Structural integrity of drilled shaft foundations by thermal measurements

Thermal integrity profiling can evaluate overall shaft integrity, including reinforcement cage alignment and concrete cover.

By Garland Likins, P.E., and Gray Mullins, Ph.D., P.E.

Thermal Integrity Profiling (TIP) is a new technology that utilizes the heat of hydration of curing concrete to evaluate the integrity of drilled shaft foundations. This technology, developed initially at the University of South Florida, is being implemented by a joint effort of Foundation & Geotechnical Engineering, LLC (FGE) and Pile Dynamics, Inc. (PDI). In general, TIP can evaluate overall shaft integrity, including reinforcement cage alignment and concrete cover. Temperature measurements for TIP are currently made using probes inserted in the same access tubes provided for Crosshole Sonic Logging (CSL) or Gamma Gamma Logging (GGL) integrity testing. The Florida Department of Transportation (FDOT) requires access tubes in all drilled shafts. Utilizing existing access tubes is important because additional construction costs are not incurred and secondary CSL and GGL testing can still be performed. Further developments in the thermal method can eliminate the access tubes by using wires with an array of disposable thermal sensors for the temperature measurements.

During the construction of drilled shafts, both concreting logs and inspection records are routinely scrutinized to identify the possibility of questionable structural integrity. Many state specifications require that shafts identified as questionable be further evaluated using non-destructive integrity testing methods. For the state of Florida, further evaluation includes CSL and optionally GGL. FDOT has recently also included the thermal testing method in the specifications for special projects.

The acceptability of shafts based on integrity test results varies with the three test methods:

1) For CSL, acoustic wave arrival times are recorded and converted to wave speed using the tube spacing (distance/arrival time). Slower wave speeds imply weaker concrete (e.g., FDOT accepts up to 29 percent wave speed reductions; the Washington State Department of Transportation (WSDOT) defines good concrete as that with 10 percent or less reduction in wave speed).

2) GGL tests measure the gamma count rate from a probe with a radioactive emitter and detector. Higher gamma count rates indicate lower density materials, implying weaker concrete. Shaft acceptance is based on statistical thresholds of gamma count rates. Shafts with concrete gamma count rates that fall within two standard deviations (SD) of the mean are normal, between 2 and 3 SD are questionable, and greater than 3 SD are poor. This approach can be misleading unless the measuring device is calibrated to true bulk density; gamma count rates from a shaft with uniformly poor concrete quality may all fall within 2 SD of the mean.

3) The thermal method measures the internal shaft temperature to detect the presence of heat producing cementitious material. Lower temperatures imply less or weaker concrete. Given the known volume of concrete placed (from logs), the measured temperature can be converted to the local radius of concrete. This then provides information on the position of the reinforcing cage location at each point of temperature measurement relative to the center of shaft, as well as the surrounding concrete cover.

A comparative case study of these three methods follows.

FDOT and WSDOT have used the new thermal method for several years. One of the largest projects on which TIP has been implemented is the Interstate 4 / Crosstown Connector project in Tampa, Fla. (Figure 1). This project, estimated at $613 million, is a fully elevated section of roadway approximately one mile long. The numerous spans of the bridge are founded primarily on drilled shafts. The high water table and the associated blind construction techniques, as well as a local history of foundation issues, led to an intensified quality control program.

Over 100 drilled shaft foundations were tested with the thermal method, some of which were also tested with CSL and GGL. To compare test results, thresholds were established for each test to identify three basic conditions: Good, questionable, and poor (Table 1).

Table 1 Evaluation Criteria

Test Method	Good	Questionable	Poor
CSL*	Velocity reduction 10% or less	Velocity reduction 11 to 29%	Velocity reduction 30% or greater
GGL	Counts per second within 2 standard deviations of mean	Counts per second >2 up to 3 standard deviations from mean	Counts per second >3 standard deviations from mean
TIP	No radius reduction	Radius reduction up to 1 inch	Radius reduction 1 inch or greater

Table 1: *CSL evaluation criterion based on WSDOT.

