessively large lift heights such as this can create suction forces (if the stem does not drain faster than the lift, which is usually the case) and cause necking defects, and is the reason for this lift height restriction.

For the minimum target grout ratio of 125% for this project, the operator was fortunately led by the monitoring equipment to pump sufficient grout into each 2 ft depth increment, until the “grout return” was observed at the ground surface (at about 6 ft auger tip depth). Section 3.4.7 of the DFI ACIP manual (*3*) recommends after grout return is observed that the grout pumped should be at least 100% of the theoretical volume of the hole, so after grout return this pile was under-pumped.

Had the operator simply counted pump strokes for estimated volume, it is likely that grout deficiencies would have occurred because of the operator’s poor judgment and inconsistency in estimating lift heights. When the lift heights are excessive, there is then an increased risk of having grout deficiencies in the pile due to caving or necking. Automated monitoring equipment with the special "lift mode" function makes it possible to give adequate guidance and evaluate this type installation process.

CASE HISTORY USING LARGE PUMPS WITH SMALL DIAMETER HOLES

Automated monitoring equipment recorded 15 inch diameter ACIP piles drilled 65 to 70 feet. All piles were installed with a 100-yard/hour pump with a field calibration of 0.92 ft^3/stroke. For a 15 inch hole with a nominal area of 1.23 ft^3, each stroke would fill about 0.75 lineal feet. Although the recommended output increment is 2 feet (300 mm), the contractor initially selected output increments of 5 feet.

Due to the large pump used relative to the hole size, the operator was required to withdraw the auger at a very rapid rate to avoid large amounts of excess grout. Although the DFI manual (*3*) is silent about the pump size relative to the hole diameter, conventional wisdom and customary practice is to select pump capacity based on the diameter of the hole (e.g. use smaller displacement pumps for smaller diameter holes) to provide more control.

An additional problem with a high withdrawal rate occurs when the pump misses one or more strokes, resulting in a substantial percentage under-pump and thus potentially a major structural deficiency. If the operator experienced missed strokes in the 5 ft increment, he could slow the auger withdrawal at the end of the increment to compensate. Thus, the 5 foot section may look "filled", although not uniformly, but the 5 feet increments had insufficient resolution to see any short grout deficiencies. Figure 6 shows the automated monitoring equipment result for a pile using 5-foot increments showing no grout deficiencies.

However, the project also required that every pile be tested with low strain pile integrity testing (*7*). Pile integrity testing (PIT) uses a handheld hammer to impact the pile top and generate a compressive stress wave in the pile. Stress wave inputs and reflections (from non-uniformities or the pile toe) are measured as a function of time by an accelerometer at the pile top. The acceleration is integrated to velocity for interpretation by the test engineer. The PIT output for this pile is shown in Figure 7, and reveals a reduction in cross section at 20 feet, as observed by the strong relative increase in signal starting at that depth (relative to start of curve at depth zero), indicating a tensile reflection from a cross section reduction.

When the data for this shaft was reprocessed using 2-foot intervals (Figure 8), 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 26 to 24 feet and 24 to 22 feet 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 fluid.

The PIT test results correlated well with automated monitoring records with the recommended 2-foot output increments. Minor differences in depth are due to assumed wavespeed 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 2 feet. 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.

CONCLUSIONS

The traditional manual inspection process for ACIP pile installation often results in inaccurate and incomplete documentation. Traditional manual inspection in the USA usually results in only a single total volume for the entire pile, and thus the grout distribution along the length is unknown. 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 by manual inspection for most projects due to several error sources including sporadic pump malfunctions and depth determination errors. 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 installation 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 when the pump malfunctions. Volumes from the magnetic flow meter are determined within 2%, and the actual depth resolution is 0.023 inch (although recording is made only to one inch). Thus, automated monitoring equipment is capable of extremely accurate determination of incremental grout volume pumped.

ACIP contractors and operators are given guidance by the automated monitoring equipment to improving 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.

