Quality Assurance for Deep Foundations

Pile Dynamics, Inc.

Thermal Integrity Profiler (TIP)

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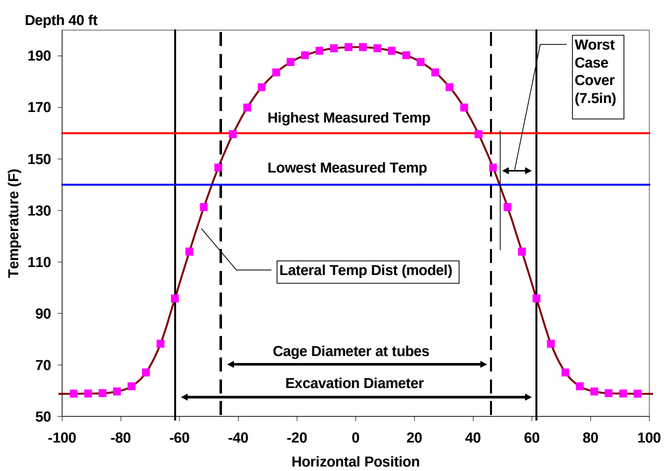
Overview

The Thermal Integrity Profiler uses the temperature generated by curing cement (hydration energy) to assess the quality of cast in place concrete foundations (i.e. drilled shafts or ACIP-CFA piles). Whereas other methods of integrity testing have limits in assessing the full cross-section or length (Cross Hole Sonic Logging (CSL): inside the reinforcing cage, or Gamma- Gamma Logging (GGL): within 75 mm (3 in) of access tube), TIP measurements evaluate the concrete quality from all portions of the cross-section along the entire length.

In general, during curing, a shortage of competent concrete (necks, inclusions or low cement content) is registered by relative cool regions; the presence of extra concrete is registered by relative warm regions (over-pour bulging into soft soil strata).

Anomalies inside or outside the reinforcing cage not only disrupt the temperature signature near the anomaly, but also at more distant locations (at progressively less effect).

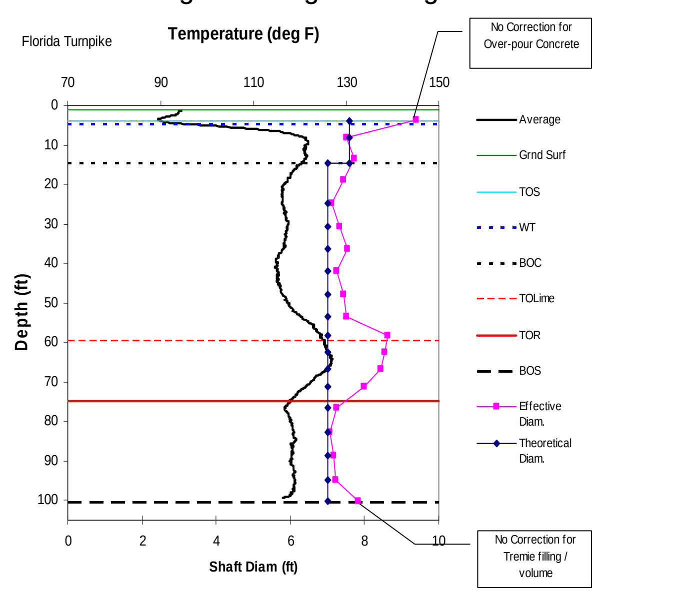


Temperature distribution for 3.05 m (10 ft) diameter shaft (WSDOT). Lowest temperature measured corresponded to a 190.5 mm (7.5 in) cover.

The shaft temperature is dependent on the shaft diameter, mix design, and the time of measurement.

As the temperature distribution within a shaft is bell-shaped with respect to radial position, the measurements are sensitive to cage eccentricity as well as the surrounding cover. A cage slightly closer to the soil on one side of the excavation exhibits cooler temperatures than average, while the cage closer the shaft center exhibits warmer temperatures than average.

Since the diameter and temperature relationship is strongly linear in the region near the cage, a plot of the average temperature from all measurement locations versus depth mimics the actual shape of the shaft as determined from field concreting logs. Use of construction and concreting logs can be used along with the TIP data to better assess the overall quality and effective shaft radius at any location along the length of a given shaft.



Average shaft temp (black) and concreting log (pink)

Data Collection

ASTM D7949-14, “Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations”, gives procedures for measuring the temperature profile within cast-in-place deep foundation elements such as drilled shafts, bored piles, augercast or CFA piles, drilled displacement piles, micropiles and jet grout columns.

