Construction Control for Augercast Piling

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Abstract:

Where soil conditions are favorable, augercast piles have significant economic advantages, but they also have some uncertainty due to the construction methods. To confirm bearing capacity and structural integrity, static testing can be performed on a small sample of piles. However, the load test piles are not necessarily constructed in a manner representative of production piling. Additional assessment methods must be used on more piles to increase confidence in augercast piling foundations.

Non-Destructive Evaluation (NDE) methods like Pulse Echo are frequently specified for a large percentage of the production piles. However, such NDE methods require testing the pile after the grout or concrete has hardened. If problems are found, then the repair or replacement can be relatively expensive. The confidence in the quality of augercast piles can be improved by automatically monitoring the grout volume pumped as a function of depth. If a low grout volume is measured for any depth increment, the pile can be repaired immediately while the grout is still fluid. Such installation monitoring equipment can be of great help to the installation crews and may reduce the need for subsequent NDE tests.

While Pulse Echo tests and monitoring during installation can assess the pile structural integrity, the bearing capacity cannot be assessed by these methods. Bearing capacity of augercast piles can be evaluated by the same high strain Dynamic Pile Testing methods used to test driven piles if a suitable drop weight is available, or by conventional static load testing.

This paper describes the background and benefits of various construction control and pile evaluation methods for augercast piles. Case studies demonstrate application of these methods.

Introduction

The perception of geotechnical engineers is that the quality of augercast piles depends on the skill of the contractor. One of the most critical operations is the control of auger withdrawal during grout placement (Roberts 1998). However, for an inspector, it is difficult to accurately assess grout volume and auger withdrawal rate simultaneously. This shortcoming may be overcome by implementing quality control procedures both during and after installation. When automated measurement systems are used, detailed augercast pile installation records are obtained. This data provides information to guide the operator during installation and generally provides more information than currently obtained by manual inspection.

Post construction testing of selected piles verifies the effectiveness of installation control. The most commonly used testing procedure is the Pulse Echo Method (Rausche 1992). This requires striking the pile top with a small hammer and measuring the motion from both input and reflections from pile non-uniformities or the pile end. The Pulse Echo Method can be applied to any one or even all of the production piles after the grout or concrete is hardened.

Bearing capacity can be evaluated on any pile on site using High Strain Dynamic Pile Testing, or, with greater effort, static load tests. Piles to be tested can be selected after installation based on their site location (to assess soil variations), on specific pile installation records, or at random. The capability of installation monitoring and subsequent low and high strain dynamic testing or static testing could help the engineer to completely investigate the foundation.

Current Installation Problems Monitoring Augered Piles

Visual inspection requires that pump strokes be detected, counted and recorded as a function of estimated auger depth. Since there is a large volume of information to be recorded, there are many possibilities for deficiencies or errors in recording all the necessary information. Further, it has been conclusively shown that pumps do not maintain a uniform volume per pump stroke but rather can be highly variable (Likins et al 1998). Thus volume obtained from counting pump strokes is not sufficiently accurate; errors as much as 20% have been observed. Further, the counting of strokes is usually done manually per 1.5 m (5 ft) interval. This large interval does not always give sufficient precision. The visual definition of the 1.5 m (5 ft) interval has been observed to be not very precise, with 0.3 m (1 ft) errors being common. Alternative methods of more accurate volume determination are desirable.

Automated Monitoring of Augercast Piles during Installation

Automated monitoring (Likins et al 1998) of grout volume pumped versus auger position aids in proper installation by evaluating in real time the grout pumped for each depth increment. The Pile Installation Recorder for Augercast piles (PIR-A) or other similar equipment can fulfill these monitoring requirements.

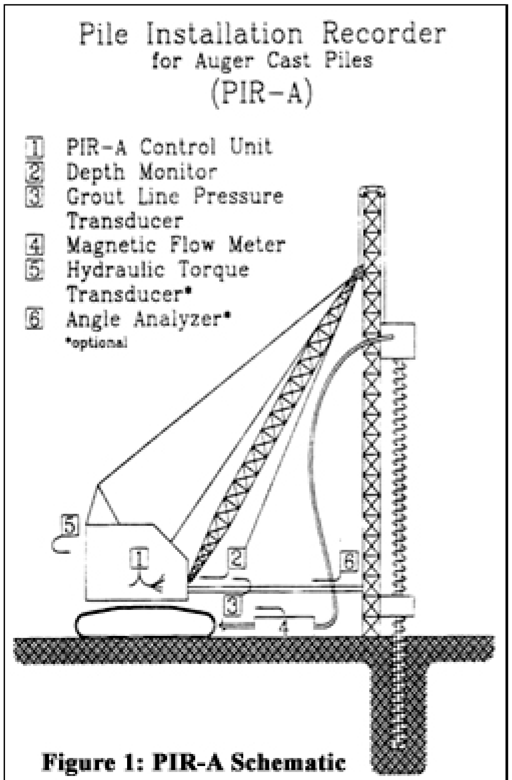
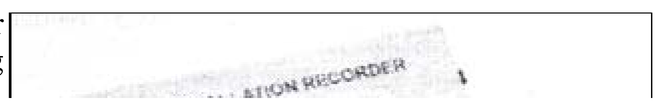