USA practice allows ACIP piles to be installed by either a continuous withdrawal method or by discrete lifts. Automated monitoring equipment documents incremental volume versus depth for the continuous withdrawal method. For ACIP piles installed using a lift method, the PIR-A is very beneficial to the operator, inspector, and engineer as it provides accurate incremental grout volume for each discrete lift, and it easily alerts the inspector when any discrete lift has exceeded a predetermined maximum lift height. The lift heights can be determined to within an inch for automated monitoring equipment and can guide the operator during the lift process to desired lift heights and grouting the required volume per lift.

It is shown that recording incremental grout volume for 5-foot increments, as recommended by DFI guidelines for manual inspection, is not sufficient as there can very easily be large sections in this 5 foot increment that have been 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 2-foot (or finer) increments, thus eliminating this error. Use of large capacity grout pumps for relatively small diameter ACIP piles is discouraged because of lack of good control of the withdrawal rate during grouting.

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List of Figures:

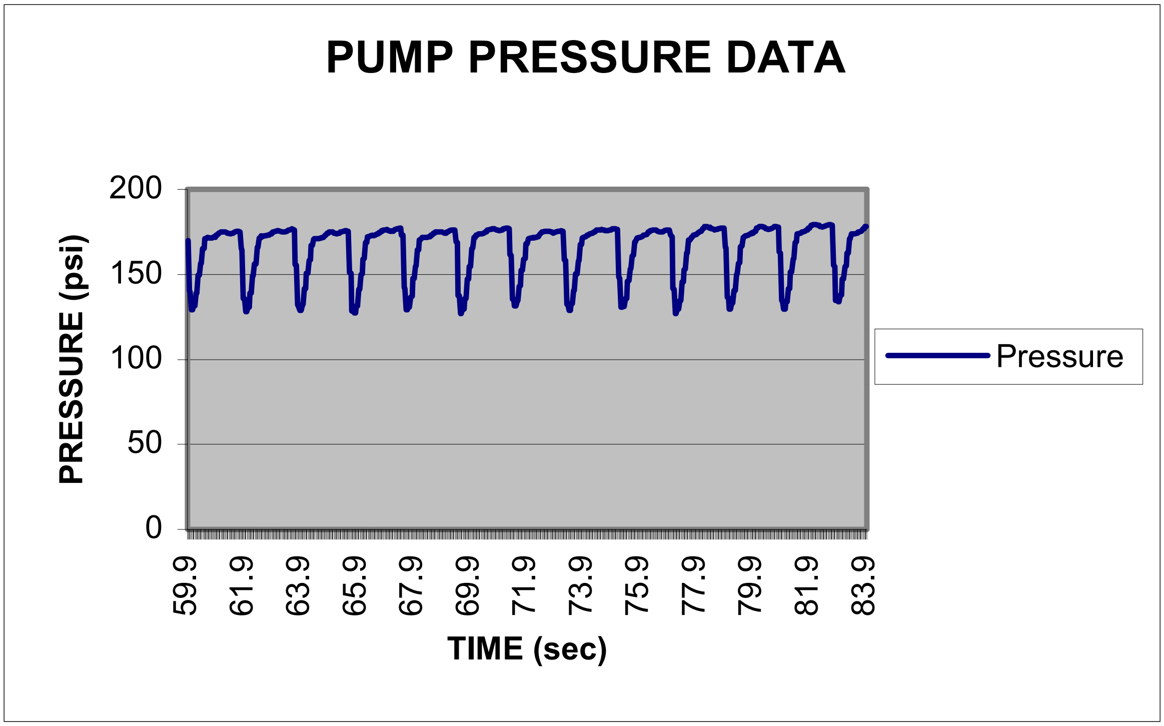

FIGURE 1 Grout line pressure for properly operating pump.

