

NON-DESTRUCTIVE TESTING METHODS FOR DRILLED SHAFT AND ACIP PILES

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There are numerous methods currently available to assess the integrity of drilled shaft and ACIP piles. Each method has its advantages and limitations. This paper will compare the various available methods as well as introduce a new method for assessing integrity of drilled shafts and ACIP piles. This new method, known as Thermal Integrity Profiling, determines the integrity of the shaft both inside and outside the reinforcing cage by measuring the hydration temperature of the concrete along the length of the shaft. These temperature measurements can be made by either passing a thermal probe through a standard Cross Hole access tube, or from embedding thermal wires within the shaft. This Thermal Integrity Profile method will be described in detail and one case history will be presented. Additional testing methods which will be compared include low strain Pile Integrity Testing and Cross Hole Sonic Logging. Advantages and limitations for each method will be discussed.

Introduction

Drilled shafts and Augered Cast-in-Place (ACIP) piles have been increasingly used over the past several years due to several reasons including the reduced noise and vibration, speed of installation for ACIP piles, and the large axial and lateral capacities which are attainable for very large drilled shafts. ACIP piles are drilled and cast without any inspection. Drilled shafts can be cast in a dry hole which allows for inspection of the hole prior to casting, but the casting process is very difficult to nearly impossible to inspect with any accuracy. Drilled shafts are frequently cast under slurry as a means to stabilize the surrounding soils during the construction process. When casting a drilled shaft under slurry, it is very difficult to accurately inspect the hole prior to casting and it is equally difficult to inspect the shaft during the casting process. Many of the above mentioned processes are blind to inspection and therefore the chances increase for having defects present in the completed elements.

There are several methods available for integrity testing completed elements. Each of these methods has advantages and limitations with no one method yielding 100% testing of the entire element. Some test methods can test the integrity with a small proximity of an access tube while others will test the shaft core but do not test the areas outside the reinforcing cage. Other test methods can be limited due to the irregular shapes that ACIP piles can have. A new integrity testing method has recently emerged which is based upon patented research conducted by Professor Gray Mullins with the University of South Florida. This new method involves measuring the heat generated in the element during the hydration process.

This Thermal Integrity Profiling (TIP) method has the ability to evaluate the entire cross-section of the element under test, allowing for verification of concrete cover while also evaluating the core of the shaft. Pile length to diameter ratios which can restrict other integrity testing methods are not a restriction to the TIP method. Additionally, the TIP method is not limited due to non-uniform

shapes that are common with ACIP piles. This paper will discuss the current state-of-practice for integrity testing of drilled shafts and ACIP piles and will detail this new TIP method. An example will be included showing how the TIP method is used in practice.

Current Pile Integrity Testing methods

Typical integrity test methods currently being utilized for drilled shafts and ACIP piles include the low strain pile integrity test and the cross hole (or single hole) ultra-sonic test. The gamma logging test is another available method but is not as widely used as the low strain integrity test and cross-hole sonic logging (CSL). The low strain pile integrity test method involves attaching an accelerometer to the pile top (typically using wax) and striking the pile top surface with a small handheld hammer. The hammer strike creates a compressive wave within the pile which will reflect off the pile toe and return to the pile top where this return signal is measured by the accelerometer. Changes in the pile cross-section (necking or bulging) will also cause reflection in the input compressive wave which will be measured by the accelerometer. These return signals due to changes in cross-section will arrive at the surface earlier than the expected pile toe reflection. This low strain integrity test will reveal major defects within a pile. This test is useful in that it is very fast and economical, requiring no special construction techniques (no access tubes required, etc.). One individual can test any or all piles on a site. Non-uniformities will cause reflections which can complicate data interpretation. Bulges located near the pile top can create multiple reflections which can make it difficult to assess the integrity of the shaft below this point. As the length to diameter ratio increases beyond approximately 30, it can be difficult to get a reflection from the pile toe thus leaving the lower section of the pile untested. Additionally, any reinforcing materials which are extending significantly above the pile top can cause vibrations which interfere with waves traveling within the pile.