Figure 1: PIR-A Schematic

The schematic in Figure1 shows the overall configuration of the PIR-A system. The data acquisition Control Unit provides signal conditioning for all sensors, and processes the measured data. The PIR-A depth monitor has a self-retracting reel attached to the head of the auger. As the auger advances or withdraws, the depth is measured by a rotary encoder attached to a pulley tracking the cable. A Magnetic Flow Meter accurately measures pumped grout volume to an accuracy within 2%. A Grout Pressure Transducer is installed in the grout line (usually near the Flow Meter) and continuously measures pressure variations in the grout line to detect minima and maxima of the grout pressure. During augering, the auger torque is measured on the auger motor.

In practice, the operator monitors the PIR-A during all phases of pile installation. After input of the pile name by the operator, the Control Unit handles virtually everything else without further intervention. During the drilling phase, the operator observes the auger's current depth and torque. Raising the torque to slightly below that which would stall the crane makes drilling more efficient and potentially reduces the spoils brought to the ground surface. From a geotechnical engineering point of view, knowing the torque allows the engineer to assess if an auger refusal comes from a strong soil condition or rather from a low applied torque.

At the pile design depth, the operator initiates auger withdrawal and grout injection. During the grouting



phase, the measured grout volume pumped per unit depth is displayed graphically (and numerically for reference). A sample grouting screen is shown in Figure 2. By observing this screen, the operator can adjust the auger withdrawal rate so that a volume sufficient to avoid deficiencies is pumped in each depth increment. If the grout pumped for any increment is less than the desired grout ratio, the pile can be reaugered immediately through this increment and the pile re-grouted. Making corrections while the grout is still fluid helps reduce the occurrence of defects in the pile and subsequent remedial measures, and may improve the engineer's confidence in the shaft quality.

Upon completion of the grouting phase, detailed and summary results for each depth increment of both auger and grout phases are output to a field printer. Detailed information including augering time, torque during drilling, grout volume, and grout pressure during grouting are listed for every depth increment. Summary information shows pumped volume for the auger stem, grout "head" (for the given shaft diameter the head is the equivalent length of extra grout pumped prior to withdrawal), grout volume per pile shaft increment (the most important information), and spill (grout pumped above ground level). The total pile shaft volume compared with the theoretical grout volume is the "grout ratio". Thus, complete printed results are immediately available in the field prior to moving the augercast rig to the next pile location. Data is stored in a removable PCMCIA memory card. Stored data can be later plotted by spreadsheets if required.

When the PIR-A results are observed during installation and used to guide the operator, the shaft installed should meet any minimum grout volume guidelines per depth increment established by the engineer. For a proper installation, the grout should also be observed returning at the surface some distance before the auger tip reaches the surface (typical distance 1.5 m or 5 ft). In this way the quality assurance of the project is improved since everyone knows exactly what happened at all times during the installation. By thorough and accurate inspection, the need for further routine testing by NDE methods such as low strain Pulse Echo integrity testing may be reduced.

Recording of other construction operations such as grout arrival time on site and collection of grout specimens for strength testing cannot be done automatically. The construction process also includes other activities such as screening, installation of reinforcement, maintaining adequate waiting times between casting of neighboring shafts and site excavation which require some human interaction in supervision. If problems are observed in any post-grouting phase, the piles can be subjected to low strain pulse echo testing to assure the shaft integrity.

