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Inspection of Foundation Piles: Geometric Evaluation and Structural Integrity – Innovative In-Situ Control Methods

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Abstract:

Bored piles require increasingly stringent quality control, in line with the design trend toward higher loads and a reduced number of foundation elements. Since piles cannot be directly inspected and the available tests are mostly indirect, it is essential to adopt methodologies capable of promptly identifying geometric or construction-related irregularities. This paper presents three advanced tools for in situ quality control: SHAPE® for verifying verticality and excavation profile, SQUID™ for assessing base cleanliness, and CHAMP for Cross-Hole investigation of concrete integrity.

Keywords: SHAPE®, SQUID™, CHAMP; Deep foundations; Bored foundation piles; NDT (Non-Destructive Testing)

1 Introduction

Bored foundation piles are widely used due to their high axial and lateral load bearing capacity.

Modern design practice adopts higher foundation loads, a reduced number of elements, and optimized pile lengths compared to the past. In this context, quality control—performed both before and after concrete casting—plays a crucial role in ensuring the correct in service performance of the foundation system. In essence, it is essential to ensure consistency between the design assumptions and the actual conditions realized on site. Inspection and control procedures therefore reduce risk by identifying and assessing, at an early stage, deviations from the design or construction defects.

All testing methodologies applicable to foundation piles must overcome objective difficulties inherent to the structural element under investigation—the pile itself. Among the most evident are: the pile is not visible to the operator during testing; it has a particular geometry (typically slender); only indirect testing methods are generally feasible and no single testing method is capable of revealing all the characteristics to be investigated.

As is often the case, also for in situ testing of foundation piles, the effectiveness of a testing methodology is closely related to the capabilities of the instruments used and to their ability to provide early information with respect to the construction progress on site.

An exhaustive review of all available testing methodologies is beyond the scope of this paper; however, three testing methods that meet the technical requirements outlined above are presented. Specifically, a method for verifying verticality and excavation profile (the SHAPE® system), a method for assessing the cleanliness of the bottom of the drilled shaft (the SQUID™ system), and the Cross-Hole methodology for evaluating the quality and integrity of the concrete placement (the CHAMP system) are described. All the instruments presented are part of the product portfolio of Pile Dynamics Inc., a leading company in the field of deep foundation testing.

2 SHAPE® - verifica della verticalità e del profilo del pozzo trivellato.

2.1 General

Reinforced concrete bored piles are commonly used elements in deep foundations. Thanks to increasingly advanced construction techniques, this type of foundation element is being used more and more frequently, with ever larger diameters and lengths, in order to support very high loads.

During the design phase, it is generally assumed that the pile diameter is uniform along its entire length and that the pile is perfectly vertical. However, for various reasons related to construction practice, this assumption may not always be valid. In reality, excavation and subsequent concrete placement may exhibit bulges or reductions in cross-section due to soil conditions and/or construction techniques. Piles may also present verticality defects caused by bent Kelly bars, permissible tolerances in long piles, improper alignment of the drilling rig, or deflection of the drilling tool due to harder soil layers.

If the pile verticality is outside the specified tolerances, eccentric loading may occur at the pile head, inducing additional lateral forces that could potentially cause damage under extreme conditions. Minimum reinforcement cage cover requirements may also not be satisfied; however, this type of nonconformity can only be investigated using the TIP™ (Thermal Integrity Profiler) testing method

Over the years, various methods have been attempted to measure the verticality of bored shafts, including levels, ultrasonic instruments, and inclinometers.

The methodology presented here, the Shaft Area Profile Evaluator (SHAPE®), is based on an ultrasonic device capable of operating both in dry conditions and in excavations supported by drilling fluids. The test is performed after drilling, prior to installation of the reinforcement cage and subsequent concrete casting.

2.2 Equipment Description – Operating Principle

The SHAPE® device measures distances from the centerline to the sidewall of bored pile excavations constructed using drilling fluids such as water, bentonite slurry, or polymer slurry. The equipment emits ultrasonic pulses that propagate through the fluid, and measures the time required for the pulses to reach the sidewall and be reflected back to the device (first arrival time, FAT). The system calculates the distance between the sensors and the sidewall based on the wave velocity measured at each depth using the following relationship: distance = wave velocity × time

For the same FAT, a higher measured wave velocity results in greater calculated distances.

The equipment can be connected to a Kelly bar or lowered into the drilled shaft using a winch system at a speed of approximately 30 cm/s. Figure 1 shows the SHAPE® device

Figure 1 SHAPE® device

The equipment consists of eight ultrasonic transmitters and one ultrasonic receiver for measuring distances to the lateral wall. In addition, integrated calibration sensors are used to directly measure the wave transmission velocity in the medium. This measured wave velocity is then used to calculate the distance to the wall, as described previously. Two pressure transducers mounted on the device estimate the depth of the equipment at each measurement, thus allowing the exact correlation of the measured distance with the depth at which it was acquired. A gyroscope identifies magnetic north and tracks any rotation of the device during its descent [1].

The use of this instrument, equipped with the described sensor array, therefore allows the lateral profile of the excavation to be obtained without the need to stop at predefined depths and without restricting the rotation of the instrument.

SHAPE® connects via WiFi to a Windows tablet. This minimizes the risk of data loss caused by potential damage to connection cables.

Figure 2 shows typical ultrasonic signals at a specific test depth. The first eight plots display the signals received from the eight ultrasonic transmitters. The final plot represents the measurement performed by the calibration sensors, which the instrument uses to evaluate the wave travel velocity through the medium (drilling fluid)—1533 m/s in the example shown. All eight signals exhibit a similar first arrival time (FAT), indicating that the device is equidistant from the sidewalls. The centered position of the device is also evident from the excavation plan view at the recorded depth, shown on the right-hand side of the figure.

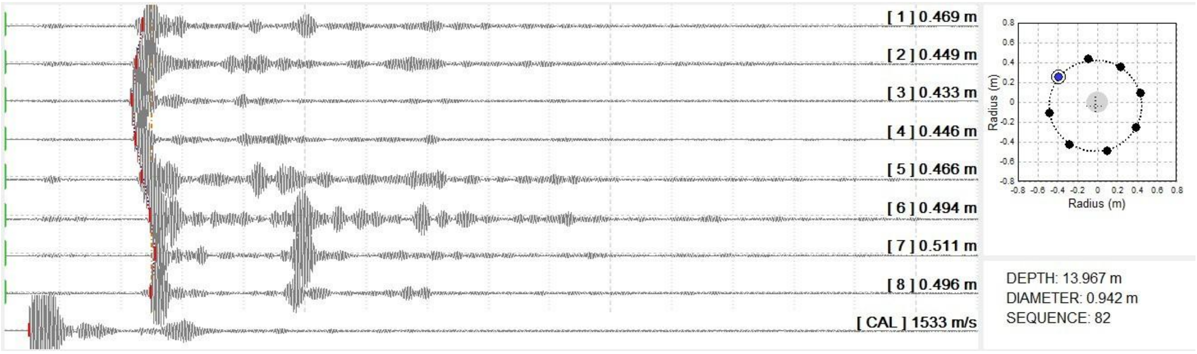


Figure 2 Ultrasonic signals from eight radial transmitters and calibration pulse

Similar scans and measurements are typically collected once per second while the device is lowered toward the bottom of the drilled hole. After data processing, the eight scans are presented as radius versus depth (two-dimensional representation). Based on the collected data, the verticality of the borehole is calculated as the relative displacement of the centers of the circles obtained at two defined depths, divided by the vertical distance between them.