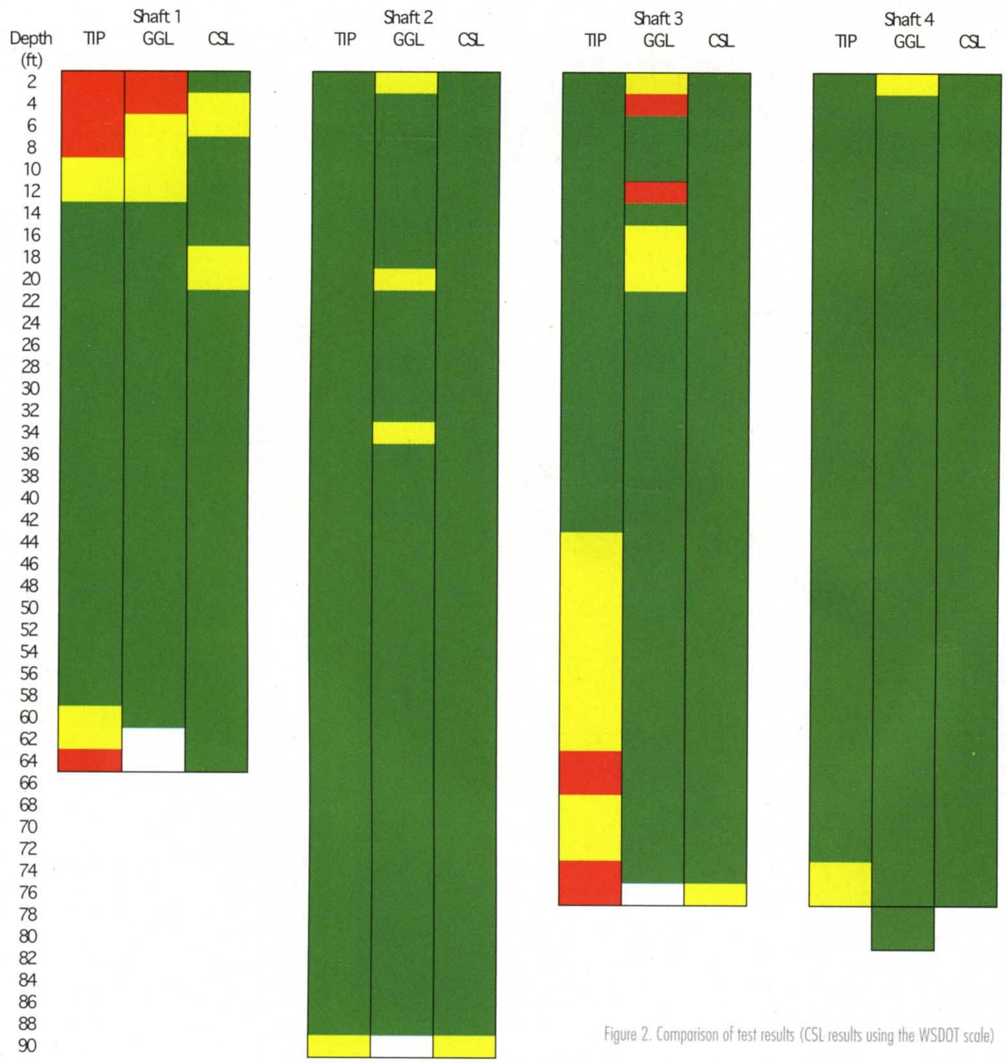

Figure 2. Comparison of test results (CSL results using the WSDOT scale)

A quick overview of the test results from four of the shafts tested is summarized in Figure 2 using green, yellow and red zones to represent good, questionable and poor areas, respectively, from the Table 1 definitions. Depth measurements from GGL were inconsistent with the other two methods, with three of the shafts appearing to be shorter than actual (shown in white) and shaft 4 appearing to be longer.

In general, the CSL results indicate that the internal concrete core of all four shafts were acceptable using the FDOT 29 percent threshold criteria; while TIP indicated questionable to poor integrity at several locations. Some CSL velocity reductions were very near the 29 percent threshold and were manually interpreted by the initial CSL tester as aberrant readings. As a means of resolving the conflicting test results, GGL was performed. Both TIP and GGL identified multiple areas of questionable and poor integrity.

FDOT deemed Shaft 2 needed no further evaluation. However, the three remaining shafts required further testing and evaluation; Shaft 1 is discussed below.

Figure 3 shows Shaft 1 test results. CSL wave speed reductions were within FDOT limits (but would not have satisfied WSDOT criteria). GGL results showed questionable and poor conditions in the upper regions. Focusing on TIP results, the measured temperature in the entire upper region was less than expected from a normal step shaft (36-inch rock socket with an oversized 39-inch temporary casing). The normal step shaft was modeled for the concrete mix used and is displayed as the dashed curve (the expected temperatures). In regions where the temperature was greater than the expected normal, the shaft was oversized. The average temperature of all tubes is proportional to the shape of the shaft. A reduced section, reduced cover, or poor quality concrete is detected by lower than expected temperatures.

