Structural integrity of drilled shaft by Thermal Integrity Profiling (TIP)

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Summary

The Thermal Integrity Profiling (TIP) utilizes the heat generated by the curing concrete during the casting phase to assess the quality and integrity of the drilled shafts, both inside and outside the reinforcing cage. The TIP method overcomes the limits of the methodologies employed up to now (e.g. CSL, PIT); in particular, it offers the advantage of estimating the entire pile shape and analyzing the whole cross-sectional area including the concrete cover, which is the most important since it covers the reinforcement from contact with the soil. The TIP allows for a quick continuation of the construction works, offering the first results in only a few hours after the shaft placement; additionally, it offers quick data collection and objective evaluation by straightforward interpretation.

Concrete hydration is a highly exothermic process, and in concrete elements, such as drilled shafts, a significant amount of energy is released, causing elevated temperatures in both the shaft and surrounding soil, typically for several days. The amount of temperature increase at any given point depends on the volume of hydrating concrete in proximity as well as the cementitious content of that concrete, both of which help to define shaft serviceability. In the curing phase, the presence of soil inclusions, reductions in diameter, or low cement content is observed as relatively cold regions. Alternately, the presence of excessive concrete, as in the case of diameter increases (bulge), is recorded by relatively hot regions. A special software, using the thermal profile recorded in the field, builds a 3-D model of the pile shape and highlights defects such as bulges, neckings, cavities, soft bottoms, profile breaks, and it also evaluates the exact position of the reinforcing cage (cage alignment) and the thickness of the concrete cover along the pile axis.

The temperature measurements are performed by either passing a Thermal Probe through a de-watered access tube or by embedding Thermal Wire® cables within the shaft. Thermal Wire cables automatically record continuous data, allowing concrete temperature monitoring for the entire curing time.

Developed initially by the University of South Florida in the late 1990's, it is the most recent of non-destructive test methods for drilled shaft evaluation and represents today the most comprehensive integrity survey method in the United States.

Introduction

When constructing a drilled shaft, it is difficult to accurately inspect the hole or to inspect a slurry filled shaft during the casting process. Therefore the construction is blind to inspection and there is a risk of having structural defects and imperfection that endanger the structural integrity (Fig. 1), thereby affecting the shaft's load carrying capacity [Piscsalko and Cotton, 2011]. For this reason, the integrity test becomes a fundamental component of a product quality control program.

This paper introduces an innovative technology developed in the US that falls into the category of non-destructive testing: Thermal Integrity Profiling, defined by the acronym "TIP". This methodology is a valid tool for evaluating the integrity and quality of drilled piles. It overcomes the limits of the methodologies used to date, in particular it has the peculiarity of allowing the knowledge of the entire pile shape and the characteristics of the concrete cover.

The TIP method is based on the measurement of the temperature fluctuation along the shaft reinforcing cage during the concrete curing phase, when the exothermic phenomenon is active. The expected temperature at any cage location is dependent on the shaft diameter, mix design, time of measurement and distance to the center of the shaft. Since the diameter and temperature relationship is strongly linear in the region of the cage, the actual shape of the shaft can be estimated [Mullins, 2010].

Currently the most commonly used integrity test methods are the Cross-hole (CSL) and the Pile Integrity Test (PIT) (4 EMME technical staff, 2016), discussed in the following paragraphs. The TIP method overcomes their limitations and has proven

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Tab. I – Tip detection and interpretation methods (adapted from PICSALKO *et al.*, 2015)
Tab. I – Metodi interpretativi dei risultati TIP (riadattato da PICSALKO et al.*, 2015)*

to be more effective and to have improved diagnostic properties [LIKINS and MULLINS, 2011].

The following are the main peculiarities of the TIP method:

– it evaluates the entire cross-section area, both inside and outside the reinforcing cage. The knowledge of the concrete quality and thickness outside the reinforcing cage, the concrete cover, is fundamental to the durability and load bearing capacity of the pile;
– it has no limitations on the diameter-to-length ratio, therefore it is applicable to any pile dimension;
– the results of the test can be evaluated soon after the shaft placement, thus allowing for a rapid continuation of construction works;
– it provides quick data collection and objective evaluation by straightforward interpretation.

1. Methodology

The Thermal Integrity Profiling method uses information derived from the heat produced from curing concrete and its consequent dissipation in the soil to detect any defects in the pile, since the heat dissipation rate depends on the quality and volume of the cement material present [MULLINS and KRANC, 2007]. Once the temperatures along the cage are measured, the interpretive software constructs a pile shape 3-D model in which defects are highlighted: necking, bulges, voids, inclusions, soft bottom, cage alignment issues, and concrete cover insufficiency.

The method is based on the observation that the average temperature at the cage, measured along the entire shaft length, is proportional to the average shaft radius (which can be computed from known concrete volume placed and the total shaft length), and the variations in temperature can be linearly converted to effective radius since the temperature is linearly decreasing outside the cage [MULLINS, 2010].

