Custom tailoring quality assurance for augercast piles

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ABSTRACT: Quality assurance of deep foundations is more difficult than quality assurance of any other structural element. One of the most widely used methods for post installation integrity inspection of concrete piles, drilled shafts or Augercast piles is the Pulse Echo Method, which relies on low strain stress wave reflections from shaft discontinuities. A small hand held hammer is used to generate the stress wave. Another method, the high strain dynamic pile test, requires the impact of either a pile driving hammer or a substantial drop weight. In addition to providing information about the shaft integrity, the high strain method also tests its bearing capacity.

A complementary construction control device that greatly reduces the probability that a shaft defect or pile damage develops is the Pile Installation Recorder for augercast piles (PIR-A).

The paper describes the use of the PIR-A during construction, and post-construction test methods. A correlation of PIR-A construction records with post construction test results is documented.

KEYWORDS: Augercast Piles, Installation Monitoring, Pulse Echo Method, Integrity Testing

1 INTRODUCTION

A consensus exists among geotechnical engineers that the installation of augercast piles is prone to errors. One of the most critical operations is the control of auger withdrawal during grout placement (Roberts 1998). This shortcoming may be overcome by implementing quality control procedures both during and after installation.

Detailed pile installation records, obtained through automated measurement systems, improve information available to guide the operator during installation and assure the quality of the inspector's records. Post construction testing of selected piles verifies the effectiveness of installation control.

2 METHODS OF ANALYSIS

2.1 Pile Installation Recording

Pile installation recording of augercast piles (Likins, Piscsalko and Cole, 1998) consists of the electronic data acquisition of data on grout volume pumped and auger position, and utilization of this data in real time to aid in proper pile installation. The PIR-A has the following components:

Depth Indicator. The depth indicator (Figure 1) automatically measures the location of the bottom of the auger as the auger penetrates during drilling and as it is removed during grouting. The depth measurement is made by a rotary encoder on a self-retractable reel.

Magnetic Flow Meter. A Magnetic Flow Meter (Figure 2) provides accurate pumped grout volume. This precise measurement is a marked improvement over the traditional method of counting pump strokes during augercast pile installation, which has proven to be unreliable. Grout pressure is measured in the grout line with a pressure transducer.