The Cross Hole Sonic logging test requires that access tubes be planned into the shaft prior to casting. If the access tubes are not planned into the construction, the test can't be conducted. For the Cross Hole Sonic Logging (CSL) test, steel or plastic pipes of a typical 2" (51mm) diameter are cast into the shaft. These access tubes are immediately filled with water upon completion of the shaft. For CSL testing, steel access pipes are preferred as they don't typically suffer from de-bonding with the concrete as can happen with plastic access pipes. The CSL test entails inserting an ultrasonic transmitter into an access tube and a receiver into another access tube for a particular shaft. The transmitter and receiver are lowered and/or raised at a constant rate while keeping the transmitter and receiver parallel to one another. The transmit frequencies are typically 40 KHz to 70 KHz. Knowing the tube spacing at the surface, the arrival times for the received signals are converted to wavespeed (tube spacing's are measured at the surface and assumed to be constant throughout the length of the shaft). Additionally, the received signal energy can be an indication of poor concrete quality or a void within the pile. The CSL test is limited in that it only provides an indication of concrete quality between the access tubes which are scanned. Scanning all access tube combinations will give a fairly accurate assessment of the pile core but the CSL test cannot scan outside the access tubes which are located on the inside of the reinforcing cage. Thus the concrete cover cannot be determined with the CSL method.

The Single Hole Sonic Logging (SSL) test uses the same equipment as the CSL test but rather than placing transmitter and receiver into separate access tubes and scanning between the tubes, the transmitter and receiver are placed in the same access tube, one on top of the other separated by a known and constant distance. The transmitter and receiver are lowered and/or lifted together keeping the separation constant. This test allows the concrete around the access tubes in all directions to be scanned. For this test the

access tubes must be plastic. Steel pipes do not work in this application as the wavespeed for steel is faster than the wavespeed for concrete. This SSL test will find major defect located within close proximity to the access tube being scanned. Defects that are not continuous around a significant portion of the access tube circumference may go unnoticed by this test.

The CSL access tubes can also be used to perform a gamma-gamma logging test. In this test a probe typically containing cesium-137 (a radioactive material) is lowered into the access tube and the probe will emit particles which are transmitted through the concrete to a photon

counter which determines the density of the adjacent material through which the particles passed. This test can scan in 360 degrees around the access tubes so there is some testing of the concrete outside the reinforcing cage, but the sensing range is limited to perhaps 3 inches (76 mm) as the energy is halved every two inches (51 mm). This test will scan less than 20 percent of the pile cross-section in all cases and for large diameter shafts, this test will scan less than 10 percent of pile cross-section (figure 1).