It is preferable to lower the device as close as possible to the center of the pile. If the device is operated using a Kelly bar, the verticality of the Kelly bar must be ensured before lowering the equipment. These precautions ensure that the device remains sufficiently distant from the sidewalls and that the data analysis is reliable.

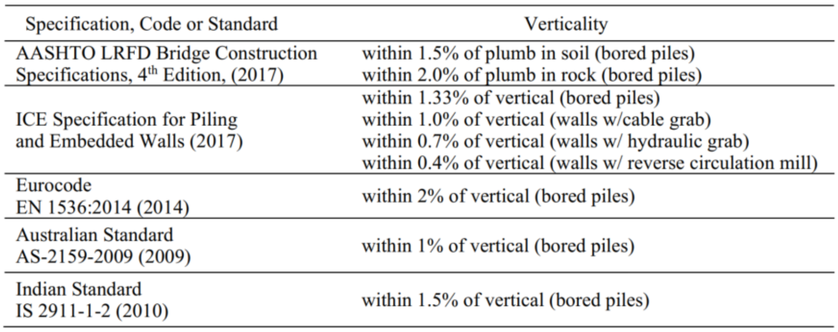
At present, the limitations of the methodology are related to the difficulty of obtaining verticality and profile data in drillings carried out with high viscosity fluids and when the sand content exceeds 5%. From an application standpoint, it is not possible to use the winch system in the case of inclined piles.

2.3 Acceptance Criteria

Various codes and specifications worldwide emphasize the importance of borehole verticality before the pile is cast in place. However, the actual measurement of this important parameter is often neglected.

Most specifications or codes around the world prescribe a verticality tolerance in the range of 1%–2% [2]. The FHWA has suggested that verticality specifications may allow a tolerance within 1.5% in soil and within 2% in rock [3]. The ICE specification for piles and diaphragm walls specified an allowable verticality within 1.33% for drilled piles [4] – SHAPE® can be used on D-wall with a dual cable winch system. The Eurocodes and Australian standards allow tolerances of 2% and 1%, respectively [5][6].

Table 1 below provides a summary of the requirements contained in the main international codes and standards



Specification, Code or Standard	Verticality
AASHTO LRFD Bridge Construction Specifications, 4th Edition, (2017)	within 1.5% of plumb in soil (bored piles) within 2.0% of plumb in rock (bored piles)
ICE Specification for Piling and Embedded Walls (2017)	within 1.33% of vertical (bored piles) within 1.0% of vertical (walls w/cable grab) within 0.7% of vertical (walls w/ hydraulic grab) within 0.4% of vertical (walls w/ reverse circulation mill)
Eurocode EN 1536:2014 (2014)	within 2% of vertical (bored piles)
Australian Standard AS-2159-2009 (2009)	within 1% of vertical (bored piles)
Indian Standard IS 2911-1-2 (2010)	within 1.5% of vertical (bored piles)

Table 1 Summary of Verticality Requirements for Bored Piles and Diaphragm Walls

2.4 *Application Examples*

Two examples of application of the described methodology are presented below. The real case studies refer to two installations carried out in India [7]. The material presented was provided courtesy of Pile Dynamics Inc.

2.4.1 *Case Study 1 – Railway Project – India*

This case concerns a large diameter bored pile (diameter: 1.8 m; length: 31.1 m) constructed in Vadodara, Gujarat – India. The soil conditions consisted mainly of clay, with stiff clay expected at the maximum depth.

During drilling, temporary casing was installed over the upper 4.5 m with a diameter of 1.83 m to prevent soil collapse in the initial portion of the borehole. A polymer slurry was subsequently added to the drilling fluid to stabilize the sidewalls. The fluid level was maintained at 2.1 m below the top of the pile. On site fluid control personnel measured a sand content of 0.75%.

The SHAPE® instrument was positioned centrally above the borehole once drilling was completed. Figure 3 shows the initial position above the shaft and the pulley centering operations. Once properly positioned, the unit was armed for data acquisition (using a tablet) and lowered using a winch at a speed of approximately 300 mm/s. Figure 4 shows data acquisition in progress, with the equipment immersed in the drilling fluid. Data were collected during both the lowering and retrieval of the device.

Figure 5 presents a summary of the typical results obtained from the SHAPE® system. The drilled hole profile was found to be vertical and uniform. The average diameter measured by SHAPE® was 1.82 m, and the verticality tolerance was satisfied in accordance with the local standard IS: 2911 2010 (Part 1/Section 2).

Figure 6 presents the three-dimensional rendering of the data, clearly confirming the previously observed results.

Figure 3 Device centering

Figure 4 Collecting data phase

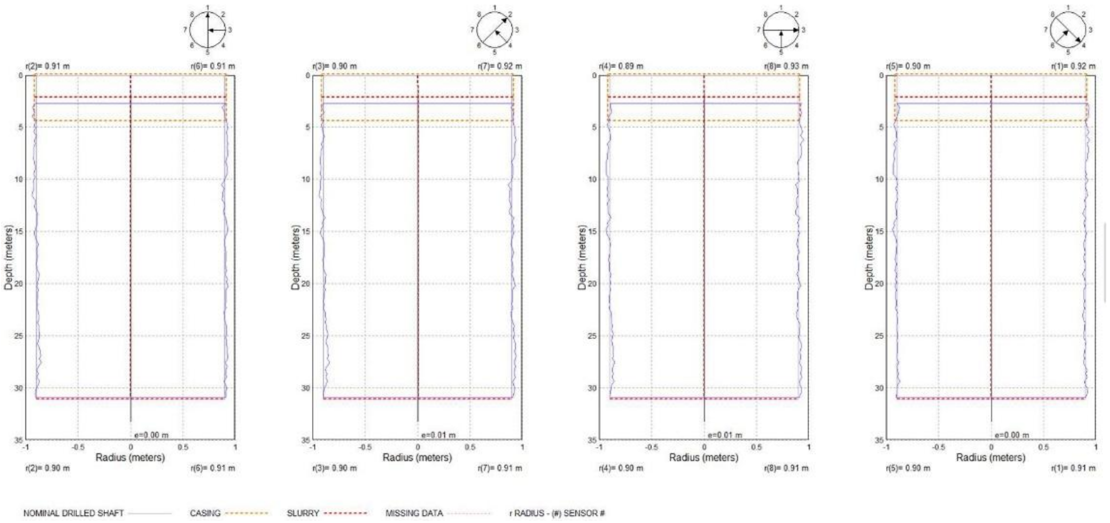


Figure 5 Measurements results

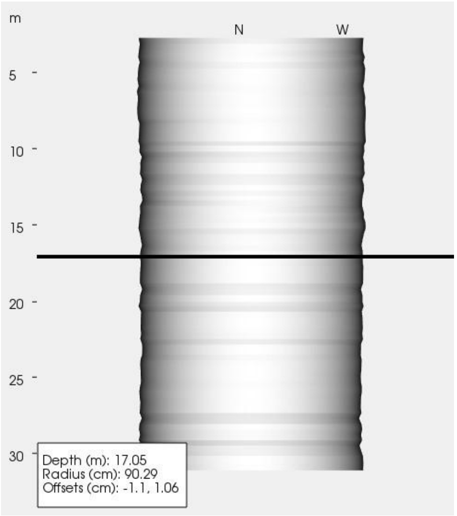


Figure 6 3D Rendering from acquired bore hole

2.4.2 Case Study 2 – Metro Project – India

This case presents an excerpt of the results obtained from the application of the method within the construction project of the Ahmedabad Metro, Gujarat, India. The piles had a diameter of 0.98 m and a length of 28 m. The soil profile consisted mainly of sandy clay and sandy soils along the entire pile length.