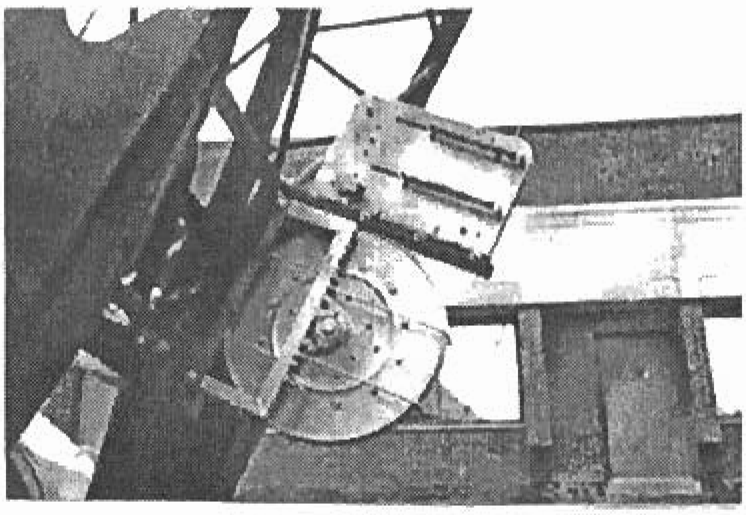

Figure 1. Depth Indicator

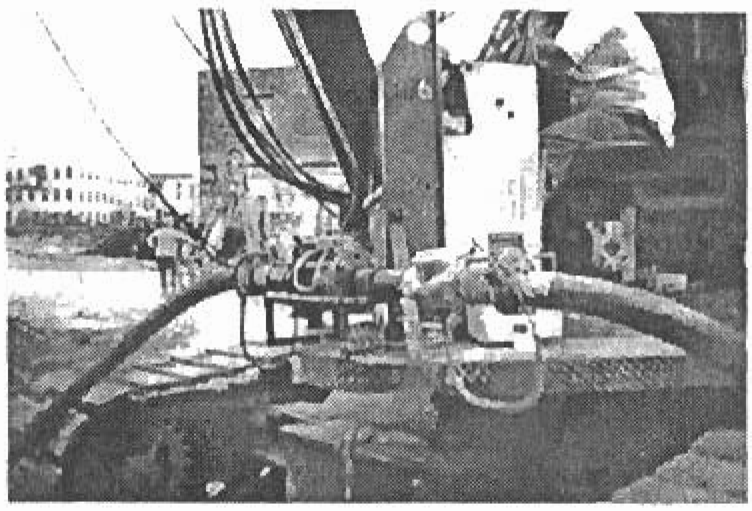

Figure 2. Magnetic Flow Meter

Data Recording, Storage, and Display Unit - (Control Unit). The data acquisition unit (Figure 3) provides signal conditioning for all sensors, and processes the measured data. The drilling depth, auger torque, and drilling rate are displayed during the drilling phase. During the grouting phase, the nominal pumped grout volume per unit depth is plotted on the screen. The operator observes the volume ratio and is guided to maintain an ideal withdrawal rate. This rate is slow enough to assure a minimum volume per unit depth yet fast enough to avoid grout waste. If a cross section reduction is observed, the operator can immediately lower the auger down into the hole a second time while the grout is still fluid. Data is stored in a removable PCMCIA memory card.

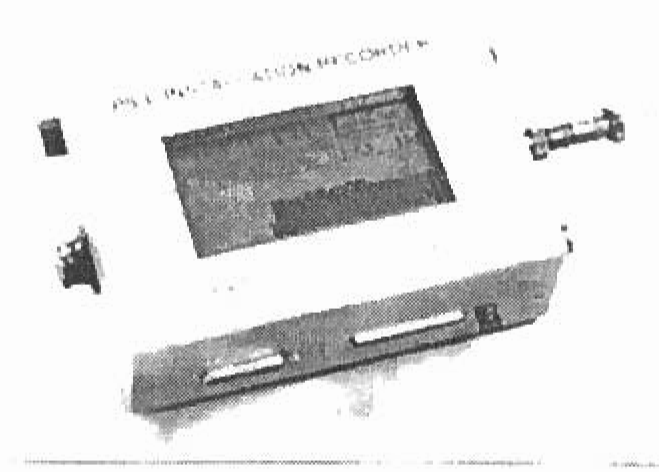

Figure 3. Control Unit

Figure 4 is a schematic showing the overall configuration of the Pile Installation Recorder system.