The relationship between temperature and shaft shape is presented in the graph of temperature versus diameter in figure 2, left. Considering a shaft cross section, the temperature distribution across the diameter follows a bell shape, where the temperature is maximum in the pile center and decreases approaching the perimeter (PISCSALKO *et al.*, 2015), and is approximately linearly decreasing in the region of the cage. In the TIP test, temperature is best measured in the hours following the pile casting, when the temperature gradient is still evident. The measurement is carried out along the entire shaft length and at different points across the section area; data recorded are expressed in a graph of temperature versus shaft depth, the so called "thermal profile" (Fig. 2, right). Since the temperature is measured in several points across the section area, several thermal profiles are generated.

Figure 3 shows the effect of shaft size on radial temperature distribution. The inflection point of each curve, where slope is the steepest and most linear, is at the edge of shaft, near the cage location. This makes temperature measurements at the cage highly sensitive to both shaft size and cage eccentricity. The dashed lines represent cage position whe-

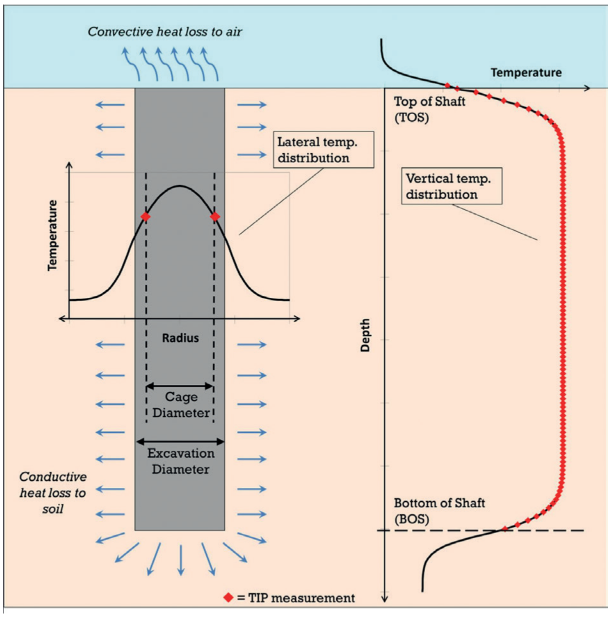

Fig. 2 – Temperature distributions in an idealized shaft. Theoretical radial temperature distribution of shaft cross-section slice (left); theoretical vertical temperature distribution (right).

Fig. 2 – Distribuzione della temperature in un palo ideale. Distribuzione della temperatura radiale di una sezione trasversale di palo (sinistra); distribuzione della temperatura teorica verticale (destra).

re measurements are taken, the bold colored lines represent the temperature distribution corresponding to the local shaft size, and the intersection of the lines reveals the temperature that would be measured. Note that for larger shaft sizes, temperatures near the core are not affected by size or position, but for smaller shafts, all locations are still highly sensitive to shaft radius. For a given radial position, the dashed lines in figure 3 reveal the unique correlation that exists between shaft size and temperature. This relationship is asymptotic towards soil temperature and the concrete's adiabatic temperature, and has an inflection point where shaft radius equals the given measurement position (Fig. 4). Note that measurements taken at cage radius will fall near the inflection point, where the relationship between shaft size and temperature is strongly linear.

An ideal pile without any anomaly, with a uniform cross-section and with a perfectly centered cage, will produce a uniform thermal profile along its length (except at the top and bottom of the shaft where the heat can radiate in 3D instead of only radially along the center of the shaft); whereas the presence of defects, such as bulges, neckings or cage eccentricity, will interrupt the uniformity of this profile [PISCSALKO *et al.*, 2015]. Specifically, an increase or decrease in temperature of all thermal profiles at a certain depth indicates an increase or reduction of the section, respectively. Comparing temperature measurements from diametrically opposite locations versus the average value allows for assessing the cage alignment, as will be better explained in the paragraph on the data interpretation.

The temperature is measured through two possible alternative instruments that represent two methods exploiting the same interpretative philosophy:

Thermal Probe (TPM) - Use of a thermal probe, with four infrared sensors, dropped in special inspection tubes, like those of the Cross-hole test; Thermal Wire cables (TCM) - Installation of cables equipped with thermal sensors positioned every 30 cm and attached to the reinforcing cage prior to the casting. Regardless of the instruments chosen, the temperature profiles should be recorded at the peak temperature, which is reached in the first 12 to 36 hours upon the pile casting and depends on the mix design and the pile diameter. When employing Thermal Wire cables, the measurement takes place continuously, without concern of choosing the optimal test execution time and ensuring that right data is available for the subsequent interpretation step [SELLOUNTOU *et al.*, 2013].

