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Detection and prevention of anomalies for augercast piling

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ABSTRACT: On many sites, augercast piles have significant advantages including cost and low vibration. They also have some uncertainty due to the construction methods. Visual inspection during grouting is often difficult. Static test piles have been used to confirm installation procedures and soil conditions, but are restricted to only a small sample of piles. Furthermore, load test piles receive special attention during the installation compared with typical production piling.

To verify installation and increase confidence, Non-Destructive Evaluation (NDE) methods like low strain Pile Integrity Testing are often specified for some percentage of production piles. Because such NDE methods require testing the pile after the grout or concrete has hardened, the repair or replacement can be expensive if problems are found. However, preventing defects through thorough monitoring during installation is preferred over Pile Integrity Testing. Augercast piles can be automatically monitored for grout volume pumped versus depth. With this information available during installation, if a low grout volume is measured for any depth increment, the pile can be repaired immediately while the grout is still fluid. Installation monitoring reduces the need for subsequent NDE tests.

While installation monitoring and NDE tests assess pile structural integrity, the bearing capacity cannot be assessed by these methods. Bearing capacity of augercast piles can be evaluated economically by high strain Dynamic Pile Testing methods used to test driven piles if a suitable drop weight is available.

Keywords: augercast pile, installation monitoring, integrity testing, dynamic pile testing

1 INTRODUCTION

The quality of augercast piles often depends on the contractor's skill. The most critical is the control of auger withdrawal during grout placement (Roberts 1998). However, for a visual inspector, it is difficult to accurately assess grout volume and auger depth simultaneously. Automated measurement systems can accurately monitor volume pumped as a function of depth (Likins 1998). This information can guide the operator during installation to produce a shaft exceeding any minimum requirements.

Low Strain Pile Integrity Testing of selected piles verifies the installation monitoring effectiveness. This requires striking the pile top with a small hammer and measuring both input and reflections from pile non-uniformities or the pile end (Rausche 1992). Pile Integrity Testing is applied to any pile or even all piles after the grout is hardened. There are some limitations for long or jointed piles.

Bearing capacity can be evaluated on any pile on site using High Strain Dynamic Pile Testing (Likins 2000a). Test Piles 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 allows the engineer to completely investigate the foundation.

2 CURRENT INSTALLATION PROBLEMS MONITORING AUGERED PILES

Visual inspection counts pump strokes as a function of estimated auger depth to estimate volume versus depth. Due to a large volume of information, there are many possibilities for deficiencies or errors in recording all the necessary information. Further, the volume per pump stroke can be easily vary by as much as 20% (Likins et al. 1998). Further, pump strokes are usually manually counted per five foot interval; this interval has marginal precision and even the visual determination of the depth may have one foot errors. Alternative methods of more accurate inspection are desirable.

2.1 Automated monitoring of augercast piles during Installation

Automated monitoring (Likins et al. 1998) of grout volume pumped versus auger position provides information to the piling crew which can guide the operator during auger withdrawal. The schematic in Figure 1 shows the overall PIR-A configuration. A small Control Unit conveniently located for the crane operator acquires and processes all measured data. The PIR-A depth monitor has a self-retracting cable attached to the auger gear box. As the auger advances or withdraws, the depth is measured by a rotary encoder tracking the cable. A Magnetic Flow Meter accurately measures pumped grout volume to an accuracy within 2%. A Grout Pressure Transducer installed in the grout line (usually near the Flow Meter) continuously measures pressure in the grout line. During augering, the auger torque is measured.