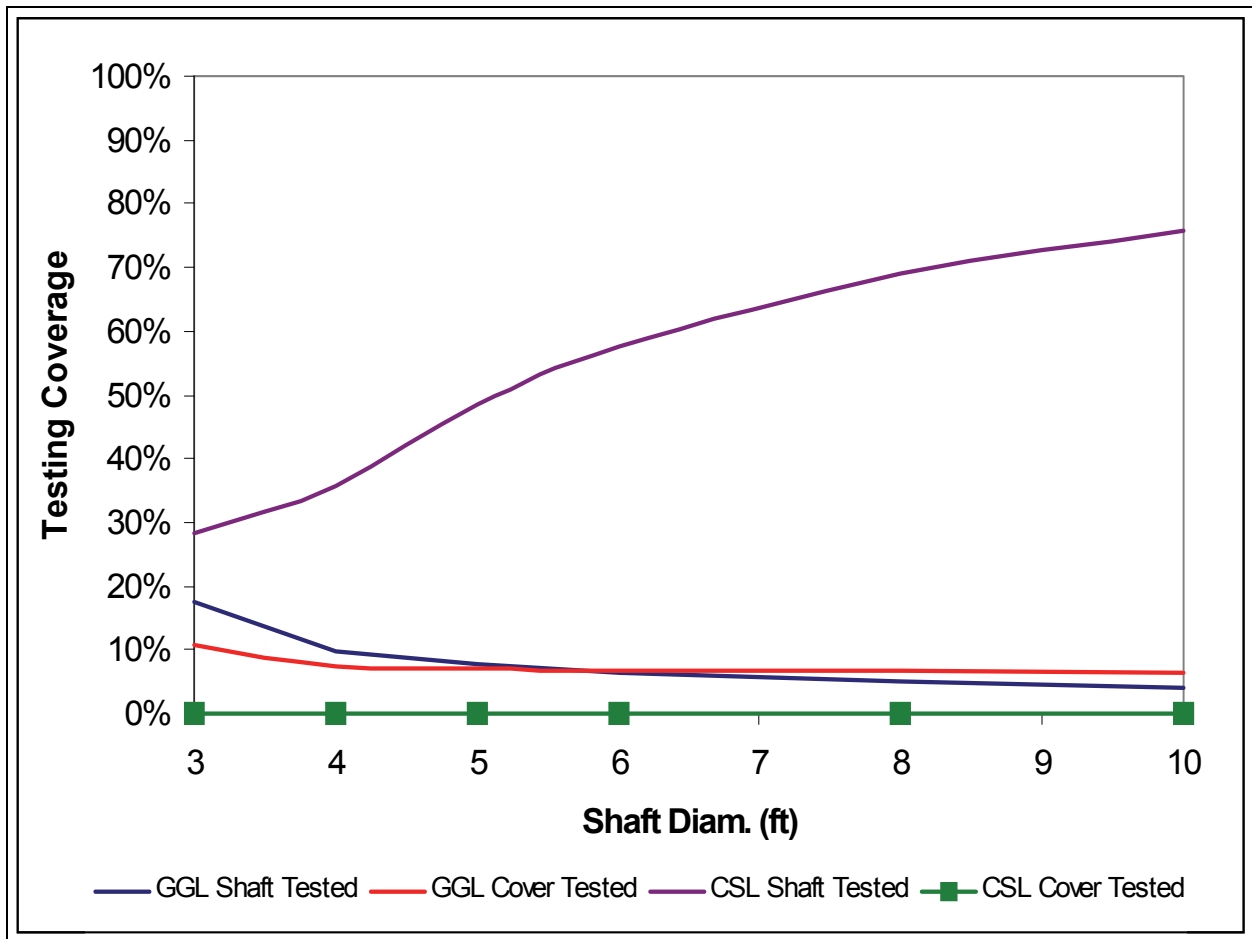


Figure 1

Each of the above mentioned test methods can be successfully used to help determine the integrity for drilled shaft and ACIP piles but as notes in the previous text, each test method also has limitations associated with it. The Thermal Integrity Profiler (TIP) is a new method that has the ability to overcome many of the limitations that the other test methods exhibit.

Thermal Integrity Profiler

The Thermal Integrity Profile (TIP) method determines the integrity of a shaft both inside and outside the reinforcing cage by measuring the hydration temperature of the concrete along the length of the shaft. The temperature measurements are made by passing a thermal probe through a de-watered CSL access tube or from embedding thermal wires within the shaft. Temperature measurements at a particular depth are all averaged together to determine the overall shape of the shaft. Curing concrete exhibits a normal heat signature dependent upon the shaft diameter, concrete mix design, and soil conditions. A lack of concrete (defect) will interrupt the normal temperature signature in the area of the defect. This defect will also be seen in locations further away, but the effect is reduced. Any temperature measurements which are cooler than the average are areas of reduced concrete volume (defect) and any area with a higher temperature than the average are areas of increased concrete volume (bulge). Figure 2 shows measurements which would indicate a defect located closer to location C2 in this example (normal temperature signature is interrupted greater in measurement location C2 as compared with measurement location C1).