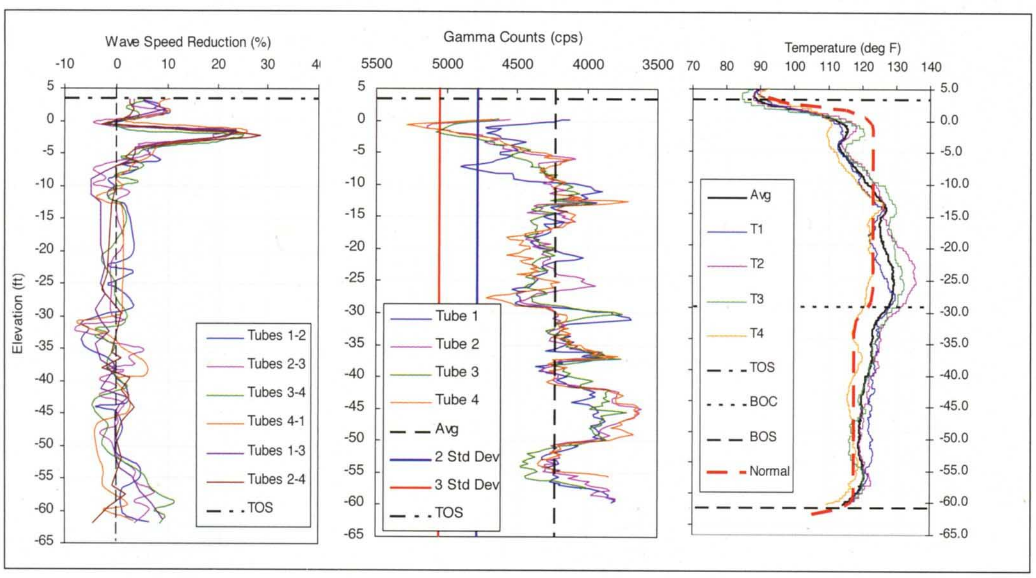

Figure 3. Test results from CSL (left), GGL (center), and TIP (right); dashed lines show ideal conditions.

TIP at I4 Crosstown Connector Tampa

The contractor chose to install a replacement shaft in lieu of repairing Shaft 1, which allowed the evaluation of Shaft 1 by destructive means. The upper 10 feet of the shaft was excavated and the shaft was cut off at 7 feet and cored in both directions from the cut. Forty two compression tests were conducted from the cores. Concrete strengths ranged from 1,340 to 8,790 psi with 51 percent of the samples below the design strength of 4,000 psi and 81 percent of the samples below the average 28-day test cylinder strength of 7,520 psi (Figure 4).

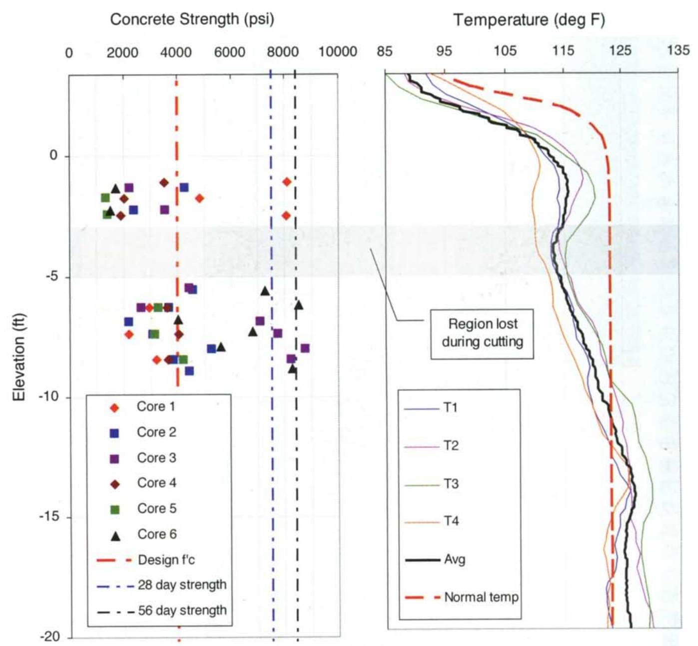

Figure 4. Temperature and concrete core strength results. Summary and discussion

For decades, engineers have tried to assess integrity issues associated with drilled shaft blind construction methods. This started with requiring detailed construction records, moved to low strain integrity testing, then CSL, GGL, and now thermal methods using TIP. The advantages of the thermal method include easily evaluated shaft geometries, assessment of reinforcing steel cover, reinforcement cage alignment, and overall shaft integrity. The information gained from TIP testing cannot be replicated even when a combination of the other test methods is used.

As demonstrated in the case study, TIP testing provides greater test coverage and superior information compared to CSL and GGL because TIP evaluates the entire concrete mass, including outside the reinforcement cage. CSL normally provides no information outside the cage and GGL at best provides 10 percent coverage outside the cage. This outer area is the most important from both a structural and geotechnical perspective, thus it stands to reason it should be the most heavily regarded.

Garland Likins, P.E., is president of Pile Dynamics, Inc. Gray Mullins, Ph.D., P.E., is a professor at the University of South Florida and the technical director of Foundation & Geotechnical Engineering, LLC.