TIP data is obtained through embedded Thermal Wire® cables. Thermal Wire cables with thermal sensors are attached to the reinforcing cage. Typically one Thermal Wire cable is attached for approximately each foot (300 mm) of shaft diameter. An even number of cables are suggested to make the analysis more straightforward.

Data from Thermal Wire cables are sampled automatically typically every 15 minutes from each embedded Thermal Wire by a battery powered data acquisition unit, allowing the concrete temperature to be monitored over the entire curing duration. Data are retrieved on site at any time after casting for evaluation.

If a local relatively cool spot is not detected by embedded Thermal Wire cables, then the shaft has no local defects and no additional analysis is then usually required for shaft approval, speeding the remaining construction process.

Because, access tubes are not required, the cables allow better concrete flow through the cage. In the USA, the installed cost of the Thermal Wire cables and subsequent collection and evaluation of the data are less than the comparable cost to install, test and evaluate CSL data using probes inserted into water-filled steel access tubes. A single embedded Thermal Wire cable is attached to a center rebar for smaller augered cast-in-place or continuous flight auger piles.

Embedded Thermal Wire cable (yellow) attached to rebar cage

Data Analysis

Field measurements alone highlight glaring irregularities since the average temperature profile shows the general shaft shape. This level of review reveals cage alignment irregularities, casing location, locations of over-pour bulges, layers of deficient cement content (weak concrete) or necking, and can easily alert the user or an owner to areas of concern.

The data can be quickly searched over time for local relatively cool spots which indicate areas of structural weakness; the temperature time history is searched during the period well before the peak temperature is achieved for local decreases in temperature which signal a reduced amount of heat producing cement, either from a necking or from a contaminated concrete.

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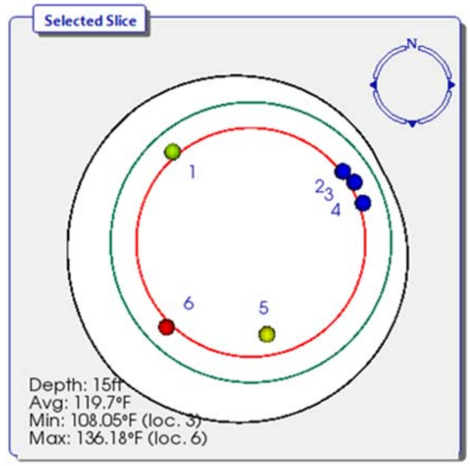
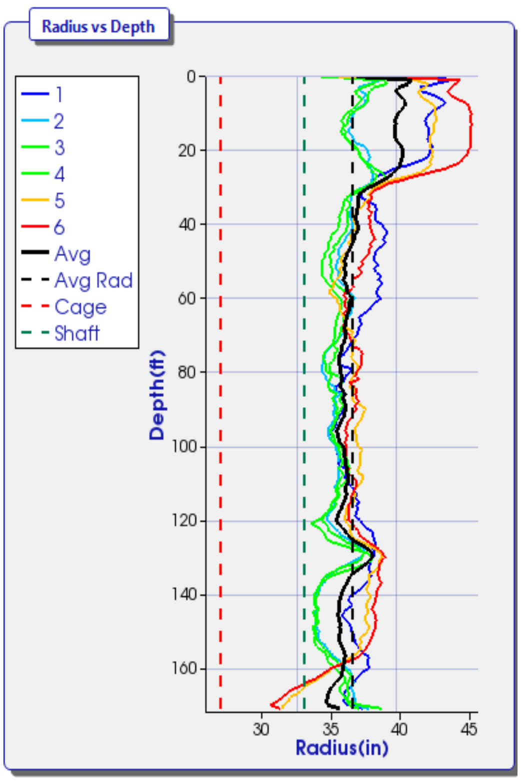
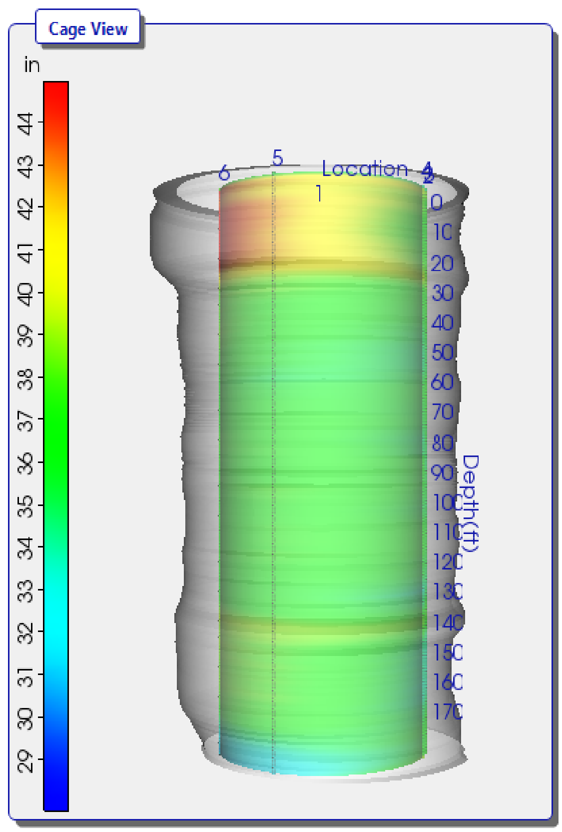
The radius at any location along the shaft can be estimated by equating the average temperature (usually near the time of peak temperature) to the average radius computed from the total installed concrete volume and total pile length. In the following example an upper casing is offset from the main shaft alignment over the top 28 ft of the shaft. Both 3-D and 2-D (“slice” – at any depth) evaluations can be generated.