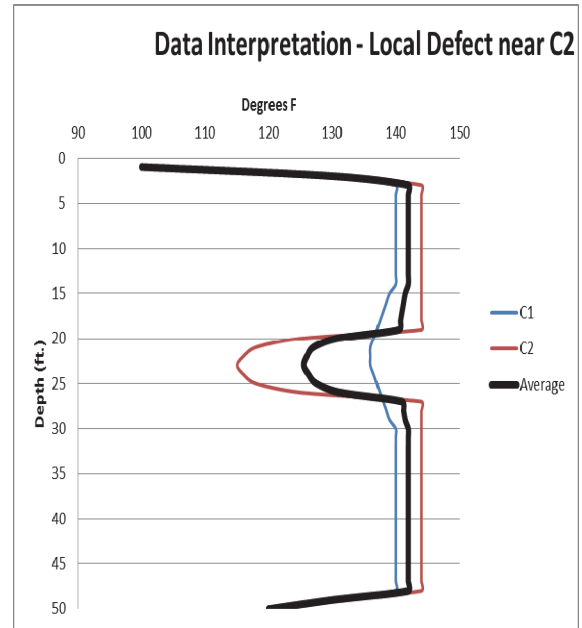


Figure 2

In addition to determining shaft integrity, the TIP test will also reveal any potential issues with reinforcing cage alignment. When comparing TIP measurements from radially opposite locations versus the average value, the cage alignment can be determined. If the first location is cooler or warmer than the average and the radially opposite location behaves in an opposite manner (warmer than average at measurement location two if measurement location one is cooler than average). If measurement location one is cooler than the average this indicates that this location is closer to the surrounding soil while measurement location two is warmer than the average this indicates that this location is closer to the shaft center. When considering both these measurements together, it can be determined that the cage has shift such that location two is closer to the shaft center and location one is closer to the surrounding soil (figure 3).

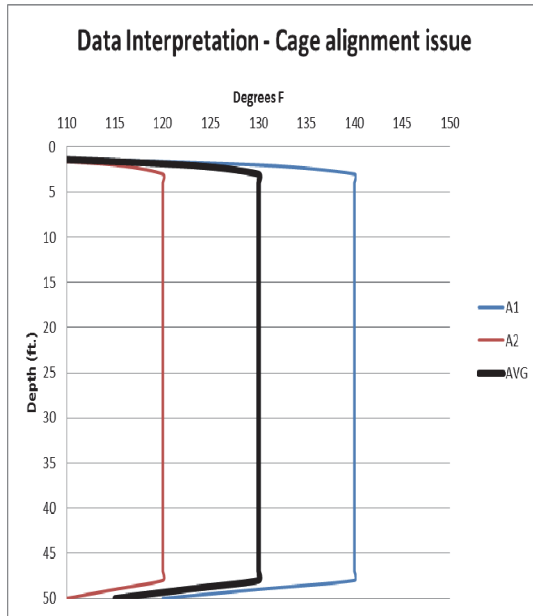


Figure 3

This gives additional information on concrete cover, which can be reduced even without having a defect present. In the example shown in figure 3, location A1 is warmer than average while location A2 is cooler than average, so we can determine that the cage is shifted such that location A1 is moved closer to the Shaft center and location A2 is closer to the surrounding soil (loss of cover).

The TIP measurements using a thermal probe require that CSL access tubes be installed in the shaft. These tubes can be steel or plastic. The test will be performed typically 18 to 48 hours after completion of the shaft. The optimum time is dependent upon the shaft diameter and mix design. Large diameter shafts or mix concrete designs that are high in slag will take a longer time to reach peak temperature. The measurement is made by first de-watering the first access tube (water should be stored in a thermal container). The probe is then warmed in this water to allow the probe to come to approximate temperature of the shaft. Next the probe is lower into the access tube at a rate of

no more than 0.5 ft. /sec. recording all temperatures from four infra-red temperature sensors located at every 90° radially around the probe. When the first tube is completed, the water from tube two is transferred to tube one and the thermal measurement is taken in tube two. This is continued around the shaft until all tube measurements have been completed. Once the final tube has been thermally tested, the water that was removed from tube one is replaced in the final access tube. If no CSL testing will be conducted, the tubes may not be required to be water filled, thus simplifying this thermal test.