Pulse Echo Integrity Testing

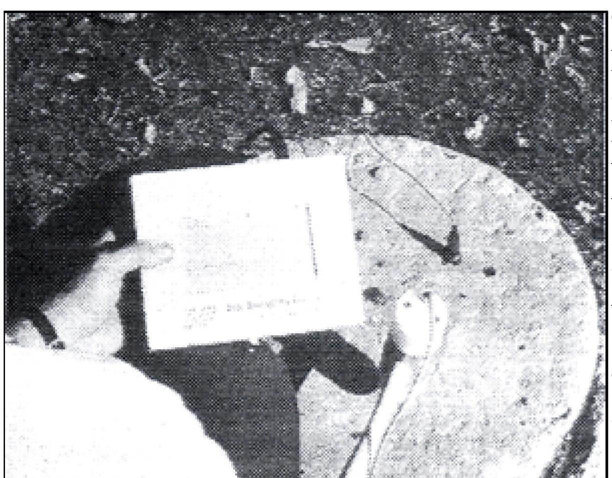


Figure 3: Pile Integrity Tester (PIT) With Hammer and

The pulse echo method (Rausche et al 1992) uses a hand held hammer to impact the pile top and generate a compressive stress wave in the pile. Figure 3 shows a Pile Integrity Tester (PIT) for pulse echo testing. 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 by PIT, and then interpreted by the test engineer.

The pile top surface is prepared by removing the upper concrete if it has been contaminated with soil, bentonite slurry or other foreign materials during construction, and by finding or making a smooth location. An accelerometer is then attached to the pile top surface with a thin layer of a soft paste like Vaseline, petro wax, etc. Accelerations from several hammer blows are normalized, integrated, averaged and displayed as velocities. Further data processing includes wavelet analysis and application of an exponentially increasing magnification function. The wavelet analysis (Rioul 1991) is a specialized filter that effectively strengthens the signal frequency components that match the input pulse and removes undesirable frequency components resulting from noise. The magnification restores reflection details which are diminished by soil resistance, pile material damping or pile non-uniformities.

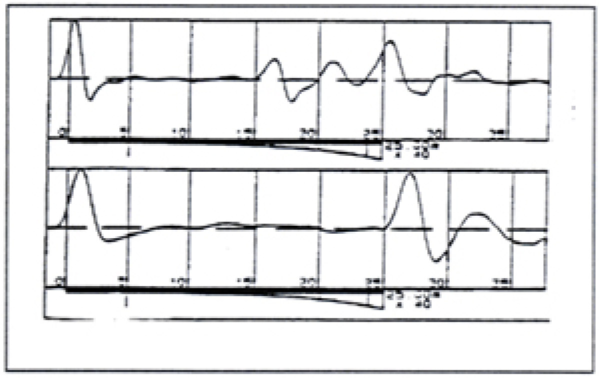


Figure 4: PIT Velocity versus Depth Records of a deficient pile (top) and a normal pile (bottom).

Figure 4 shows an example output with an exponential magnification increasing from zero at the left or pile top to a maximum multiplier (40 times in this example) at the expected time of reflection from the pile bottom on the right (2L/c, where L is the pile length, 25 meters (82 ft), and c the stress wave velocity of 4150 m/s or 13,610 ft/s in this example). The bottom plot shows a clear signal from the pile bottom together with a steady velocity signal between the impact and pile bottom, indicating a good pile shaft. The upper plot for another pile on the same site shows a pronounced velocity increase at about 16 m (52.5 ft) which indicates a reduction in pile cross section or concrete quality. In general, relatively sharply defined reflections are attributed to impedance changes, while slowly changing reflections are usually caused by soil resistance. If the effect of soil resistance is known from reference piles, then unusual shafts can be identified. This method can be applied to almost any shaft.

Comparative Results for Augercast Piles

Both PIR-A and PIT testing have been used on recent construction projects. Records from these methods are compared and interpreted.

Case History for PIR-A and PIT

The site had 500 mm (20 in) augercast piles ranging in length from approximately 18 to 20 meters (58 to 66 ft). Soil borings generally indicated medium dense sands transitioning into dense sands at a depth of approximately 13.7 to 15 m (45 to 50 ft). The shafts were socketed at least one meter (3 ft) into the weak bedrock formation. Following an initial static test failure on this site, PIT was used on several piles and the PIR-A was specified for use on all remaining production piles to improve quality assurance.

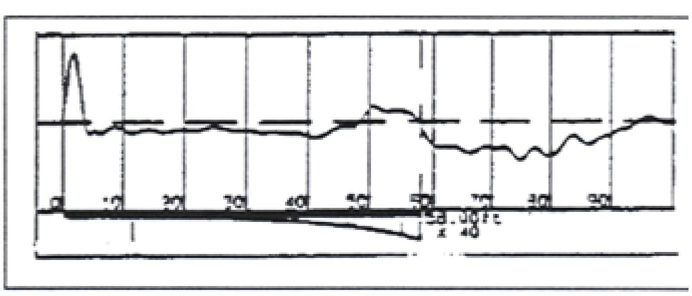


Figure 5: PIT Velocity versus Depth Record (Case 1)

The PIT records of all the shafts in Pier B18 indicated a characteristic decrease of impedance (evident by an increase in velocity) beginning at depths 12 to 15 m (40 to 50 ft). Although the impedance decrease cannot be quantified by it seems likely that the decrease is due to a return to nominal diameter in the lower denser soils from a larger shaft diameter in the upper less dense soils.