2. On-site data collection and equipment

The actual number of measuring locations in one shaft is selected as one location for every 0.25 m to 0.35 m of shaft diameter, uniformly distributed along the circumference of the reinforcing cage. This corresponds to the number of access tubes in the case of TPM or of Thermal Wire cables in the case of TCM (it also often coincides with the number of access tubes recommended for the CSL test). Following these instructions, the TIP test is able to evaluate the entire

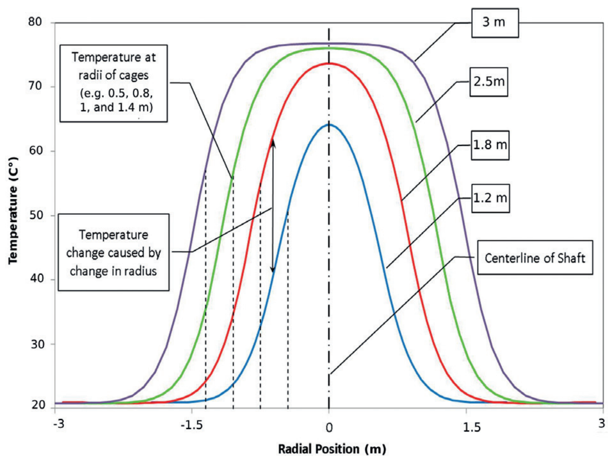

Fig. 3 – Radial temperature distribution for various shaft sizes [MULLINS, 2012].

Fig. 3 – Distribuzione della temperature radiale su pali di diverso raggio [MULLINS, 2010].

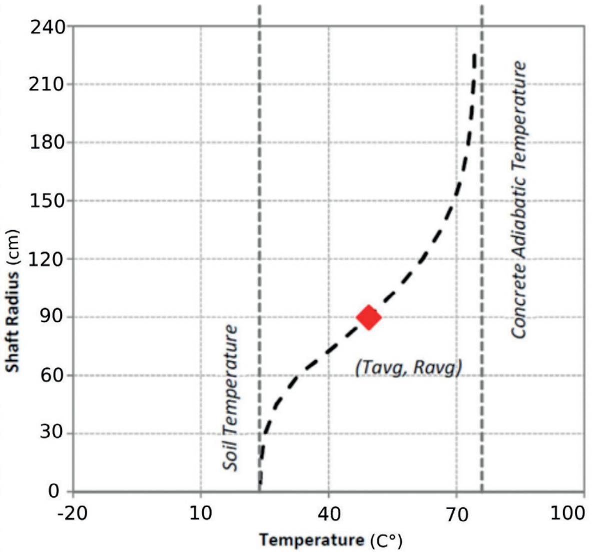

Fig. 4 – Relationship between shaft size and temperature for a given cage position.
Fig. 4 – Relazione tra dimensione del palo e temperatura.

shaft cross-section and to identify any anomaly greater than 10% of the section [PISCSALKO, 2014].

To accurately identify any reinforcing cage eccentricity, it is advisable to place an even number of inspection tubes or Thermal Wire cables, allowing for direct comparison of temperatures on diagonally opposite locations [PISCSALKO, 2016].

2.1. Thermal Probe Method (TPM)

Data is acquired with a thermal probe [MULLINS and KRANC, 2004; MULLINS and PISCSALKO, 2012] lowered through access tubes (plastic or steel) tied to the rebar cage, installed prior to concreting (Fig. 5). The thermal probe has four infrared sensors and is connected to a TIP Main Unit. The temperature data is collected by dropping the probe in the de-watered tube at a speed of between 0.2 and 0.4 m/s. The tubes used for the Cross-hole test may also be employed, making sure that they are emptied since infrared signals do not penetrate water. The operator through the Main Unit can observe the thermal profile in real time, as the probe is lowered in the tube and an encoder accurately records its depth position.

The TIP test, performed with the thermal probe, is affected by the time of the testing; once the peak temperature is reached, the hydration process slows down, the temperature and temperature variation decrease and the interpretation of recorded data becomes more difficult. Usually, therefore, the ideal testing time is between 12 and 36 hours upon shaft construction. The overall pile shape is best evaluated at the peak temperature. Therefore, this test should be repeated more than one time in order to catch the peak temperature.

2.2. Thermal Wire Method (TWM)

Data is collected via a specialized cast in place cable labeled the Thermal Wire cable [PISCSALKO, 2016; COTTON *et al.*, 2010]. The Thermal Wire cable contains multiple evenly spaced temperature sensors (sensors placed every 30.5 cm), which send measured temperature values to a Thermal Acquisition Port, TAP (Fig. 6). Each Thermal Wire cable is paired with a respective TAP that interrogates the cable to receive and continuously record temperature measurements for the duration of the connection period, giving a temperature versus time history. Once data is collected and stored, the TAP may be connected to the TIP Main Unit to transfer this acquired information for a basic field review.