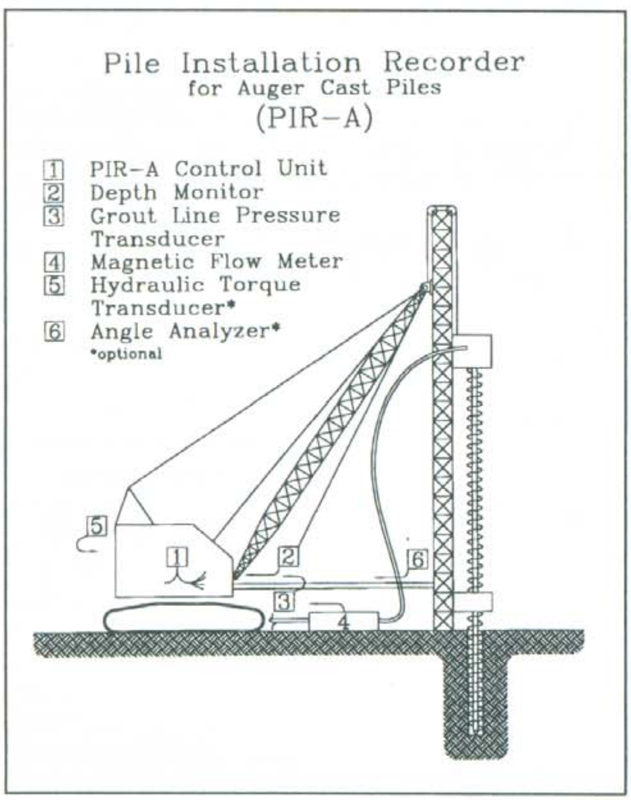

Figure 1. PIR-A schematic.

In practice, after the operator inputs the pile name, the PIR-A Control Unit handles virtually everything else. During drilling, the operator observes the auger's current depth and torque. Higher torque (just below the crane stall torque) makes drilling more efficient and reduces the spoils brought to the surface. Geotechnically, the engineer can assess the torque at auger refusal to distinguish strong soils or low torque.

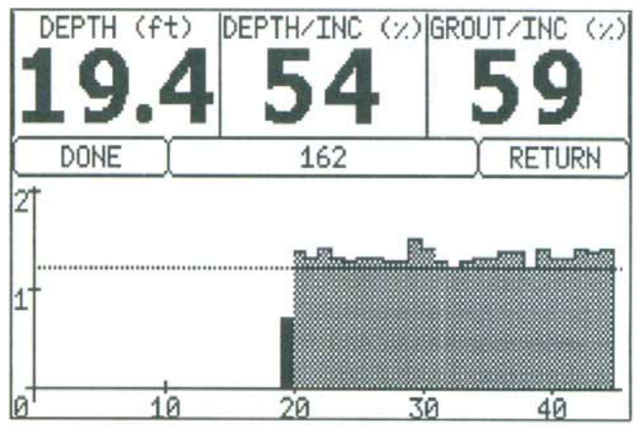

Figure 2. PIR display during grouting phase.

At the pile design depth, the operator initiates auger withdrawal and grout injection. During grouting, the measured grout volume pumped per unit depth is displayed graphically as in Figure 2 for pile 162. The operator can adjust the auger withdrawal rate to keep the grout above the target line. This can also be guided by keeping the grout/inc display slightly above the depth/inc display. If the grout per increment is low, the pile can be re-augered immediately through this increment and the pile re-grouted to eliminate defects in the pile and subsequent remedial measures. The operator presses "return" when grout is observed at the surface and "done" when the pile is completed.

Upon completion of the pile, monitoring results for each depth increment are printed in the field. Auger time, torque during drilling, and grout volume and pressure during grouting are listed for every depth increment. Summary information shows pumped volume for the auger stem, grout "head" (for the given 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). Printed results are available prior to moving to the next pile location.

When the operator uses the PIR-A results to guide the pile installation, the installed shaft should meet any minimum guidelines established by the engineer. Thus, the quality assurance of the pile is

Figure 3. Pile integrity tester system.

improved. By thorough and accurate inspection, the need for further NDE testing such as low strain Pile Integrity Testing is 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, observing for subsidence for previously grouted piles, site excavation, etc. which require some human supervision. If problems are observed in any post grouting phase, the piles can be subjected to low strain Pile Integrity Testing to assure integrity.

3 PILE INTEGRITY TESTING

Pile Integrity Testing (Rausche et al. 1988, Likins et al. 2000b) uses a hand held 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 by an accelerometer. Figure 3 shows a Pile Integrity Tester (PIT), accelerometer and hammer. This method can be applied to almost any solid concrete shaft. The pile top is prepared by removing the upper concrete if it has been contaminated during construction, and making a smooth location and attaching an accelerometer with a thin layer of bonding material. Accelerations from several hammer blows are normalized, integrated, averaged, digitally filtered and displayed as velocities. Further processing applies an exponential magnification function which restores reflection details diminished by soil resistance, pile material damping or pile non-uniformities. The resulting signal is interpreted by the skilled test engineer.