An alternate method for measuring the concrete temperatures during the hydration process is to embed thermal wires into the shaft. These thermal wires are placed adjacent to or instead of the CSL access tubes (typically one thermal wire per foot of pile diameter). The thermal wires are simply tie wrapped to the vertical rebar members of the reinforcing cage. The thermal measurements are taken automatically at regular time intervals (about every 15 minutes) at least until the shaft has reached its peak temperature. One additional thermal wire can be installed in a radial direction with a known and fixed horizontal distance (typically 2- 3 inches (51 – 76 mm)) from another thermal wire. This measurement is used to convert temperature to radius and to determine concrete cover and cage movement.

Thermal Example

In this example, a 5 foot diameter x 80 foot long drilled shaft was installed with five steel CSL access tubes and five thermal wires located adjacent to the CSL access tubes. The shaft was TIP tested using both thermal probes via the CSL access tubes as well as thermal wires embedded into the shaft. The shaft was also CSL tested. The thermal wire data is shown in figure 4.

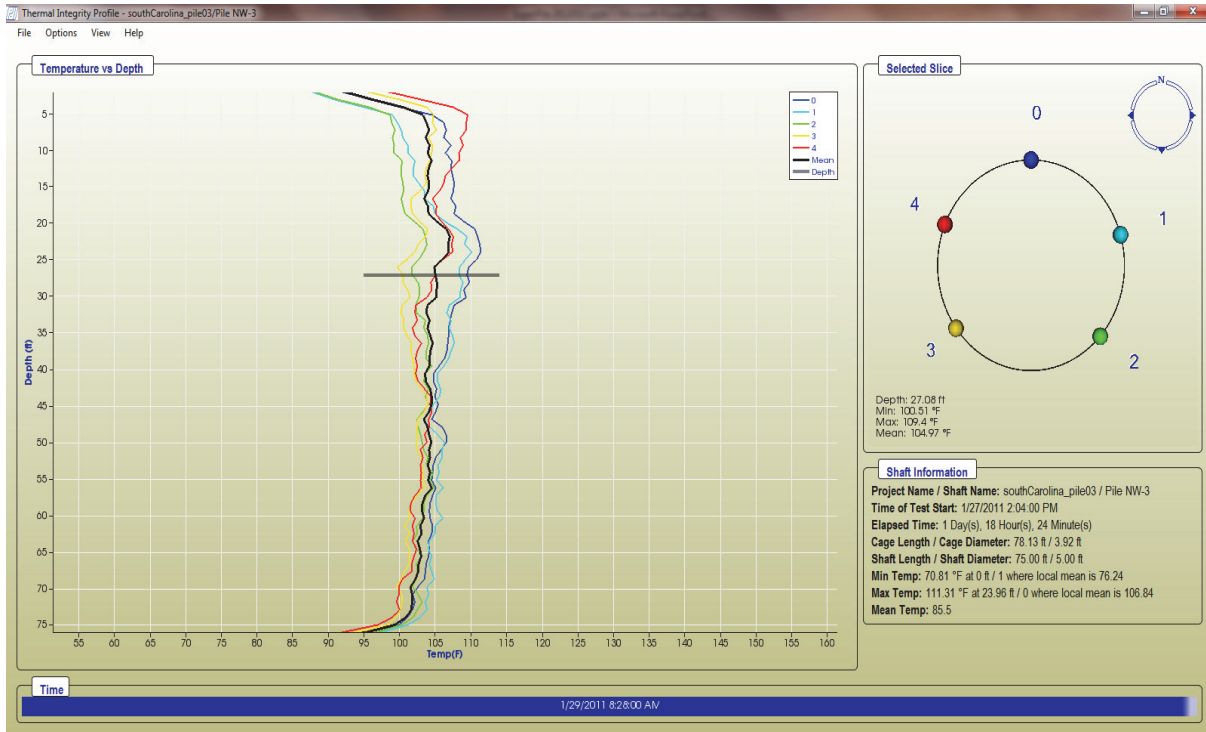


Figure 4

The thermal data shows that the shaft has no defects but does indicate that the cage is misaligned down to approximately 40 feet. Figure 5 shows the data collected from the

thermal probes and the conversion from temperature to effective shaft radius. The data clearly shows that the 60 inch shaft diameter is maintained throughout the length of the shaft.