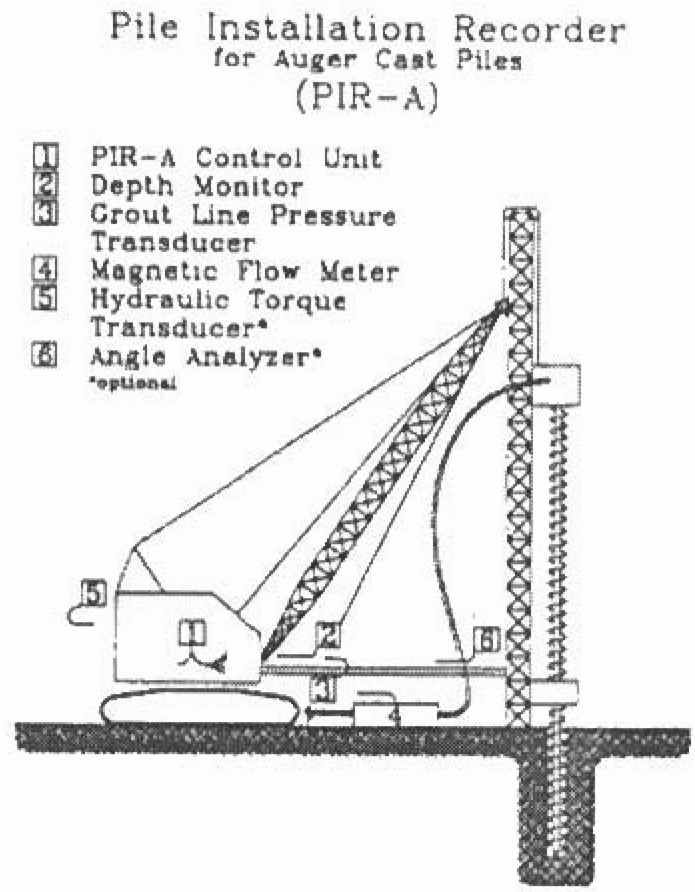

Figure 4. PIR-A Schematic

2.2 Pulse Echo Method

The Pulse Echo Method (Rausche, Likins and Shen, 1988) uses signals from a hand held hammer impacting the pile top and generating a compressive stress wave in the pile. Stress wave reflections from non-uniformities or the pile toe are observed at the pile top, processed and interpreted by the engineer. The Pulse Echo Method records the pile top velocity as a function of time.

Figure 5 shows a schematic of the Pile Integrity Tester (P.I.T.) for the application of the Pulse Echo Method.

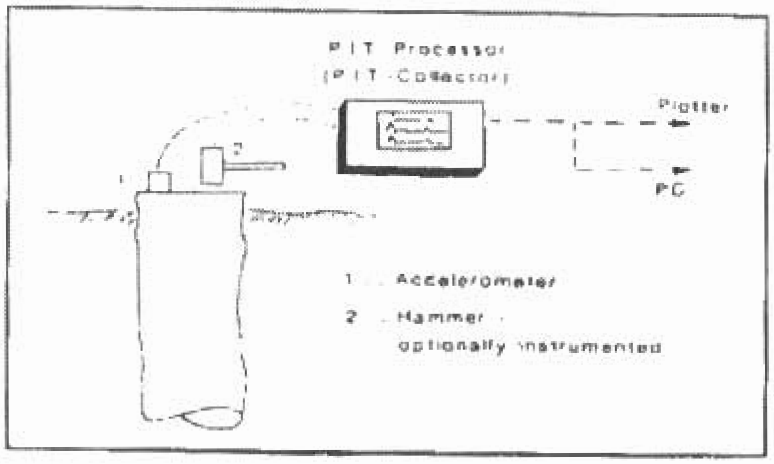

Figure 5 . Pile Integrity Tester

The first and sometimes most important step for any low strain test is the preparation of the pile top surface. In fact, depending on the construction method, it may be necessary to remove a short section of the upper concrete if it has been contaminated with soil, bentonite slurry or other foreign materials during construction. After a clean, healthy and hard concrete top surface has been exposed, the accelerometer is attached to the pile top surface with a thin layer of a soft paste like vaseline, petro wax, *etc*.

After this preparation, an impact with the hand held hammer is applied. The impact typically generates accelerations in the 10 to 100 g range, pile strains around 10^{-5}, velocities near 30 mm/s (0.1 ft/s) and displacements less than 0.03 mm (0.001 inches). Accelerations produced by several hammer blows are integrated and displayed as velocities (which are more useful than the accelerations) on the processor's screen. Consistent records are selected, averaged, scaled and then redisplayed. Further data processing includes wavelet analysis and application of an exponentially increasing magnification function. The magnification restores the reflection detail which is diminished by soil resistance.