During drilling, a temporary casing with a diameter of 1.1 m and a length of 3.5 m was installed. Similar to Case Study 1, a polymer slurry was added to the drilling fluid to stabilize the excavation. The polymer level was maintained at 3 m below the pile top. The sand content was not available on site.

After completion of the excavation, the device was positioned centrally above the borehole, as shown in Figure 7, and lowered using a winch at a speed of 300 mm/s. Figure 8 shows data acquisition in progress. Data were collected during both the lowering and lifting phases of the device. The tests were repeated several times to verify the repeatability of the results.

Figure 9 and Figure 10 show the results of the measurements performed. The borehole geometry was found to be uniform, with an average measured diameter of approximately 1.0 m. However, a deviation from verticality was observed, with evident eccentricity in both the north–south and east–west directions. In one direction, the eccentricity was 30 mm, while in the other (the perpendicular direction) it was 120 mm. The maximum eccentricity was 0.45%, which remained within acceptable limits.

Following further investigations, the main cause of the eccentricity was attributed to the telescopic mast of the drilling rig. The mast exhibited bending deformations, detected after the measurements, and these anomalies were corrected before resuming subsequent drilling operations. Figure 11 presents a 3D rendering showing a pile shaft that is nevertheless uniform throughout its entire depth.

Figure 7 Device centering

Figure 8 Collecting data phase

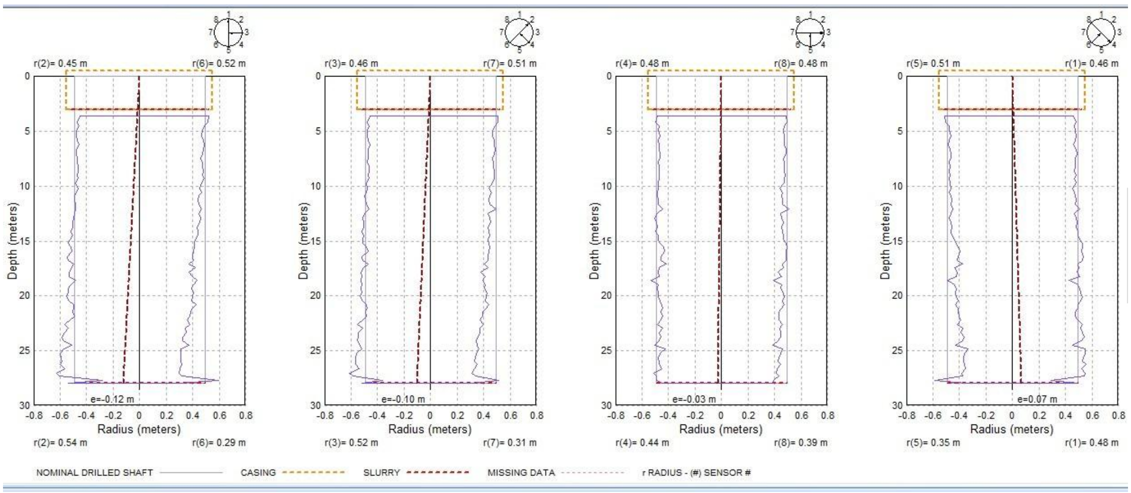


Figura 9 Risultati delle misurazioni

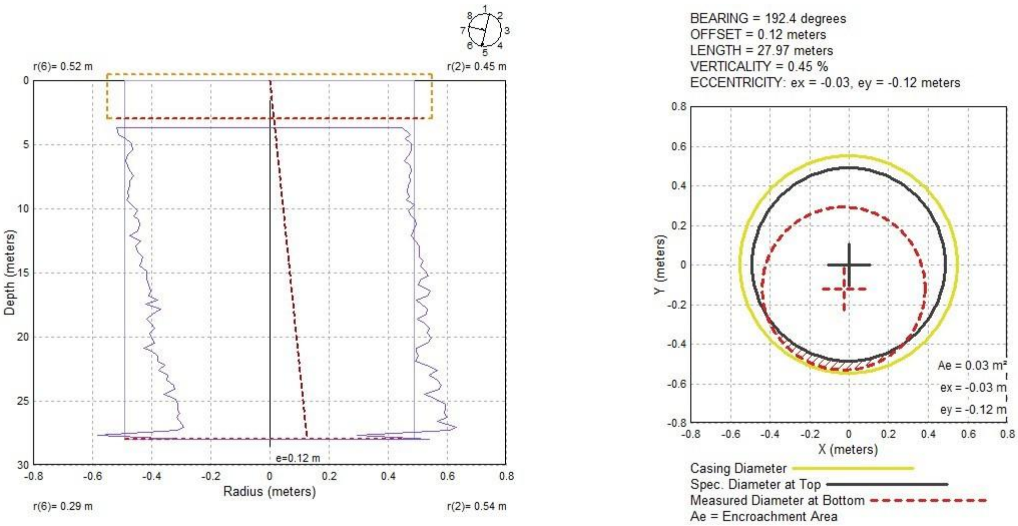


Figura 10 Risultati delle misurazioni - verticalità

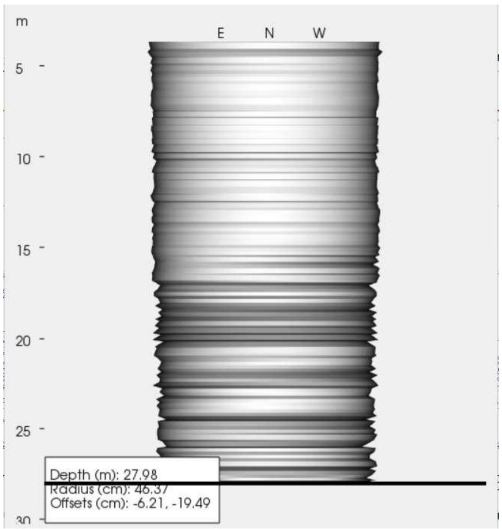


Figura 11 Rendering 3D del palo acquisito

2.5 Final Considerations on the Method

Large diameter reinforced concrete bored piles, subjected to high service loads and significant embedment depths, are increasingly used worldwide. The construction of such foundation systems requires verification of every aspect of the installation process.

Low Strain Integrity Testing (PIT), Cross Hole Sonic Logging (CSL), Thermal Integrity Profiling (TIP), static load tests (SLT), high strain dynamic testing (PDA), and similar methods are well established tools for the QA/QC of pile foundations and allow the evaluation of pile integrity and capacity. However, the measurement of pile verticality is often not routinely performed.