An advantage of this method is that the optimal data for the analysis are chosen from the recorded library, increasing the reliability of interpretations;

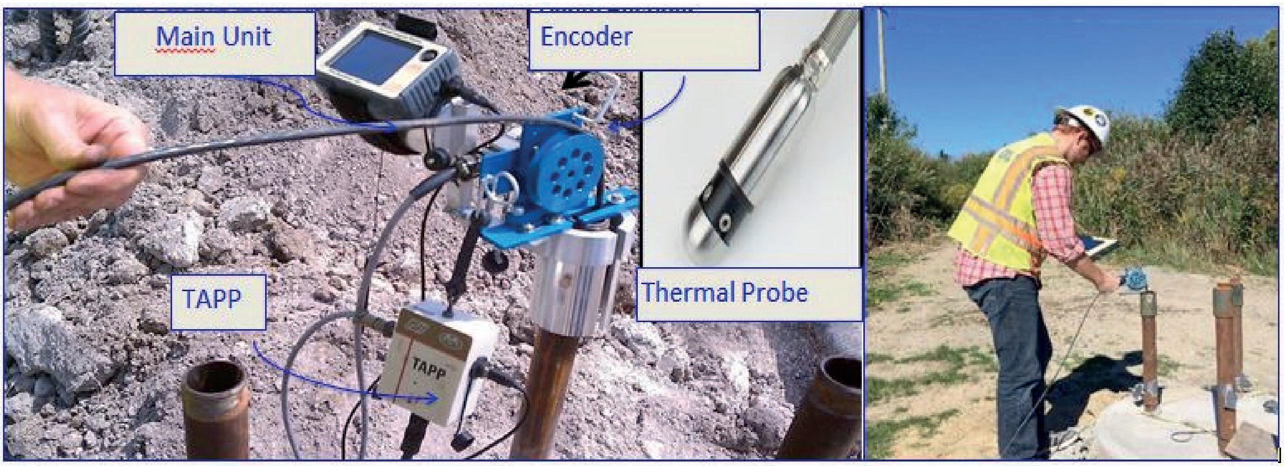

Fig. 5 – Thermic Probe Method (TPM).
Fig. 5 – Metodo della Sonda Termica.

Fig. 6 – Thermal Wire Method (TWM).
Fig. 6 – Metodo del Cavo Termico.

whereas with the Thermal Probe method, the ideal best times for testing are not known in advance.

3. Data analysis and interpretation

This paragraph describes how main shaft defects are identified starting from the thermal profiles acquired.

Soil inclusions, neckings, shaft diameter reductions, or local concrete quality variation are detected by a sudden drop in temperature at a specific depth, as a result of the absence or deficiency of heat-producing cementitious content. Therefore the average thermal profile at the depth of the soil inclusion would show a clear reduction from the average temperature, as illustrated in the example of figure 7. In the chart on the left, all the thermal profiles (and therefore the average, indicated by the black line) display a clear decrease at a depth of 27 m. The central image presents the defect in a 3-D format and also points out that the concrete cover thickness is not adequate. The image on the right illustrates the coring made to confirm the defect found by the TIP model.

Bulges are detected by a relative rise in temperature at a specific depth, as a result of the excess of heat-producing cementitious content. Therefore the average thermal profile at the depth of the bulge would show a clear increase from the average temperature, as illustrated in the example of figure 8 at depth 9 to 10 m. Figure 8 also demonstrates a soft toe below depth 12 m. It is likely that that missing extra soil that allowed creation of the bulge has fallen to the shaft base to create the soft toe.

Reinforcing cage anomalies are detected comparing temperature measurements from diametrically opposite locations versus the average value. If one location is cooler than the average and the diametrically opposite location is warmer than the average, it indicates that the cage is not centered. The cooler measurements indicate a location shifted towards the soil interface while the warmer measurements indicate a location shifted towards the shaft center [Piscsalko, 2015]. This concept is explained in figure 9, where the two purple and green thermal profiles are measured in two diametrically opposite