Figure 6 shows a standard P.I.T. output. It includes the exponential magnification function (40 times in this case) with the maximum multiplier shown at time of expected reflection from the pile bottom (2L/c, where L is the pile length, 25 meters in this example, and c the stress wave velocity of 4150 m/s). The second plot shows a clear signal from the pile bottom together with a steady velocity signal between the impact and pile bottom. These are signs of a sound pile shaft. The first plot shows a pronounced velocity change at about 16 m. Changes such as this may result from variations in pile cross section, concrete quality or soil resistance. In the absence of major soil resistance changes, pile top velocity variations are caused by pile impedance changes. For example, relative increases in pile top velocity are usually the result of a cross sectional decrease of impedance. The pile impedance is defined as

$$Z = EA / c = A\Delta c \qquad (1)$$

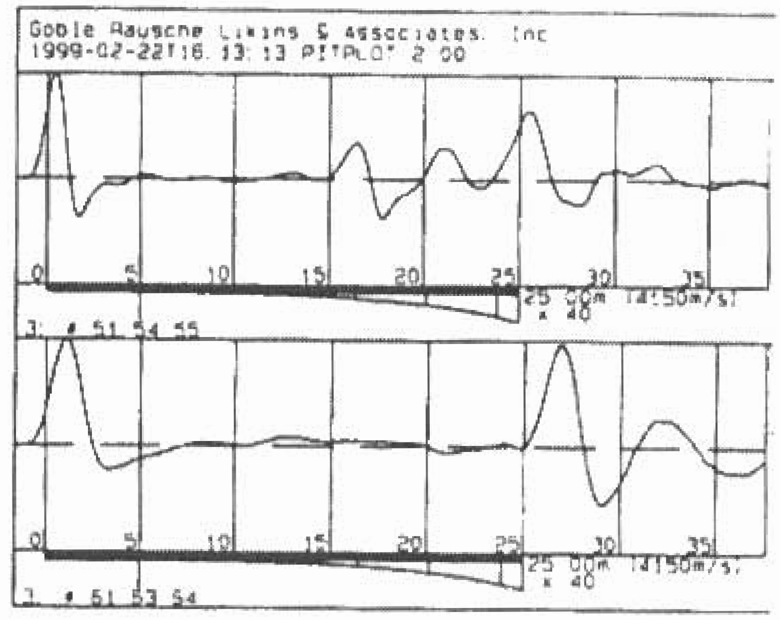

Figure 6. P.I.T. Velocity Records

Thus, an impedance reduction can be caused by a decrease either in area, A, or in the concrete's modulus, E, or in density, Δ. Since both modulus and density are related to concrete strength, shaft impedance depends on cross sectional area and concrete quality.

In general, relatively sharply defined reflections are attributed to impedance changes, slowly changing reflections are usually caused by soil resistance. Gradual pile tapers cannot be detected. On the other hand, if the effect of soil resistance is known from reference piles, then unusual shafts can be identified. Improved quantitative interpretations require further signal processing or pile profile calculations and comparison with records of other piles at the same site. But even with these more sophisticated methods, the question of the effect of soil resistance still ay not be clear.

An advantage of this method is its simplicity and very low cost per test. This makes it practical to test every shaft when questionable conditions occur. It can be applied even after all shafts are installed and requires no advance planning or access tubes.

2.3 High Strain Dynamic Testing

High Strain Dynamic Testing has its theoretical basis in the Case Method (Rausche, Goble and Likins 1985). The Case Method is a closed form solution of the one dimensional wave propagation traveling along an ideally elastic and uniform pile. Given the measured pile top force F(t) and pile top velocity v(t), the total soil resistance is

$$R(t) = \{[F(t) + F(t_2)] + Z[v(t) - v(t_2)]\}/2 \quad (2)$$

where

Z is the pile impedance (EA/c)
t_2 is time (t + 2L/c)
L is pile length below sensors
c is the speed of the stress wave
E is the elastic modulus of the pile , and
A is pile cross sectional area