If an installed pile is excessively out of plumb, eccentricities may introduce bending moments that can damage the pile. It is therefore advisable to measure pile verticality in order to identify and correct deviations or anomalous borehole geometries before installing the reinforcement cage and casting the concrete. For the case studies presented, the entire data acquisition process for the excavation profiles required approximately 15 minutes and did not interfere with piling operations.

Quantitative evaluation of the borehole diameter provides structural and geotechnical engineers with a valuable tool for moment calculations, estimation of unit pile resistance, and refinement of design load capacities. The method is also applicable when, for large diameter piles with under reamed bases, it is necessary to map the extent of the enlargement, or when excavation support is insufficient to prevent inward collapse of the sidewalls.

3 SQUID™ - Quantitative Verification of Excavation Base Cleanliness

3.1 General

The cleanliness of the base of bored pile excavations is a fundamental issue with significant implications for the quality and performance of this type of deep foundation. Proper cleaning of the base of bored piles also represents a key risk mitigation measure to reduce concrete contamination during placement. In addition, it helps prevent post construction settlement problems caused by excessive layers of soft or loose debris left at the base of the excavation [8].

Over the years, various instruments and approaches have been proposed and published to evaluate the cleanliness of shaft bases. In deep foundation works using bored piles, particularly in the presence of soils with poor stability and shallow groundwater levels, the use of drilling fluids is the most commonly adopted method. In this approach, drilling slurry is introduced into the borehole to maintain excavation stability and prevent groundwater inflow. During drilling operations, debris and sediments tend to accumulate at the bottom of the borehole; if not adequately removed prior to concrete casting, these materials can adversely affect the performance of the foundation element [9].

The base of the drilled shaft is typically cleaned using airlift systems and/or cleaning buckets. After completion of these operations, the condition of the pile base can be quantitatively assessed using dedicated inspection devices.

In this context, the SQUID™ instrument represents the state of the art. The test is performed after drilling and before installation of the reinforcement cage and subsequent concrete casting.

3.2 Equipment Description – Operating Principle

The SQUID™ device has an octagonal shape with a maximum diagonal length of 647 mm and a height of 635 mm. The instrument is equipped with three penetrometers and three retractable displacement plates, which are used to simultaneously record force and displacement. The penetrometers are designed with conical or flat tips having an average cross sectional area of $10\ \text{cm}^2$ (see Figures 12 and 13). Penetration resistance is measured by strain gauges with a full scale capacity of 100 MPa. The SQUID™-36 model (with reduced dimensions) also allows testing on small-diameter drilled shafts — from 450 mm upward.

The testing procedure consists of mounting the device onto the Kelly bar and lowering it into the drilled shaft. Once the device is positioned at the bottom of the borehole, the weight of the Kelly bar applies sufficient force to the probes to measure the resistance required to penetrate the debris layer and reach the bearing strata, while the displacement plates retract, recording the corresponding movements. The associated forces and displacements are continuously recorded. Real time force–displacement graphs are generated and displayed on the tablet supplied with the instrument, as shown in Figure 14. As an alternative to the Kelly bar, other configurations can be used, such as a 1 ton beam.

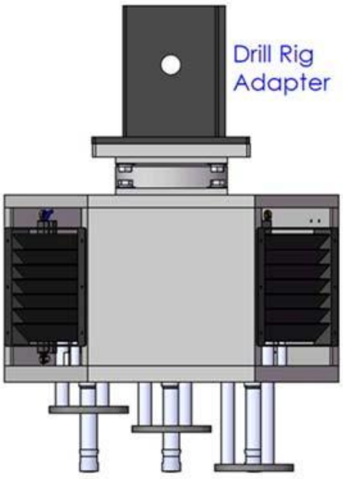


Figure 12 SQUID™

Figure 13 SQUID™ mounted on the Kelly bar (left) and 1 ton beam (right) at the construction site

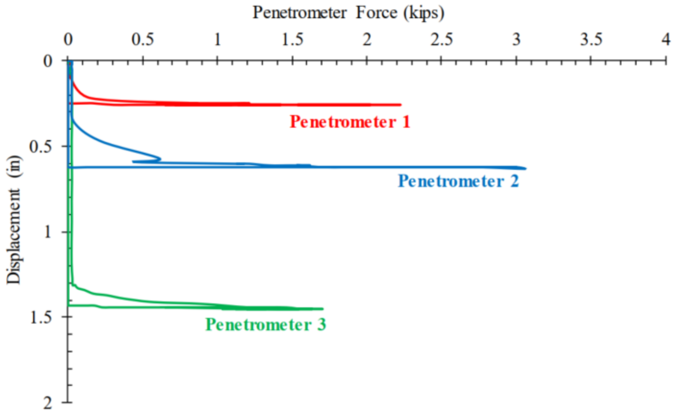


Figure 14 Penetration force–displacement graph (SQUID™ test output)

3.3 *Acceptance Criteria*

Based on the consistency of a material classified as debris, it is reasonable to assume that such material exhibits strength properties similar to those of soft to medium clay, with an unconfined compressive strength ranging between 0.25 ksf (12 kPa) and 2.0 ksf (95 kPa), and a unit weight between 100 pcf (16 kN/m³) and 120 pcf (19 kN/m³).

Using these strength parameters, and applying the general bearing capacity theory proposed by Terzaghi (1943) for circular foundations—Equation (1)—the penetration resistance of a flat tip with a cross sectional area of 1.55 in² (10 cm²) was determined to range between 0.020 kips (0.089 kN) and 0.160 kips (0.712 kN).

$$q_{ult} = 1,3 s_u N_c \tag{1}$$

where:

q_{ult} is the ultimate bearing capacity of a circular base,

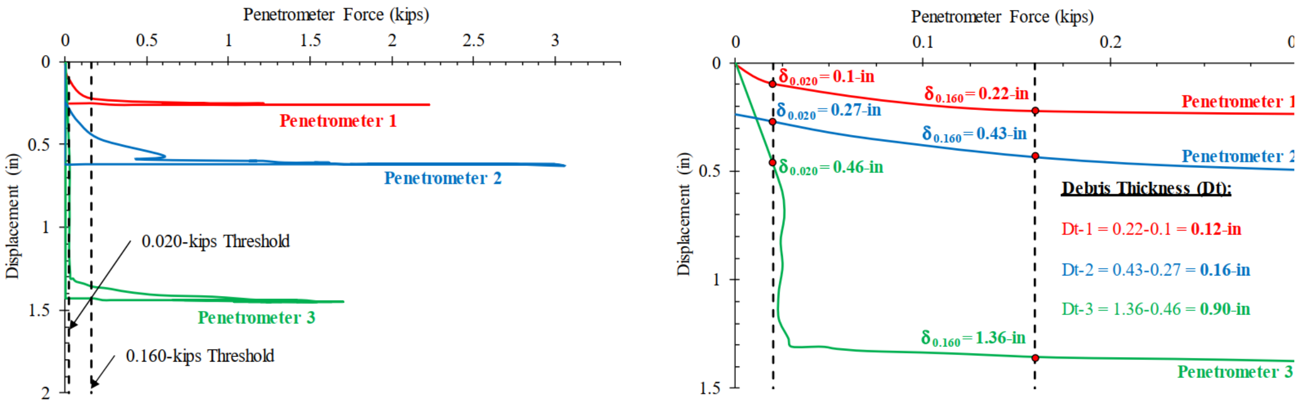
s_u is the undrained shear strength of the material, and

N_c is the bearing capacity factor.