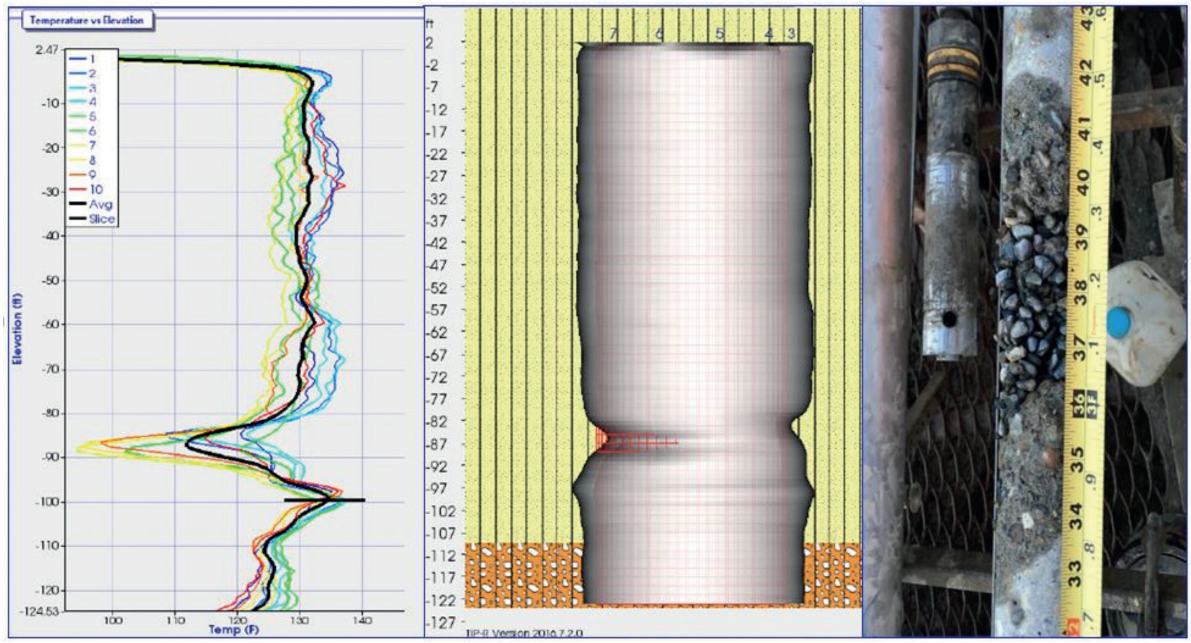

Fig. 7 – Example of necking. Thermal profile registered (left); model output (center); drilling at the anomaly depth (right).
Fig. 7 – Esempio di riduzione del diametro del palo. Profilo termico misurato (sinistra); output del modello (centro); carotaggio nei pressi dell'anomalia riscontrata (destra).

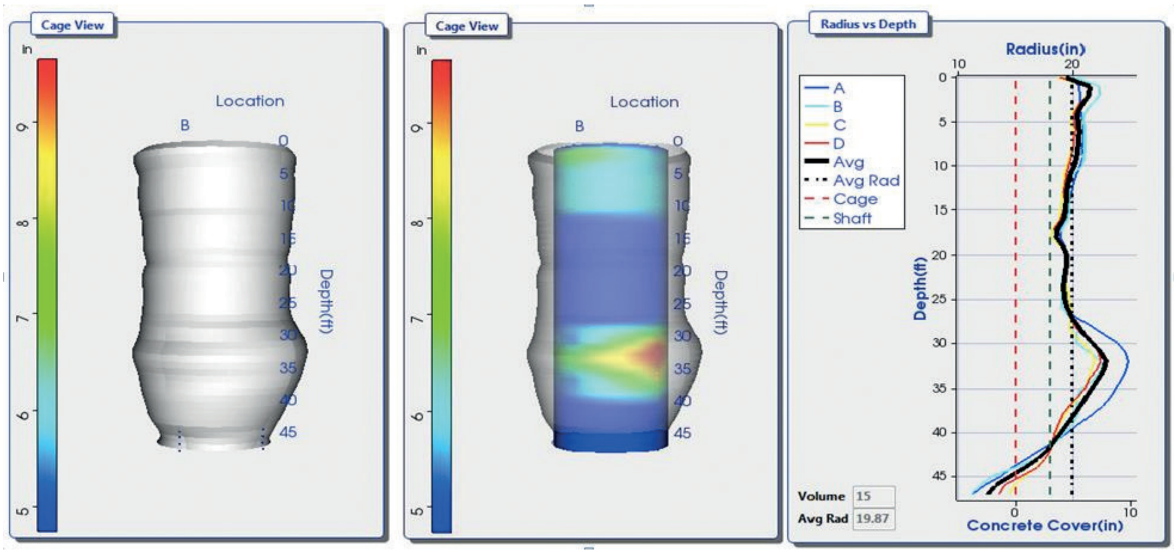

Fig. 8 – Example of a bulge (SELLOUNTOU and ALVAREZ, 2013) and a soft toe.
Fig. 8 – Esempio di ingrossamento (SELLOUNTOU and ALVAREZ, 2013) e piede del palo non adeguato.

points, and the black line is the average. The green profile shows a higher temperature than the average, implying a position closest to the shaft center, while the purple profile shows a temperature lower than the average, implying a position closer to the ground. Therefore the reinforcing cage is shifted in the direction of the cable that measures the purple profile. The software calculates the concrete cover thickness and the amplitude of the cage eccentricity, correlating the value of the temperature deviation from the average to the temperature distribution curve along the shaft diameter (in the linear portion) [MULLINS, 2010].