2-D slice of the upper 2.13 m (7 ft) diameter casing in upper 8.52 m (28 ft), I-90 bridge, Cleveland, Ohio. Slice shows a no offset of center of the casing from center of the main shaft.



Estimated radius from temperature measurements of 1.68 m (5.5 ft) diameter shaft with 2.13 m (7 ft) diameter casing in upper 8.53 m (28 ft), I-90 bridge, Cleveland, Ohio. Shows that the as-built effective radius exceeds the design shaft radius (“Shaft”) with adequate cover compared to cage location.



3-D rendering of 5.5 ft diameter shaft with 7 ft diameter casing in upper 28 ft, I-90 bridge, Cleveland

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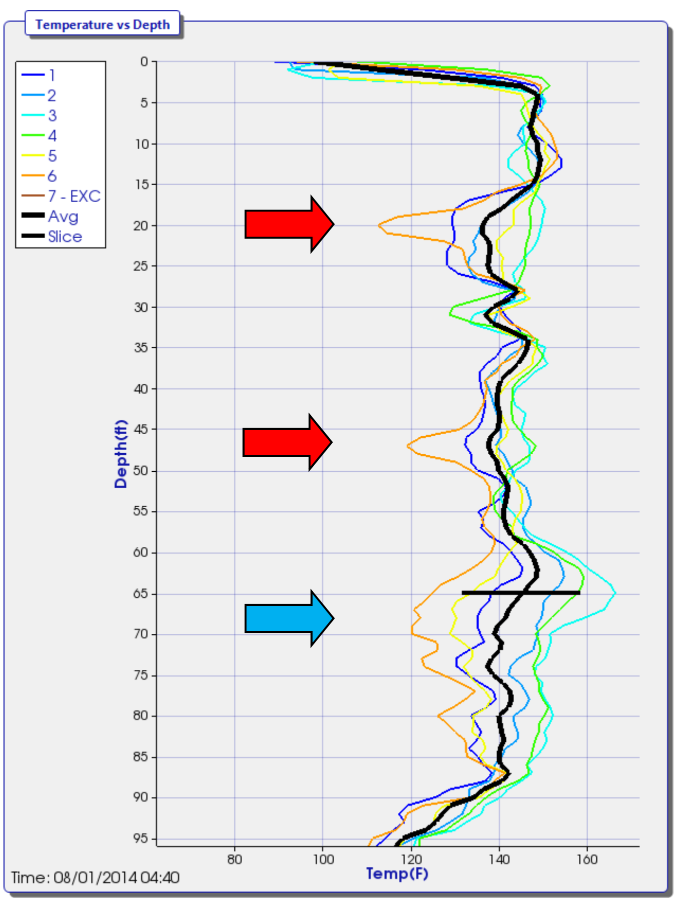
In the following case, purposely built defects representing approximately 5% of the shaft cross section were installed at approximately depths of 6 and 13 m (20 and 43 ft) near Thermal Wire cable #6. Inspecting the early temperature versus time history clearly reveals these defects (see red arrows). The blue arrow shows a section of the reinforcing cage that is not centrically located; some cables show warmer than average and are closer to the shaft center while other diagonally opposite cables which are located closer to the shaft-soil interface are cooler than average. The temperature near the top shows the normal “roll-off” due to heat radiating also from the top of shaft. The temperature roll-off at the bottom is in this case elongated due to inclusion of a bidirectional jack at the toe.



Shaft with purpose-built defects (red arrows)

References

Mullins, A. G., (2010), “Thermal Integrity Profiling of Drilled Shafts”, DFI Journal Vol 4, No.2, December.

Mullins, A. G. and Kranc, S. C., (2004), “Method for Testing the Integrity of Concrete Shafts,” **US Patent 6,783,273**.

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