According to the results obtained from Equation (1), a debris layer is defined as a material exhibiting a minimum and maximum penetration resistance of 0.020 kips (0.089 kN) and 0.160 kips (0.712 kN), respectively. Furthermore, it is reasonable to assume that materials with a penetration resistance lower than 0.020 kips (0.089 kN) have a unit weight of less than 150 pcf (24 kN/m³). Consequently, this softer material will be displaced by the concrete during placement. At the upper limit, a material with penetration resistance greater than 0.160 kips (0.712 kN) is considered to be natural soil or rock.

Debris thickness thresholds can be plotted on the force–displacement curves to determine the thickness of the debris layer according to the characteristics described above, as shown in Figures 15a and 15b. Figure 15a illustrates the results of a SQUID™ test presented as a force–displacement plot including the debris thickness thresholds. The plot includes both the loading and unloading phases of the test, during which the force progressively increases to the maximum recorded load for each penetrometer and then returns to zero during unloading. Similarly, the displacement plates record the displacements corresponding to each applied load and gradually return to zero as the weight of the Kelly bar is fully released.

For illustrative purposes, Figure 15b provides a magnified view of the threshold lines, and the debris thickness is calculated by subtracting the displacement corresponding to the soil/rock threshold (0.160 kips) from that corresponding to the debris threshold (0.020 kips). This process is automated in the instrument software, and the debris thickness is reported both graphically and in tabular form [9].



a) Debris thickness thresholds

b) Determination of debris thickness

Figure 15 Force–displacement plots obtained from SQUID™ tests

The base cleanliness specifications contained in various international standards are summarized in Table 2. These specifications range from allowable sediment thickness limits between 13 mm and 75 mm, depending on the construction technique and geotechnical support conditions, to more general, non quantified acceptance criteria.

Specification, Code or Standard	Base Cleanliness
AASHTO LRFD Bridge Construction Specifications, 4th Edition, (2017)	Dry drilled in soil < 38 mm of sediment / loose material. Wet drilled in soil < 75 mm of sediment / loose material. Drilled in rock < 13 mm sediment over 50% of base area.
Eurocode EN 1536:2014 (2014)	Disturbed soil, debris or any other material that could affect the bored pile performance shall be removed from the base prior to concrete placement.
Australian Standard AS-2159-2009 (2009)	Bored piles shall be founded in and underlain by material such that the strength and serviceability design criteria are satisfied.
Indian Standard IS 2911-1-2 (2010)	If borehole stabilized by drilling mud, the bottom of the hole shall be cleaned of all loose and undesirable materials before commencement of the concrete pour.

Table 2 Summary of base cleanliness requirements for bored piles

3.4 Case Study 1 – Oklahoma City, Oklahoma

Presented below is an example of measurements performed using the SQUID™ instrument at the base of a bored pile belonging to a group of six piles. The pile under consideration had a diameter of 1.52 m, and the test was carried out after completion of base cleaning operations. The tests were repeated at five locations on the base of the excavation by repositioning the instrument; the measurement points were identified as Center, North, South, East, and West.

The soil was classified as an Intermediate Geomaterial (IGM), identified as weathered shale.

For each pile, the device was lowered into the drilled shaft and, once it reached the base of the shaft, the Kelly bar was released to transfer its weight to the device. During this process, the penetrometers measured deformation while the displacement plates recorded the penetration distance into the debris material. The force, calculated from the measured deformation, was then plotted against displacement, as shown in Figure 16.

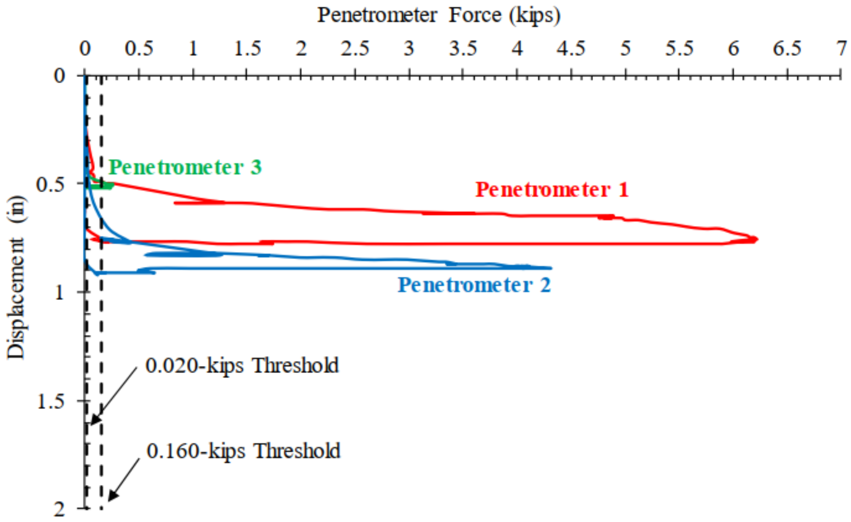


Figure 16 SQUID™ test results – Pile 161 – "Center" position

Using the force–displacement plots and the definition of debris material, the SQUID™ test results shown in Figure 16 indicated an average debris thickness of 0.20 in (5 mm) at the center of the shaft, with values of 0.23 in (6 mm), 0.04 in (1 mm), and 0.33 in (8 mm) corresponding to penetrometers 1, 2, and 3, respectively.

In the project discussed in this study, the base material tested for determining debris thickness was an IGM. From analysis of the plot shown in Figure 16, it can be observed that the penetrometers pass through a soft material until a point where a sudden increase in force occurs with minimal additional displacement. This response can be interpreted as the abrupt encounter of a stiff material (i.e., the IGM) by the penetrometers.

For comparison purposes, and to illustrate the force–displacement response corresponding to a material other than IGM, results obtained from another project located in North Carolina, where the base material consisted of very dense sand, are shown in Figure 17. As can be seen, in the tests conducted at that site the penetrometers initially penetrated fill material and, in contrast to the response shown in Figure 16, exhibited a gradual increase in force with increasing displacement rather than the abrupt increase typical of the IGM case. The response of penetrometer 3 indicates the presence of a loosely compacted sand distinct from what is defined as debris at the pile base, and the penetrometers were able to penetrate this material with displacements of up to 6 in (152 mm). Nevertheless, the average debris thickness was determined to be 0.20 in (5 mm), with displacements of 0.13 in (3 mm), 0.35 in (9 mm), and 0.13 in (3 mm) for penetrometers 1, 2, and 3, respectively [9].