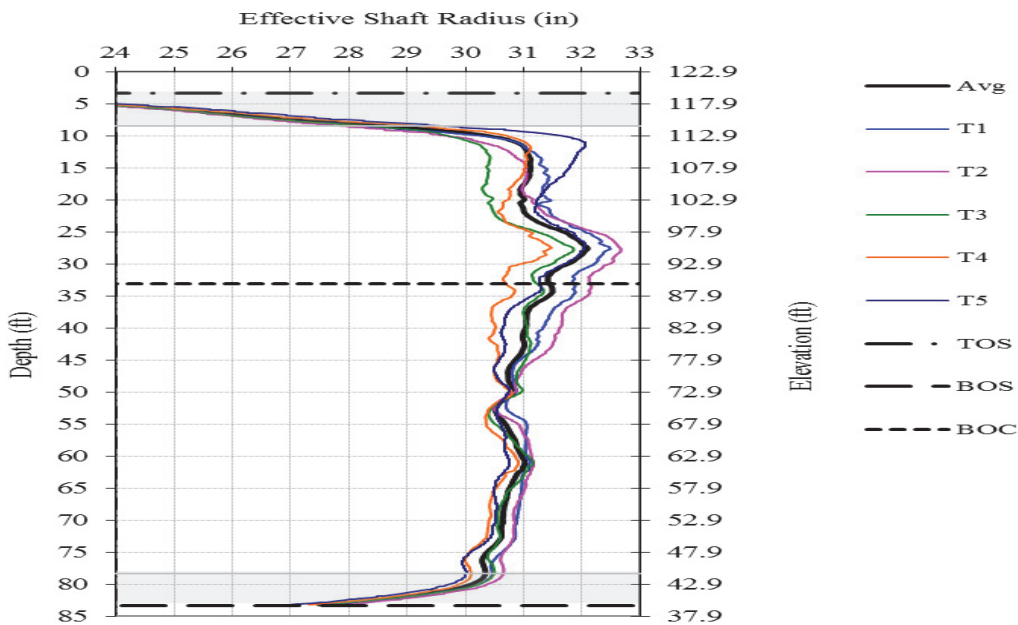


Figure 5

The CSL records for this same shaft indicate that there are no problems in any tube scan combinations (figure 6). Figure 6 shows typical CSL results. All scan combinations look similar.

The CSL test offers no indication of the concrete cover or cage alignment but simply the integrity of the shaft central section. The CSL test results agree with both TIP tests that this is a good shaft.