The total resistance consists of both dynamic and static components. Thus

$$R_s(t) = R(t) - R_d(t) \quad (3)$$

The static resistance component is, of course, the desired pile bearing capacity. The dynamic component may be computed from a soil damping factor, J, and a pile velocity, v_b (t) which is conveniently calculated for the pile bottom. Using wave considerations, this approach leads immediately to the dynamic resistance

$$R_d(t) = J[F(t) + Zv(t) - R(t)] \quad (4)$$

and finally to the static resistance by means of Equation 3. This solution is simple enough to be evaluated "in real time", *i.e.* between hammer blows, using a Pile Driving Analyzer® (PDA). However, the assumption of a soil damping constant J must be made. The time t is searched such that the maximum static resistance, RMX, is calculated. The damping constant, J, is not needed if the time, t, is chosen such that the $R_d(t)$ term vanishes. The resulting capacity value is called RA2.

Stress waves in a pile are reflected wherever the impedance (Z=EA/c) changes. The reflected waves arrive at the pile top at a time which depends on the location of the change. The reflected waves cause changes in both pile top force and velocity. The magnitude of relative changes allows calculation of soil resistance and cross sectional impedance changes. Thus, with β being a relative integrity factor which is unity for no impedance change and zero for the pile end, the following can be calculated by the PDA.

$$\beta = (1 - \alpha)/(1 + \alpha) \quad (5)$$

with

$$\alpha = 2(W_{ur} - W_{ud})/(W_{di} - W_{ur}) \quad (6)$$

where

W_{ur} is the upward traveling wave at the onset of the reflected wave. It is caused by resistance.
W_{ud} is the upwards traveling wave due to the damage reflection.
W_{di} is the maximum downward traveling wave due to impact.

The basis for the results calculated by the PDA are pile top force and velocity signals, obtained using accelerometers and bolt-on strain transducers attached to the pile near its top. The PDA conditions and calibrates these signals and immediately computes average pile force and velocity.

3 RESULTS

Two of the methods described in section 2, Pile Installation Recording and Pulse Echo Method, were employed on the construction of a bank, in Pittsburgh, Pennsylvania, USA. Records from these methods are compared and interpreted.

3.1 Site Description

The job site consists of augercast piles, ranging in depth from approximately 18 to 20 meters (58 to 66 ft). All but the first few installations were conducted with the aid of the Pile Installation Recorder.

3.1.1 Shafts

The shafts selected for further integrity testing were constructed by drilling with a 500 mm (20 inches) diameter hollow stem auger and pressure injecting grout through the auger stem during auger withdrawal.

3.1.2 Soils

Soil boring logs for this site generally indicate medium dense sand with some stiff silt layers overlying bedrock. Some of the boring logs show the medium dense sands transition into dense sands at a depth of approximately 13.7 to 15 m (45 to 50 ft). Depending on the location, the bedrock consists of sandstone, claystone and shale. The bottom of the shafts were socketed at least one meter into the bedrock formation.

3.2 Piles Tested with the P.I.T.

The Pile Integrity Tester was employed to test several shafts by the Pulse Echo Method.

The records of most shafts (all the shafts in Pier B18 showed this behavior) indicated a characteristically similar decrease of impedance (evident by a relative increase in velocity) beginning at depths ranging from 12 to 15 m (40 to 50 ft). Although the level of impedance decrease (a clear toe reflection is required for a quantitative analysis), cannot be quantified it is likely that the decrease in impedance is from a gradual return to nominal diameter in the lower denser soils from a larger shaft diameter in the upper less dense soils.

3.2.1 Pile B18A

The velocity record for Pile B18A (Figure 7) indicates a reduction in impedance at approximately 13.7 m (45 feet).