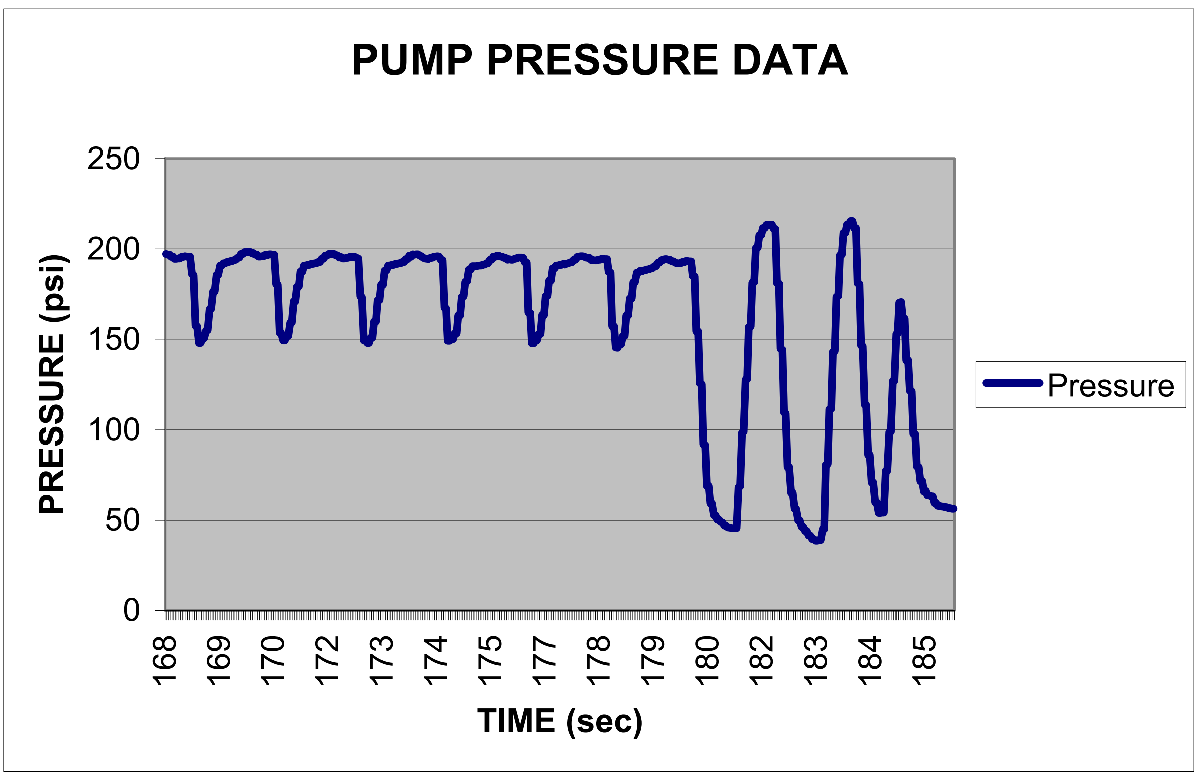

FIGURE 2 Grout line pressure for improperly operating pump (missing cycles at end).