Figure 4 shows an example output for a pile with Length/Diameter ratio of 40. An exponential magnification is applied, increasing from unity value at the left or pile top to a maximum multiplier (40x) at the right for the pile bottom at 25 meters (example assumes a stress wave velocity of 4150 m/s). The bottom plot shows a clear pile bottom reflection 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 which indicates a reduction in pile cross section or concrete quality. In general, sharply defined changes in the velocity are attributed to impedance changes, while slow changes are usually caused by soil resistance. If soil resistance effects are known from reference piles, then unusual shafts can be identified.

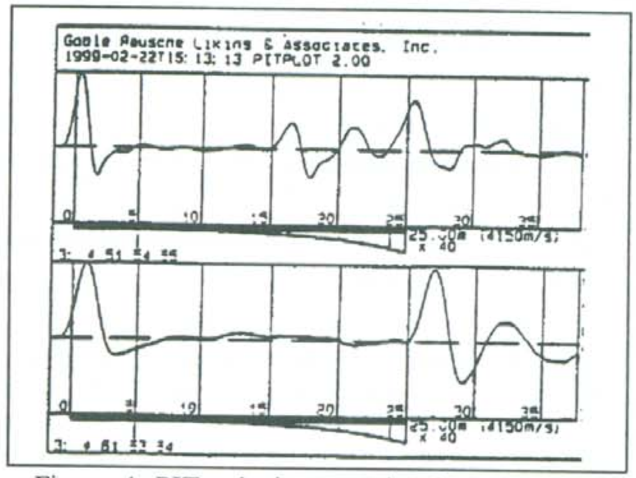

Figure 4. PIT velocity records of a deficient pile (top) and a normal pile (bottom).

4 COMPARATIVE RESULTS FOR AUGERCAST PILES

Both Pile Installation Recording for Augered Piles and Pile Integrity Testing have been employed on recent construction projects. Records from these methods are compared and interpreted.

4.1 Case history 1

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 into the weak bedrock formation. Following an initial static test failure on this site (static test pile not tested by PIT or PIR-A), Pile Integrity Testing was applied to several other completed piles and the Pile Installation Recorder (PIR-A) was specified for use on all remaining production piles to improve quality assurance.

The Pile Integrity Tester's records of all the shafts in Pier B18 indicated a characteristic increase of impedance in the upper weak soils (evident by a negative velocity to a depth of about 45 ft) followed by a decrease of impedance (evident by an increase in velocity) beginning at this depth. Although the impedance decrease cannot be precisely quantified by PIT, 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 reduction in either cross sectional area or modulus at approximately 14.6 m (48 ft). 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.

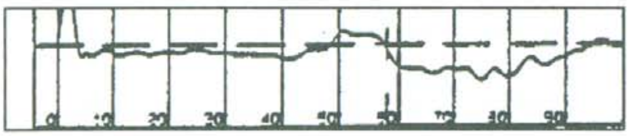

Figure 5. PIT data (case 1).

The PIR-A result for the same Pile 18A showed that between 15.2 and 14.6 m (50 and 48 ft) below the top that the grout volume per 0.6 m (2 ft) increment decreased from an oversized average of about 0.18 m^3 to 0.13 m^3 (6.5 ft^3 to 4.66 ft^3). The minimum required volume was 0.154 m^3 (5.45 ft^3) per increment. Although this one increment was slightly low, the volume for the low increment still had a grout ratio of 1.07 over the nominal hole volume and adjacent increments were higher than required; some redistribution of the fluid grout between neighboring increments is likely.

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

4.2 Case history 2

Shaft 349 is a 450 mm (18 in) diameter shaft 13.9 m (45.5 ft) in length and is one of several hundred piles on this project. All piles were installed using a PIR-A. This pile was requested to be tested to assure the PIR-A results were achieving the desired result and as a random check on the pile. The PIT record for pile 349 is shown in Figure 6. The pile toe is very clearly visible at the expected time after a magnification factor of 35 is applies and the velocity record along the shaft is relatively flat and thus indicates a relatively uniform shaft and no defects.