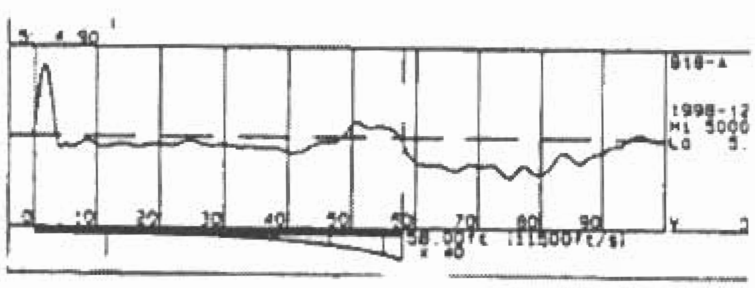

Figure 7. P.I.T. Record for Pile B18A

By examining a graph obtained from the PIR-A Summary Printout (Figure 8), one observes that between 15.2 and 14.6 m (50 and 48 feet) the grout volume per increment (increment was 0.61 m, or 2 ft) decreased from an average of about 0.18 m^3 to 0.13 m^3 (6.5 ft^3 to 4.66 ft^3). The decrease was apparently noticed by the operator, who managed to correct the withdrawal rate and keep it very close to the minimum required volume of 0.154 m^3 (5.45 ft^3) per increment for the remainder of the installation.

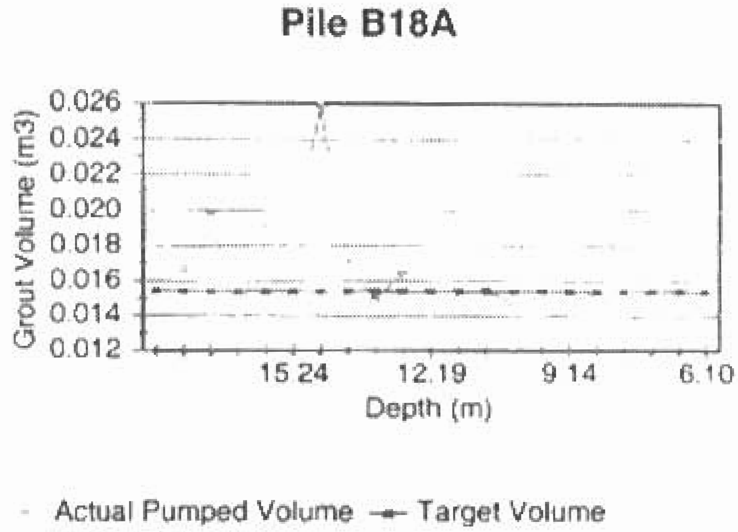

Figure 8. Plot of PIR-A Data

3.2.2 Other Piles

Following an initial pile failure on this site (a static test was performed early on), the PIR-A was used on the remaining piles on this project to improve the quality control. In addition, selected piles were tested for integrity after installation.

The Pile Installation Recorder (PIR-A) was used for all subsequent piles on this site. Examination of PIR-A records provides evidence of fairly homogeneous grouting rates, and by implication a consistent pile quality. These records indicate piles with no significant problems

Because no further difficulty was experienced due to adequate quality control by the PIR-A, there was no further testing for capacity. Had additional testing been required, the high strain dynamic PDA testing could have filled this need, as it has on numerous other augercast job sites.

4 CONCLUSIONS

Low strain PIT testing can detect major defects in the pile shaft at low cost and with little effort. Thus, all piles could be economically tested on a site. However, Pulse Echo Tests like P.I.T. are sometimes complicated 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.

Grout volume and grout pressure records from the Pile Installation Recorder can be used during installation to guide the contractor into installation of quality piles.

In this particular job, the P.I.T. detected a potential problem between 12 and 15 m (40 and 50 ft) below the pile tops. Examination of boring records offer a satisfactory explanation – the return to nominal diameter in the denser soils from larger shaft diameter in the upper less dense soils. These shafts most likely do not have any significant defects.

The Pile Installation Recorder recorded the installation of all piles. The unit performed flawlessly and automatically, requiring only entry of pile name for each pile installed. The PIR-A records were used to judge pile consistency and acceptance. For job sites where the installation of augercast piles is not closely monitored by a Pile Installation Recorder (PIR-A), the quality of the foundation is unknown and therefore risky unless there is extensive and further testing.

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