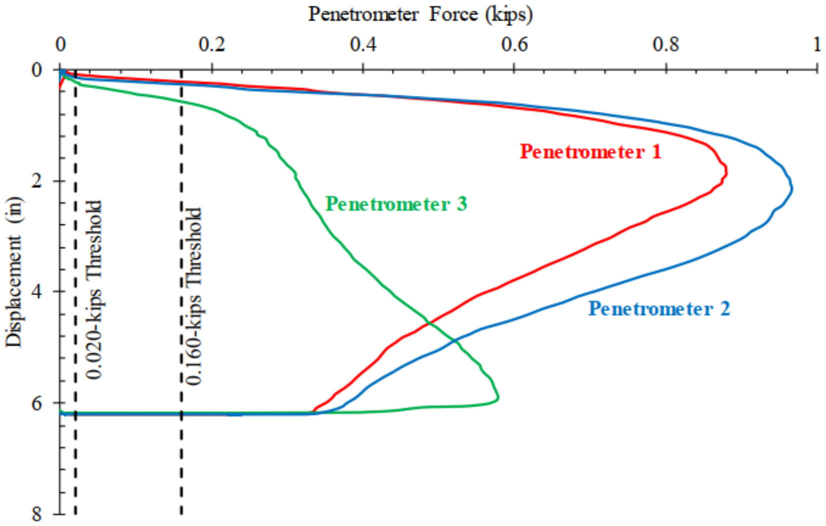


Figure 17 SQUID™ test data corresponding to dense sandy material at the base of the shaft

3.5 *Final Considerations on the Method*

The use of the SQUID™ device for the quantitative verification of drilled-shaft base cleanliness has proven to be a highly reliable and repeatable solution, capable of overcoming the limitations of traditional methods based on qualitative assessments. The ability to simultaneously measure force and displacement enables an objective distinction between debris materials and bearing strata, thereby reducing uncertainty during the most critical phases of construction.

Overall, the adoption of the SQUID™ method contributes to improving the construction quality of drilled shafts, reducing the risk of concrete contamination, geometric defects, and inadequate foundation performance. Integrating this approach into on-site quality control procedures therefore represents an important step toward higher standards of reliability and safety in deep foundation works

4 CHAMP® – Cross-Hole Sonic Logging for Verification of Concrete Quality in Bored Piles

4.1 General

Non destructive testing of bored piles using Cross Hole Sonic Logging (CSL) is frequently performed as part of the quality assurance process to evaluate the integrity of concrete in bored piles. The objective of CSL testing is to identify irregularities such as soil intrusion, cross section reductions (necking), soft bases, segregation, voids, and other defects that could adversely affect the structural performance of the foundation.

The following definitions introduce the two parameters that form the basis for interpretation of CSL results (logs):

- First Arrival Time (FAT): the time required for the initial wavefront of the ultrasonic pulse to travel the distance between the transmitter and receiver during a Cross Hole Sonic Logging test.
- Relative Energy (RE): the ratio between the energy of the received signal and the energy of a reference signal, used to assess the quality of the transmission path through the concrete.

4.2 Equipment Description – Operating Principle

Cross Hole Sonic Logging (CSL) involves attaching steel or PVC access tubes inside the cage before the cage is placed into the bored pile excavation or diaphragm wall trench, and prior to concrete casting. For circular foundations, it is recommended to install one access tube every 300 mm of pile diameter; for rectangular elements, tubes are arranged in pairs on opposite faces with a distance of 1 m (ore less) and one tube in every corner (see Figures 18 and 19).

Figure 18 Access tubes installed on a foundation pile

Figure 19 CHAMP® instrumentation – tablet interface

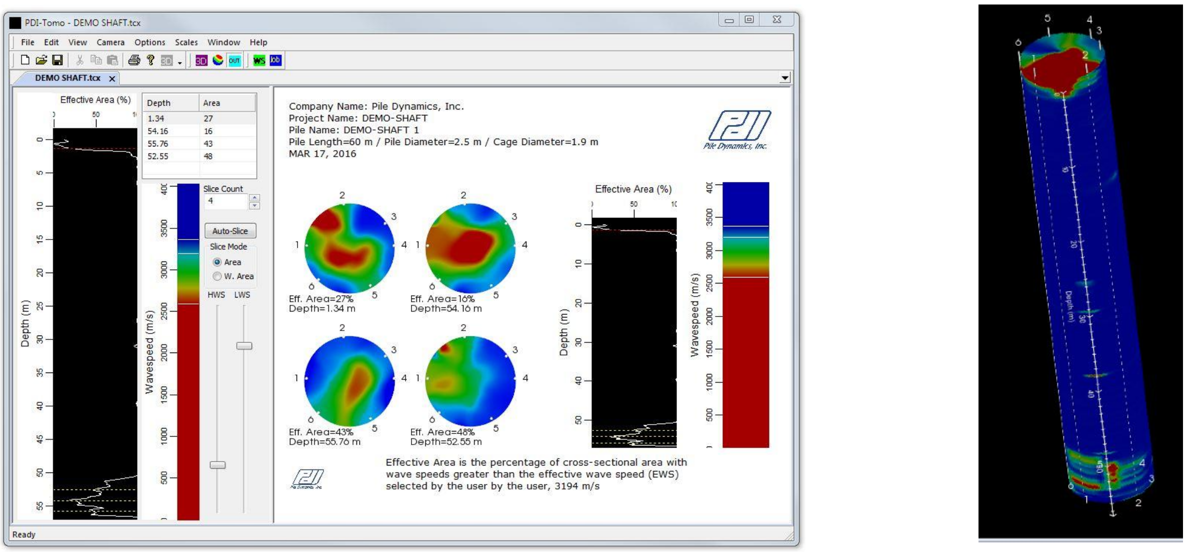
Immediately after concrete placement, the access tubes are filled with water to minimize thermal decoupling between the tubes and the surrounding concrete. In any case, the use of steel tubes is strongly preferred over PVC tubes, as steel is far less sensitive to issues related to thermal decoupling.

After a minimum curing period of three to seven days, the transducers are lowered to the base of the access tubes and then raised at a maximum speed of 1.5 m/s. The signals, acquired at 32 scans per second, provide a vertical resolution of approximately 1 cm. The resulting profiles of first arrival time (FAT) and signal energy as functions of depth can be used to identify zones of weak concrete or soil inclusions (indicated by delayed arrivals). The profiles (logs) are displayed in real time on the instrument tablet to which the probes are connected.

In the four channel version, the CHAMP® system allows simultaneous scanning of all paths (four access tubes and all cross combinations, i.e. six paths – see Figure 20) thanks to the capability of the ultrasonic probes to operate both as transmitters and receivers. The system is able to measure the probe travel distance using encoders (one per probe), which are mounted either on a site tripod or directly on the access tubes

Figure 20 Scheme of simultaneous paths analyzed with the 4-channel CHAMP system

The ability to obtain readings from probes simultaneously allows the generation of 3D sonic tomography from the resulting data by means of the dedicated TOMO® software[MS15.1]. From the tomographic output, information on the spatial distribution of potential anomalies can be derived, and sections can be extracted from the resulting three-dimensional model of the analyzed pile.