The PIT velocity record for Pile B18A (Figure 5) indicates a velocity increase or impedance reduction at approximately 14.6 m (48 feet). The PIR-A Summary Printout shows that between 15.2 and 14.6 m (50 and 48 feet) the grout volume per 0.6 m (2 ft) increment decreased from an average of about 0.18 m3 to 0.13 m3 (6.5 ft3 to 4.66 ft3). The minimum required volume was 0.154 m3 (5.45 ft3) per increment.

The PIT toe reflection in the rock socket resulted in a negative velocity (compression) at 17.7 m (58 ft). This is typical for shaft sections with either a high soil resistance or an increased pile impedance.

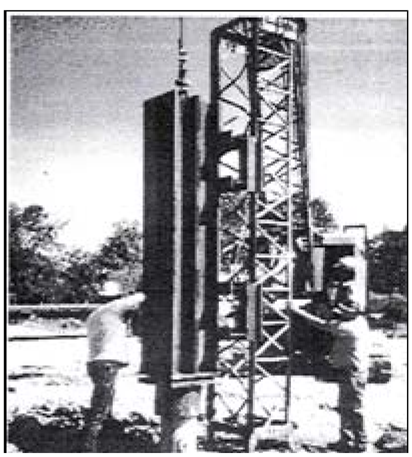
Examination of numerous PIR-A records demonstrated fairly uniform grouting rates, and by implication no significant problems. In addition, selected piles were tested by Pulse Echo using PIT for integrity after installation. Because no further difficulty was experienced due to adequate quality control enabled by the PIR-A and confirmed by Pulse Echo tests, there was no further static testing.

High Strain Dynamic Testing

Fig 6: Attaching sensors to augercast pile

Monitoring during installation does not assure the desired pile bearing capacity will be achieved. Thus, either additional static testing or high strain dynamic pile testing (Rausche 1985, Hussein 1996) may be needed for confirmation of the pile capacity. High strain dynamic pile testing has its theoretical basis on the Case Method. The Case Method was originally applied using a Pile Driving Analyzer® to driven piles. However, beginning in 1974, high strain dynamic testing has been applied to drilled shafts and augercast piles with increasing frequency using drop weights. In some countries extensive dynamic pile testing is now routinely performed on drilled shafts and augercast piles.

Figure 6 shows high strain sensors measuring acceleration and strain attached to an augercast pile. The pile was extended above the ground surface with a thin steel liner. The lower section of the liner was then removed and the sensors attached to the resulting smooth surface using concrete anchors in the same manner in which they are attached to manufactured driven concrete piles.



The pile top surface is usually flat and relatively smooth and only needs some minimal plywood cushion to distribute the impact over the entire top surface. A steel plate is then placed above the plywood as a striker plate for the impact weight. If reinforcement protrudes from the pile top, then the section can be built up above the reinforcement and then removed after the test.

To perform the high strain test, the drilled shaft or augercast pile is then subjected to an impact of a relatively large weight. In most cases a simple drop weight is preferred. Figure 7 shows a 17.8 kN (2 ton) drop weight (constructed from welding four H piles together) being positioned to test an augercast pile. Other drop weight designs include concrete filled steel pipes or heavily reinforced concrete blocks. As a general guide, the weight should be at least 1 to 1.5% of the desired ultimate capacity to be proven (Hussein 1996) to assure load activation at reasonable stresses. Larger existing weights can be used provided the weight and shaft diameters remain about comparable. Regardless of size, shape or composition, the drop weight is generally guided to an axial impact by a short set of leads, and is raised by cable and dropped by releasing the drum brake (as shown in Figure 7). An alternative and preferable drop method involves raising and securing the weight and then completely releasing it for a true free drop (e.g. releasing hydraulic jaws such as used for vibratory hammers used to grab steel piles, or by tripping a simple mechanical release).