The two ends of a typical thermal profile assume a drastic curve with a hyperbolic shape (as can be seen in the top and bottom of Figure 9). That is because the shaft base and top are subjected to the longitudinal temperature dispersion, which is added to the radial dispersion acting also on the rest of the shaft. If this drastic end curve can be fitted to a hyperbolic tangent curve then it is due solely to the effect of natural longitudinal heat dispersion, but if it cannot be fitted with a hyperbolic tangent curve then there is a shaft reduction or poor concrete quality.

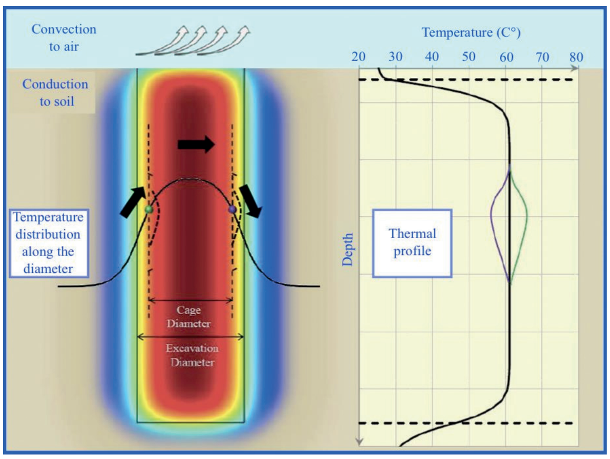

Fig. 9 – Example of reinforcing cage eccentricity.
Fig. 9 – Identificazione di un caso di eccentricità della gabbia di armatura.

The table below summarizes all possible TIP detections, alongside the interpretation method used.

As soon as the data are collected, an initial assessment of the presence or absence of serious irregularities may be conducted, without employing the software.

Afterword, when using the interpretative software, it is necessary to know the volume of the installed concrete, which is usually recorded during the construction of a drilled pile.

Using the concrete volume installation records, the average recorded temperature is equated to the average radius (which is determined from the known length and the total installed concrete volume). Once this average temperature to average effective radius correlation has been established, the radius at all points along the shaft can be calculated [PISCSALKO *et al.*, 2015]. Measured temperatures converted to radius can be used to generate the 3-D model, as well as a 2D drawing of the cross-sections at any depth.

4. Comparison with other integrity test methods

The two non-destructive methods most commonly used to study the shaft integrity are Cross-hole Sonic Logging (CSL) and Pile Integrity Test (PIT).

Tab. 1 – Tip detection and interpretation methods (adapted from Picsalko *et al.*, 2015).
Tab. 1 – Metodi interpretativi dei risultati TIP (riadattato da Picsalko et al., 2015).

TIP detection	Interpretation method
Shape of shaft	Average temperature with depth reveals overall shape of the shaft versus depth
Bulge	Localized temperature increase
Necking	Localized temperature decrease
Poor concrete quality	Localized temperature decrease
Cage alignment	Compare diametrically opposite thermal measurements
Concrete cover	Local temperature measurements compared with overall average temperature measurement combined with total volume placed
Soft bottom	Inability to properly correct the bottom roll-off with hyperbolic tangent function
Cage terminating above shaft bottom	No bottom roll-off observed in thermal data
Shaft Radius at any location	Local temperature measurement compared with overall average temperature measurement combined with total volume placed

In the following lines there is a brief description of their peculiarities and limitations.

4.1. Cross-hole (CSL)

Two ultrasonic probes are lowered simultaneously into steel inspection tubes filled with water and attached to the reinforcing cage. The principle of investigation is based on the measurement of the ultrasonic signal travel time between the two probes, one acting as transmitter and the other as receiver. While moving, the probes are constantly aligned as they are pulled from the bottom of the tubes to the top and the ultrasonic waves emitted by the transmitter pass through the concrete and are detected by the receiving probe. The same operation is performed between the different tubes until all possible combinations have been tested. The arrival time and the intensity of the ultrasonic signal depend on the distance between the tubes and the quality of the concrete; the presence of a defect, located in the ultrasonic waves path, will delay the signal transmission time and reduce its intensity (amplitude).

The main limit of this method is that only defects inside the reinforcing cage may be identified (Fig. 10, right) [Becker *et al.*, 2015].

4.2. Pile Integrity Test (PIT)

The Pile Integrity Test (also called Low Impact Pile Integrity Test, SIT, Pulse Echo Test, Sonic Test), and unlike the Cross-hole, does not require inspection tubes.