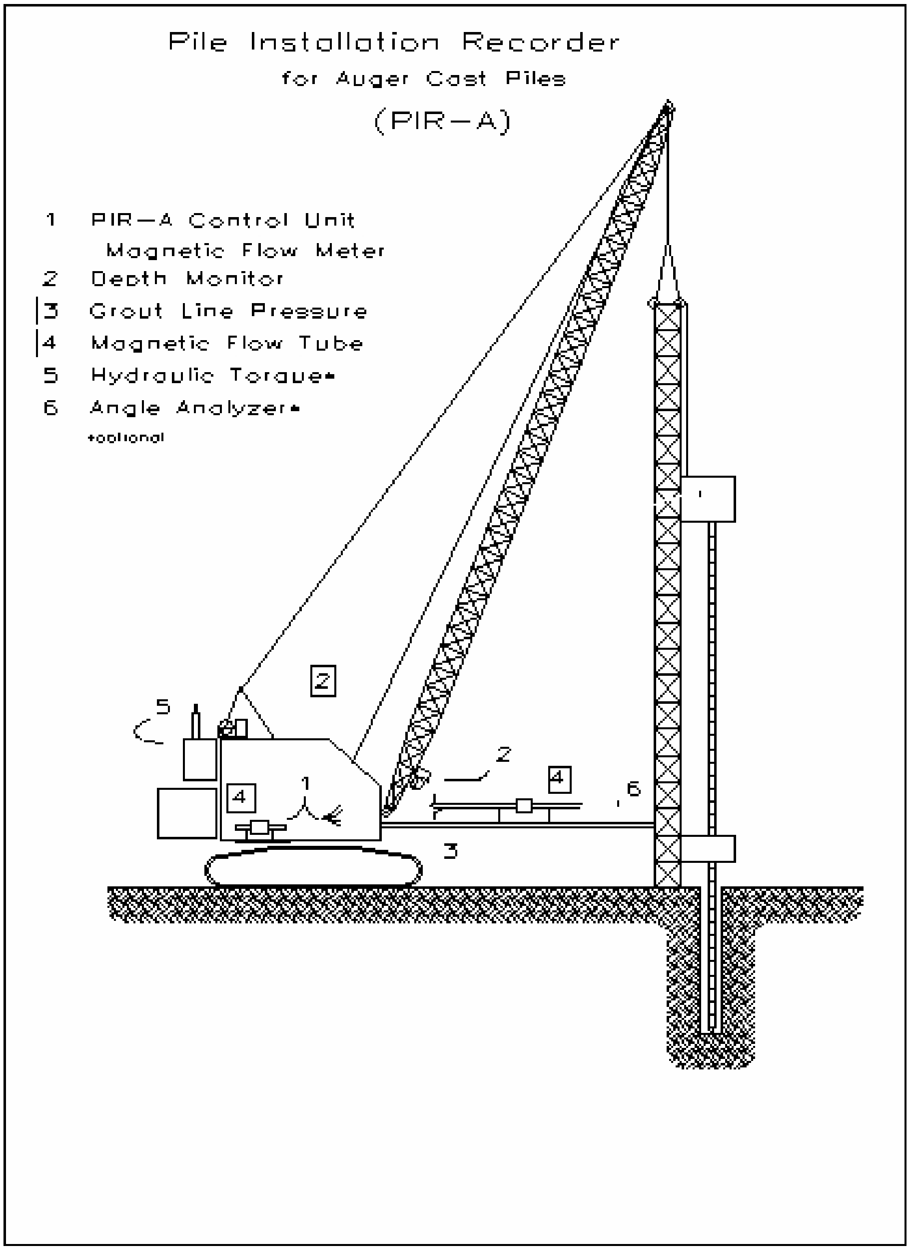

FIGURE 3 Schematic of automated monitoring equipment.