Depth	Area
1.34	27
54.16	16
55.76	43
52.55	48

Company Name: Pile Dynamics, Inc.
Project Name: DEMO-SHAFT
Pile Name: DEMO-SHAFT 1
Pile Length=60 m / Pile Diameter=2.5 m / Cage Diameter=1.9 m
MAR 17, 2016

Eff. Area=27%
Depth=1.34 m

Eff. Area=16%
Depth=54.16 m

Eff. Area=43%
Depth=55.76 m

Eff. Area=48%
Depth=52.55 m

Effective Area is the percentage of cross-sectional area with wave speeds greater than the effective wave speed (EWS) selected by the user by the user, 3194 m/s

Figure 21 TOMO® software – main interface

4.3 Acceptance Criteria

Over time, CSL evaluation criteria based on first arrival time and relative energy have evolved—sometimes inappropriately—often becoming the sole basis for determining pile acceptability. Some of these criteria have been incorporated into specifications issued by regulatory agencies, with acceptance thresholds that frequently vary from one agency to another [10]. Today, the state of the art in non destructive testing of foundation piles recommends a multi method approach, in which several testing techniques are combined to provide a comprehensive assessment, leveraging the strengths and limitations of each method.

In this context, and referring the reader to publications specifically addressing this topic, the TIP test (Thermal Integrity Profiling) is highlighted as a method capable of providing information on the integrity of the entire concrete volume of a pile (inside and outside of the cage – steel cover)—unlike the CSL method, which assesses only the portion of concrete located between the inspection tubes (only inside the cage – no concrete cover results).

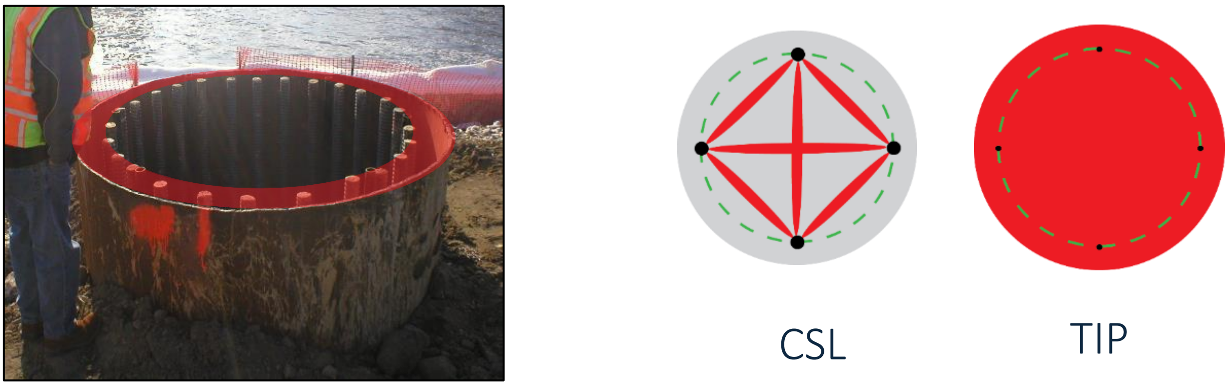


Figure 22 Concrete volumes investigated by CSL and TIP, respectively

CSL data should be used as part of the pile acceptance process and therefore require a classification system to distinguish acceptable results from anomalous ones. Once the possibility of equipment malfunction or improper testing procedures has been ruled out, CSL test results for each profile should be classified into one of the following categories (derived from a recently proposed acceptance criterion that reflects the current state of the art in CSL methodology [10]):

- Class A: Acceptable CSL results
- Class B: Conditionally acceptable CSL results
- Class C: Highly anomalous CSL results

The definition of each class is provided below (see Figure 23).

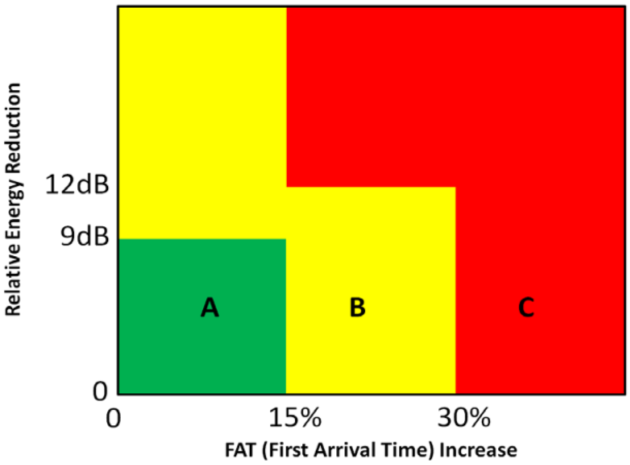


Figure 23 Graphical representation of the proposed classification

Detailed Classification:

Class A: Acceptable CSL results

For any segment of the profile, increases in First Arrival Time (FAT) are less than 15% of the local mean FAT value, and reductions in Relative Energy (RE) are less than 9 dB relative to the local mean RE value.

Racommendations:

Data within normal limits. No additional evaluation required.

Class B: Conditionally acceptable CSL results

For any segment of the profile, FAT increases range between 15% and 30% of the local mean FAT value and RE reductions are less than 12 dB relative to the local mean RE value — OR: FAT increases are less than 15% of the local mean FAT value AND RE reductions exceed 9 dB relative to the local mean RE value.

Class C: Highly anomalous CSL results

For any segment of the profile, FAT increases are greater than 30% of the local mean FAT value — OR: FAT increases are greater than 15% of the local mean FAT value and RE reductions exceed 12 dB relative to the local mean RE value.

For results classified as Class B or Class C, additional investigations are recommended to more accurately define the extent of the anomaly and assess the acceptability of the pile in question. Details are provided in the relevant literature cited in this paper. In any case, and in light of the considerations discussed above, it is recommended not to base pile acceptability solely on the results of a single test such as CSL [10].

4.4 Case Study – 1

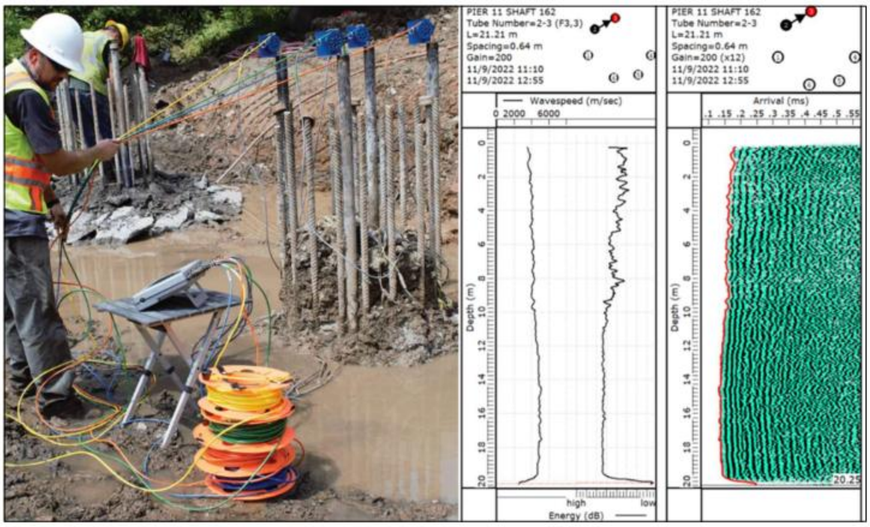


Figure 24 CSL test configuration (left), wave velocity and energy as functions of depth (center), and FAT—First Arrival Time plot (right)

A four probe CSL configuration is shown on the left side of Figure 24. The wave velocity calculated in the concrete (derived from the FAT and the spacing of the tubes relative to ground level) and the signal energy intensity are shown in the center of Figure 24, with the corresponding log for that tube pair displayed on the right. The left edge of the log corresponds to the First Arrival Time (FAT) (red line). The profile is very consistent along its 20.25 m length, except in the last 0.5 m above the pile toe, where an anomalous zone is indicated by a 72% delay in FAT and a 14 dB reduction in signal energy.