The equipment consists of a hand-held hammer and an accelerometer. The accelerometer detects the compression wave induced by a pulse generated by the hammer on the pile head. An Acquisition and Processing Unit shows and records the signals produced. The PIT is considered a low deformation integrity test as it produces a small compression impulse. If the pile has no major defects, the compression wave created by the hammer stroke will be reflected from the bottom and will return to the head

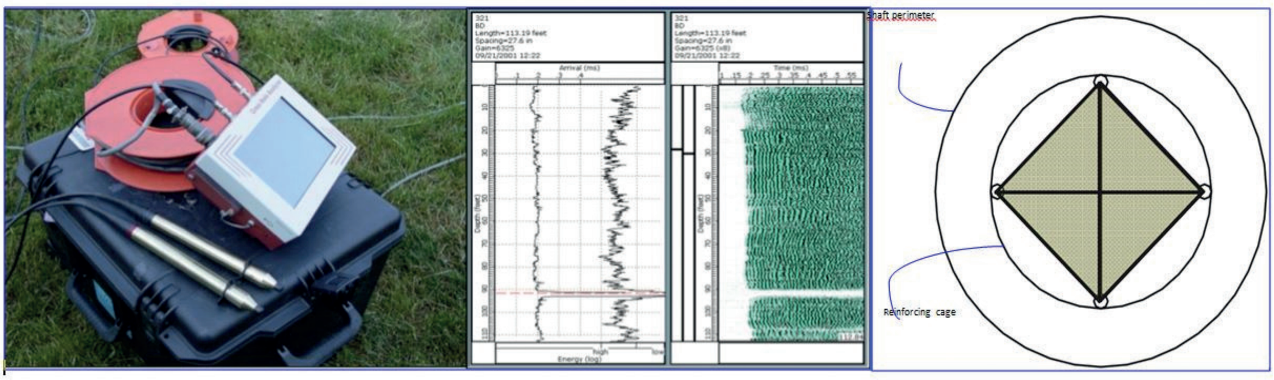

Fig. 10 – Cross-hole equipment; example of testing result; analysed shaft area.
Fig. 10 – Strumentazione CSL; esempio di rilievo; area analizzata.

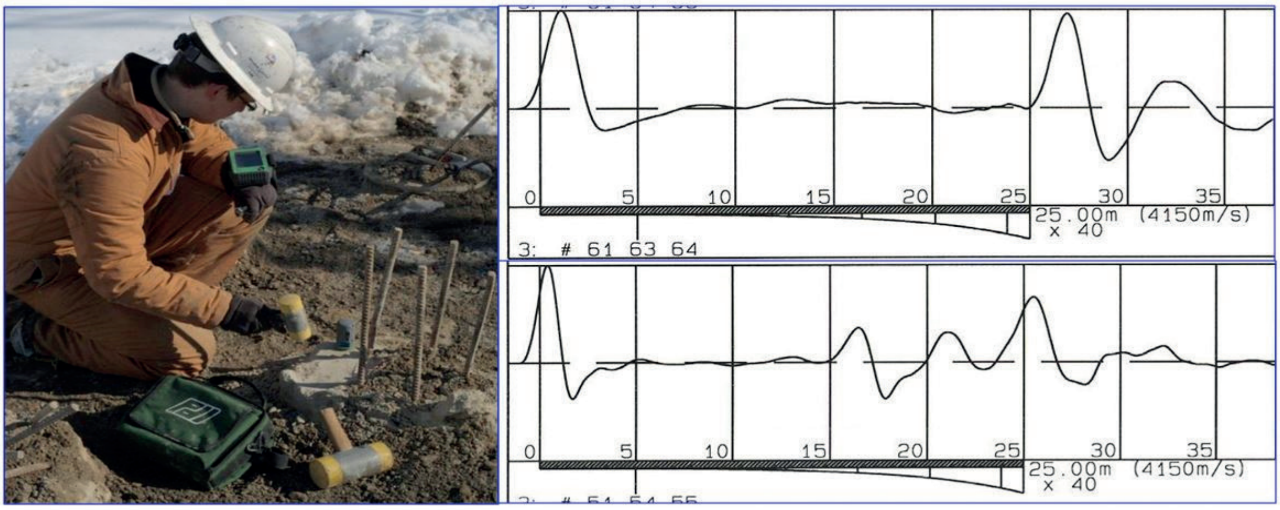

Fig. 11 – Prova PIT. Esecuzione di una prova (sinistra); risultati di due prove (destra); assenza di difetti (sopra) e diminuzione di impedenza (sotto).

Fig. 11 – PIT test. Testing execution (left); testing results (right); case of absence of anomalies (top) and case of impedence decrease (bottom).

without any intermediate distortion. Defects in the integrity of the pile, such as diameter reductions, cracks or a layer of poor concrete, are identified because their presence induces additional tension wave reflections, which reach the accelerometer before the one reflected by the bottom. This method is quick and easy to execute but has several limits.

The first is that in order to ensure its effectiveness, it is necessary for the pile to have a length to diameter ratio usually equal to or less than 30, to ensure that the signal is able to return to the pile head where it is recorded [PISCSALKO and COTTON, 2011]. It should be also pointed out that this method can only detect defects of a relevant size and that diameter enlargements or highly non-uniform shafts can create multiple reflections that make the analysis of integrity difficult.