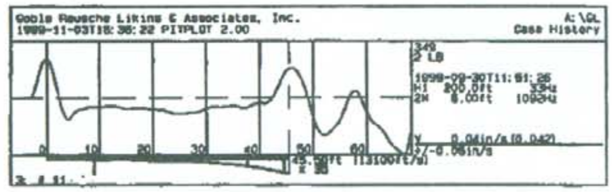

Figure 6. PIT data for pile 349.

The PIR-A result is given in Figure 7. The volumes printed are for 610 mm (2 ft) depth increments. This depth increment was selected to provide sufficient precision taking into consideration that typically about 8 pump strokes would be required for such a depth increment. As shown, the grout pumped was relatively uniform and generally above the volume required of 4.421 ft^3 per depth increment representing the 1.25 grout ratio requested. The grout ratio for two segments in the middle to lower part of the pile were slightly below the 1.25 grout ratio desired for the project, but still well above the factor 1.0. Further, the adjacent segments were above the volume required. The low volumes pumped near the pile top (bottom two lines in Figure 7) are acceptable since the grout return was already observed. This early grout return is due to

Grouting Data (1999-07-26_07:49)

Vol/inc x1.25: 4.421 ft3

depth	volume	strks	grout
44	7.88	22	0
42	4.63	7	0
40	4.63	8	0
38	4.59	8	0
36	4.45	8	0
34	4.84	8	0
32	4.63	8	0
30	4.49	7	0
28	4.27*	8	0
26	4.73	9	0
24	4.34*	8	0
22	5.01	9	0
20	4.70	7	0
18	4.70	9	0
16	4.45	8	0
14	4.66	8	0
12	4.56	7	0
10	4.49	8	0
8	4.66	9	0
6	4.91	8	0
4	1.34*	2	0
2	0.99*	1	0

(1999-07-26_07:55)

grouting time: 338 sec.

Figure 7. PIR-A data for pile 349.

the extra grout head pumped prior to auger withdrawal.

5 HIGH STRAIN DYNAMIC TESTING

Monitoring during installation does not assure sufficient pile bearing capacity. Thus, either additional static testing or high strain dynamic pile testing (Hussein et al. 1996, Likins et al. 2000a) are required. High strain dynamic pile testing with the Pile Driving Analyzer® (PDA) has also been applied since 1974 to drilled shafts and augercast piles with increasing frequency using drop weights to generate the loading. In some countries extensive dynamic pile testing is now routinely performed on drilled shafts and augercast piles.

The pile top may be temporarily extended above the ground surface to encase protruding reinforcement or to facilitate attaching the strain and acceleration sensors two diameters below the pile top. A steel striker plate and minimal plywood cushion are placed on the pile top to distribute the impact over the entire top surface. The drilled shaft or augercast pile is then impacted by a simple drop weight guided by a short set of leads. A low drop height is first applied to assess signal quality and alignment of the weight with the shaft. After each impact, the net permanent displacement or "set per blow" is carefully measured. The drop height is then increased until either the set per blow exceeds 2 or 3 mm (to activate the full capacity), or until the indicated capacity exceeds the required ultimate capacity. The PDA monitors stresses directly and additional cushion material can be inserted to avoid overstressing. The measured strain and velocity data can be analyzed on site by the signal matching software CAPWAP® to independently check if the activated capacity exceeds the desired test load.

6 CONCLUSIONS

Low strain Pile Integrity Testing (PIT) can detect major defects in the pile shaft at low cost and with little effort. However, particularly for very long piles, PIT results may be 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 (PIR-A) is installed on an augercast rig, it automatically records the installation of all piles on a job. Grout volume and grout pressure information from the PIR-A during installation guides the contractor into installation of quality piles. 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. If automated PIR-A installation records of grout versus depth indicate a good shaft, then this may reduce the need for further PIT tests. Thus, PIT testing can then be restricted to shafts with questionable PIR-A records or shafts with problems observed after installation, during installation of subsequent piles or during excavation. In addition, a small percentage of randomly selected production piles may also be tested by PIT for quality control.

Capacity of augercast test piles can be determined by a static load test. However, dynamic pile tests followed by CAPWAP analysis is 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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