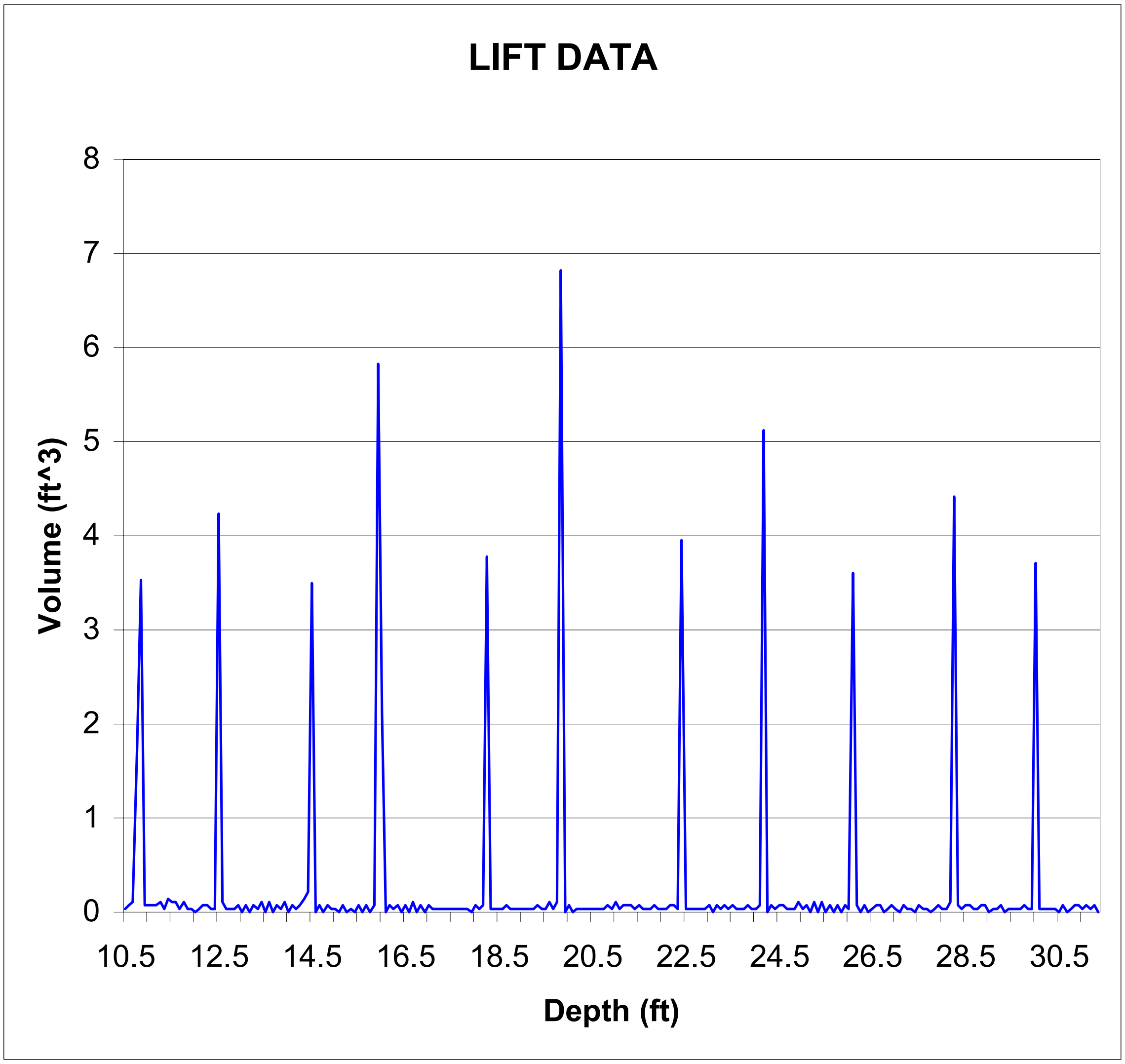

FIGURE 4 Grout volume pumped versus depth for discrete lift method.

```
Withdrawal Data  [start 7:40]

             pumped   volume
 depth  dD   volume   ratio
  (ft)  (in)  (ft3)     (%)
 48.0                        (max depth)
 45.9   24   6.11  #    138  (Stem+Head vol)
 44.7   15   6.99       198
 42.2   29   5.83  ##   165
 39.9   27   5.54  ##   157
 38.1   21   5.05  ##   143
 36.3   20   5.54  #    157
 34.7   19   7.98  #    226
 32.3   27   5.16  ##   146
 29.8   29   4.91  ##   139
 28.1   20   5.30  #    150
 25.9   25   4.73  ##   134
 24.0   22   6.14  ##   174
 22.3   20   4.87  #    138
 19.7   30   8.19  ##   232
 18.1   18   4.45  #    126
 15.8   27   8.90  ##   252
 14.3   16   4.56  #    129
 12.3   23   5.51  ##   156
 10.7   19   6.46  #    183
  8.6   24   4.27* ##   121
  5.8   32   4.13* ##   117
  4.2   18   1.94**#     55
  2.2   23   2.33**##    66
  0.0   26   3.00**##    85
             2.30           (spill vol)
                 [stop 7:51 (00:10:45)]

Nominal Vol:      84.82 ft3 (18.0 in dia)
Min Target Vol: 106.02 ft3 (125%)
Total Vol:      130.07 ft3
Spill Vol:        2.30 ft3
Pile Vol:       127.77 ft3 (151%)
Shaft Vol:      121.66 ft3 (143%)
Stem+Head Vol:    6.11 ft3 (2.0 ft)

 *  pumped volume < target volume
 ** pumped volume < nominal volume
 #  Lift Height > 15 in
 ## Lift Height > 20 in
```