4.5 Case Study – 2

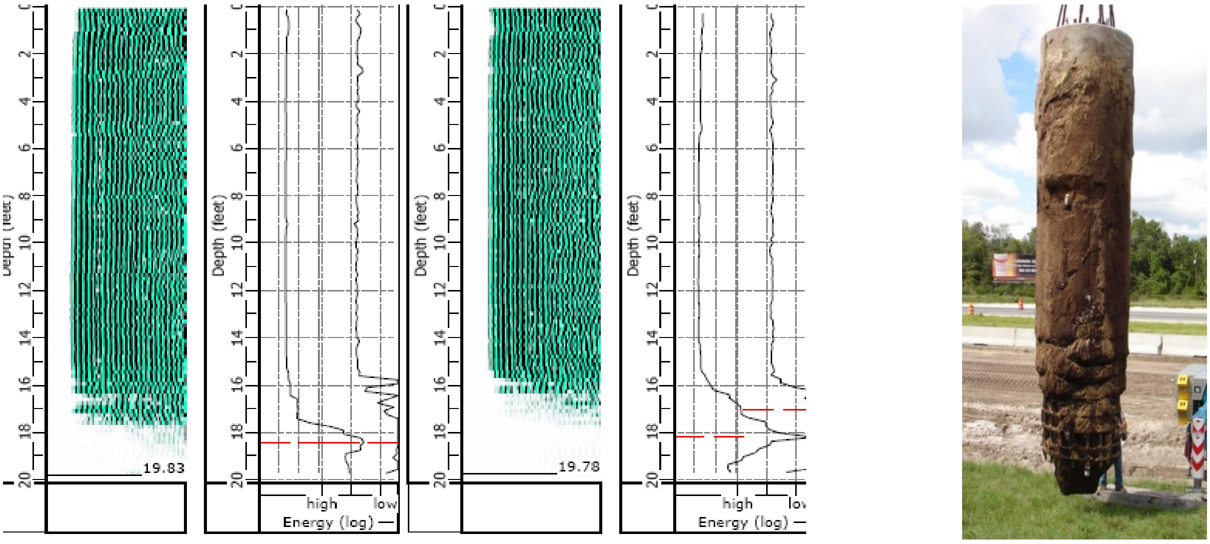


Figura 25 CSL log and photograph of the extracted pile

Two CSL logs are shown for a bored pile with a diameter of 1.5 m and a length of 15 m. At approximately 3 m above the pile toe, there is a substantial, almost complete loss of ultrasonic signals, evidenced by both an increase in First Arrival Time (FAT) and an almost total reduction in Relative Energy (RE). The pile was deemed unacceptable and was subsequently extracted. The image in Figure 25, showing the condition of the pile toe, confirms the findings indicated by the CSL test results.

5 Conclusions and final considerations on the three Methods discussed in this Paper

In situ quality control of bored piles must evolve in parallel with increasing design demands: higher loads, a reduced number of elements, and optimized pile lengths require more rigorous and timely verification procedures. Since piles cannot be directly inspected and the available tests are mostly indirect, it is essential to adopt methodologies capable of promptly identifying geometric or construction related deviations.

The analysis presented clearly shows that an integrated control protocol, based on complementary NDT tools, significantly enhances the ability to identify critical issues prior to concreting and to intervene without disrupting construction schedules. The combined use of SHAPE® (excavation profiling and verticality), SQUID™ (quantitative verification of base cleanliness), and CHAMP® (assessment of concrete integrity) provides distinct yet synergistic information: borehole geometry, presence and thickness of debris at the base, and continuity/homogeneity of the concrete. These data enable immediate evaluation and targeted operational decisions, reducing the risk of structural defects and the need for subsequent corrective actions.

The application examples demonstrate that the investigations are rapid, repeatable, and compatible with construction workflows, providing results that can be used both for quality control and for updating geotechnical and structural verifications. In particular, the ability to obtain excavation profiles and 3D tomographies allows quantification of eccentricities, cross section reductions, and internal anomalies with sufficient detail to support design decisions (e.g., reinforcement adjustments, evaluation of induced bending moments, and estimation of unit pile capacity).

To maximize the effectiveness of quality control, it is recommended to:

Integrate NDT results with complementary tests (TIP, static and/or dynamic load tests, PIT, etc.) when anomalous indications arise;

Define standardized procedures and acceptance criteria (verticality thresholds, debris thickness limits, RE/FAT thresholds for CSL) tailored to the geotechnical context and design requirements;

Ensure repeatability and traceability of measurements (real time recording, standardized reporting) to enable comparisons and quality audits.

Finally, the systematic adoption of these controls during excavation and post casting stages contributes not only to mitigating immediate construction risks but also to improving the long term durability and safety of foundations and structures. As noted in the text, “the effectiveness of a testing methodology is linked to the capabilities of the instrumentation used and to its ability to provide early information relative to construction progress on site.” This guiding principle should inform the selection and implementation of control techniques to ensure reliable results and timely engineering decisions.

6 Acknowledgements

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7 References

[1] B. White, C. Morgano e B. Phetteplace, «Quantitatively Assessing the Geometry and Base Conditions of Drilled Sahft Excavations,» *11th International Stress Wave Conference, The Netherlands.*

[2] P. J. Hannigan e G. Piscsalko, «Advances in Quality Control Methods for Bored Pile and Diaphragm Wall Foundations with Case Histories, 14th Baltic Sea Region Geotechnical».

[3] D. Brown, J. Turner, R. Castelli e E. Loehr, «Drilled Shafts: Construction Procedures and Design Methods, Geotechnical Engineering Circular No. 10, FHWA Report No.FHWA-NHI-18-024, National Highway Institute, U.S. Department of Transportation, Federal Highway Administration, Washington DC».

[4] ICE Specification for Piling and Embedded Retaining Walls, Third Edition. 2017. ICE Publishing.

[5] Eurocode EN 1536:2014. 2014.

[6] Australian Standard, AS 2159—2009. 2009. Piling—Design and installation, Standards Australia Committee CE-018.

[7] R. Brent, V. Ravikiran e S. Kulkarni, «ASSESSMENT OF PILE VERTICALITY AND PILE PROFILE USING SHAPE (Shaft Area Profile Evaluator),» in *DFI-India*, 2023.

[8] P. Hannigan e M. Saavedra, «Quality Assurance Methods for Risk Reduction in Cast-in-Place Deep Foundation Design and Construction».

[9] R. Moghaddam, P. Hannigan e K. Anderson, «QUANTITATIVE ASSESSMENT OF DRILLED SHAFTS BASE-CLEANLINESS USING THE SHAFT QUANTITATIVE INSPECTION DEVICE (SQUID)».

[10] A. Sellountou, J. Amir, G. Canivan, L. Chernauskas, B. Hertlein, P. Kandaris, T. Kovacs e G. Likins, «Terminology and Evaluation Criteria of Crosshole Sonic Logging (CSL) as applied to Deep Foundations,» 2019.