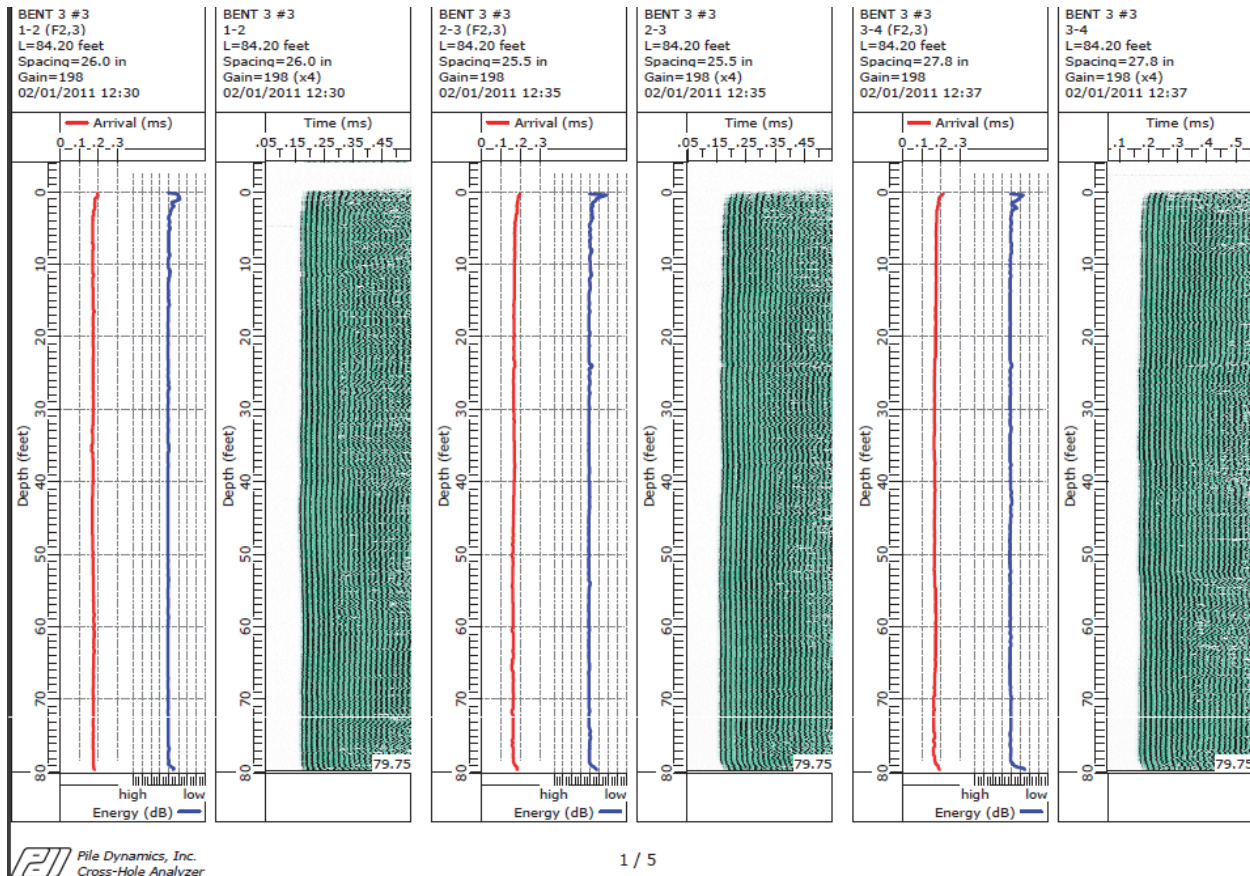


Figure 6

Conclusions

The general trend has been an increase in the use of Drilled shafts and ACIP piles. These piles are often installed with little or no knowledge of the final shaft integrity. Current non-destructive test methods can each provide partial information as to shaft integrity, but each method also has limitations which don't provide 100% testing of the shaft cross-section. The Thermal Integrity Profile method measures the shaft temperature during the hydration process to make an assessment of the shaft integrity. From these temperature measurements, the

effective shaft radius can be determined. The TIP method allows for 100% assessment of the shaft cross-section which no other current method can provide. Additionally, the cage alignment can be determined and the concrete cover verified from the TIP data. Since the TIP test is dependent upon the concrete hydration, this results in the TIP test being conducted approximately 24 hours after the shaft has been cast, which is a major advantage over current methods as this can accelerate the construction process.

Test shafts with purposely built in defects located both outside the reinforcing cage as well as within the reinforcing cage have been constructed and the defects have been easily determined from the TIP test. Many field tests have been successfully conducted and comparisons have been made with other available methods. The TIP test provides an overall look at the shaft based upon the local heat signature. Unlike current test methods which provide limited shaft integrity information, the TIP method provides the shaft integrity

without the limitations associated with other methods, overall shape of the shaft, concrete cover over entire cross-section, and cage alignment.

References

Mullins, A.G. and Kranc, S.C., 2004. Method for testing the integrity of concrete shafts. US Patent 6,783,273

Mullins, A.G., 2010. Thermal Integrity Profiling of Drilled Shafts.