FIGURE 5 Automated monitoring printout for discrete lift method.

```
Withdrawal Data  [start 14:06]
        pumped volume  line_pres
 depth  volume ratio   min   max
 (ft)   (ft3)    (%)          (PSI)
 69.0                        (max depth)
 67.6  10.28                 (Stem+Head vol)
 65.0   7.17    146     4   279
 60.0   9.57    156   171   269
 55.0   7.24    118   189   268
 50.0   9.08    148   200   272
 45.0   9.04    147   210   268
 40.0   9.43    154   206   274
 35.0   8.93    146   203   273
 30.0   8.76    143   204   265
 25.0   8.23    134   198   268
 20.0   9.04    147   194   263
 18.7  <-- return depth
 15.0   9.43    154   198   283
 10.0   9.50    155   201   261
  5.0   8.83    144   205   260
  0.0   8.37    136    69   269
        0.04                (spill vol)
                 [stop 14:11 (00:04:21)]

Nominal Inc Vol:  6.14 ft3 (5.0 ft)
Target Inc Vol:   7.06 ft3 (5.0 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 6 Automated monitoring printout with continuous lifts at 5 ft resolution.

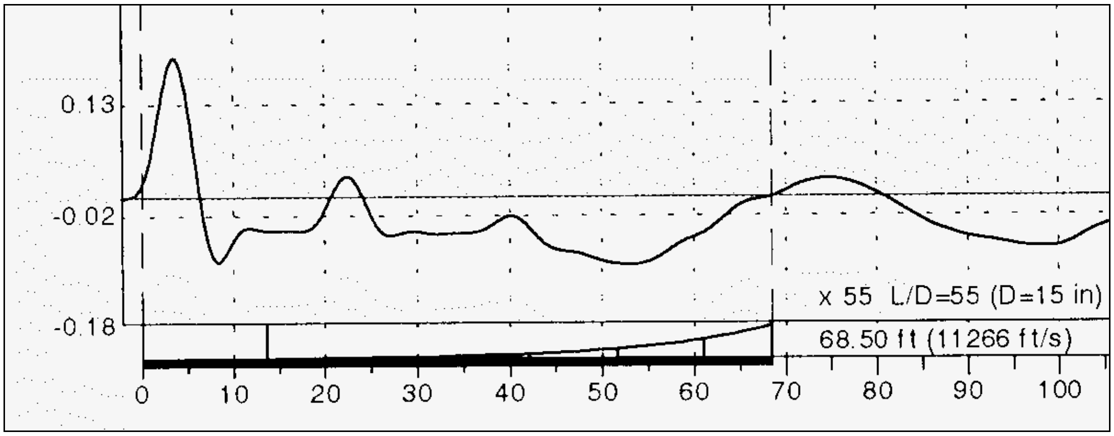

FIGURE 7 Pile integrity testing with defect at 20 ft.

```
Withdrawal Data  [start 14:06]
        pumped volume line_pres
 depth  volume ratio  min   max
 (ft)   (ft3)    (%)       (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 8 Automated monitoring printout with continuous lifts at 2 ft resolution.