The test usually consists of a few separate impacts. An impact with low drop height is first applied to assess signal quality and alignment of the weight with the shaft. After each drop, the net permanent displacement or "set per blow" is carefully measured; a minimum set per blow is an indication of full capacity activation. The compressive stresses are reviewed and compared with the concrete strength. Alignment adjustments are made if necessary and a second higher drop height is applied. The test continues with increasing drop heights until either the set per blow exceeds a value sufficient to insure the full capacity has been activated, or until the indicated capacity is well above the required ultimate capacity, or until the stresses become too large and the risk of pile damage is then too high. Most tests are completed in less than five impacts. If the pile top has been built up to accommodate the dynamic test, the extra top section is removed to facilitate completing the foundation.

The measured pile top strain and acceleration are converted to force F(t) and pile top velocity v(t). The stresses are output directly after each blow. Instead of using the Case Method capacity estimate, the force and velocity data are analyzed by special signal matching software called CAPWAP® to independently check the total capacity mobilized for each blow. A CAPWAP analysis can be performed in a short time on site after each impact to determine if the set per blow is low so that the full capacity has not yet been activated and another larger impact is required. Upon completing the CAPWAP analysis, a simulated static load test is obtained.

High Strain Test Case History for Augercast Pile

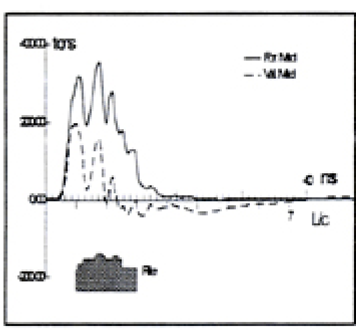


Fig 8: Force and velocity record for augercast pile (top) and pile model (bottom)

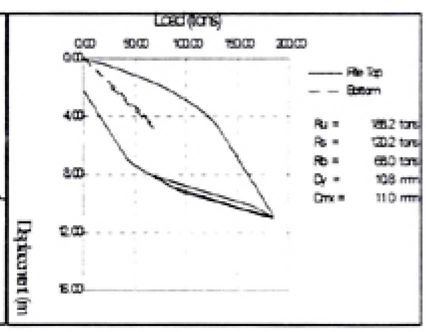


Figure 9: CAPWAP simulated static test result

Foundations were installed specifying 400 mm (16 inch) augercast piles. The piles were built up with a temporary shell above ground level as in Figure 6. The grout ratios suggest that the actual pile shaft diameter in the upper sands and silts (N values of about 15) is larger than the nominal diameter. The piles were drilled to end bearing on shale. The dynamic test used an existing 29 kN (6.6 kip) drop hammer with a free release with drop heights from 0.9 to 1.5 m (3 to 5 ft). A 75 mm (3 inch) plywood cushion was used for the pile top. Resulting compression stresses were below 28 MPa (4 ksi) even for the higher drop heights and tension stresses were negligible. Data as shown in Figure 8 is of good quality and the determined pile model shows the impedance (e.g. area) increase in the upper shaft from oversized grout ratio recordings. The shaft resistance determined by CAPWAP increases gradually with depth and is in general agreement with the soil borings. The CAPWAP simulated static load test results of 1840 kN (188 metric tons) are shown in Figure 9, resulting in a sufficient factor of safety for the given design load of 540 kN (55 metric tons).

Conclusions

Low strain Pile Integrity Testing (PIT) can detect major defects in the pile shaft at low cost and with little effort. However, PIT tests are sometimes difficult to interpret and should not be the only means to verify the quality of the foundation. As a minimum, geotechnical borings and field installation observations should be included in the evaluation process of the foundation. For very long piles the method may not provide conclusive evidence of integrity of the whole shaft.

Where the Pile Installation Recorder for Augercast Piles (PIR-A) is installed on an augering rig, it automatically records the installation of all piles on a job. The PIR-A records are used to judge pile consistency and acceptance. With more accurate information available, augercast piles are more readily specified and accepted by designing engineers.

Grout volume and grout pressure records from the PIR-A can be used during installation to guide the contractor into installation of quality piles. If these automated installation records of grout versus depth indicate a good shaft, then this may reduce the need for PIT. Thus, PIT testing can be restricted to shafts with questionable PIR-A records or shafts with problems observed either after installation, during installation of subsequent piles, or during excavation. In addition, a small percentage of randomly selected production piles may also be subjected to PIT testing.

Although capacity of augercast test piles can be determined by a static load test, dynamic pile tests followed by CAPWAP analysis are a well proven alternative for augercast piles when minimum installation time is critical or if multiple tests are desirable to evaluate site variability. Dynamic tests on augercast piles usually require some pile preparation and a drop weight to apply the impact.

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