To illustrate the PIT data interpretation, figure 11 shows the time-measured velocity in two distinct piles. The top chart of the first pile shows no defects, while the second shows a clear reflection before the pile bottom, which is an indication of an impedance decrease.

4.3. Advantages of the TIP method

Both previous described methods can be successfully employed to help determine the integrity of a pile, but each has specific limitations; in particular when the pile has several defects the interpretation becomes more complicated for PIT, and the CSL can only evaluate within the re-bar cage, and only after several days to allow the concrete to cure.

The TIP test overcomes these limits and it is therefore a reliable and comprehensive tool for a more certain assessment of the shaft geometric and mechanical features.

To ascertain the TIP superiority above the other two tests, piles with several defects were tested through the three different methods [MULLINS and WINTERS, 2011, PISCSALKO *et al.*, 2013; SELLOUNTOU *et al.*, 2013]. This literature shows how defects not identified through CSL and PIT were instead correctly recognized with the TIP test.

TIP testing duration is comparable to the one required from Cross-hole testing, when performed on small piles (diameters from 60 to 80 cm), with 3 inspection tubes. For larger size piles, with a larger number of inspection tubes, the time for the CSL increases, because all combinations have to be tested; instead the TIP performed with the Thermal probe needs only one scan per tube, and with the Thermal Wire cable method requires only minimal effort to download the data.

The TIP therefore offers many advantages over the commonly used integrity tests:

- it evaluates the entire cross-section area of the pile, both inside and outside the reinforcing cage;
- it provides additional information, such as reinforcing cage alignment issues and inadequate thickness of the concrete cover; this information is fundamental because although there may be no defects inside the cage, the concrete cover thickness can still be reduced to an unacceptable level;
- it is not limited to any length-to-diameter ratio, therefore every shaft can be tested;
- the test is conducted within a few hours after the pile placement, typically within 12 to 36 hours (depending on pile diameter); this is especially welcome when it is necessary to speed up the construction time;

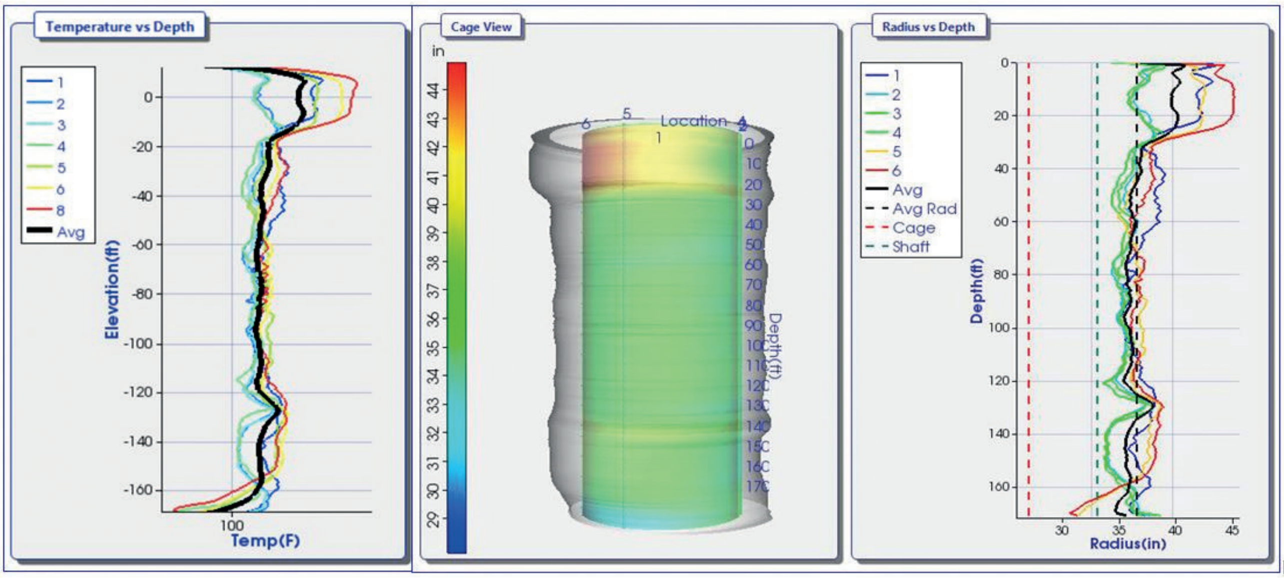

Fig. 12 – TIP testing. Thermal profiles registered (left); shaft shape, model output (center); radius along the shaft axis, as calculated from the software (right).

Fig. 12 – Prova TIP. Profili termici misurati (sinistra); forma del palo output del modello (centro); raggio in funzione della profondità come calcolato dal modello (destra).

– data collection is fast, especially when using the Thermal Wire cable method;
– data analysis does not suffer from subjectivity.

4.4. Costs comparison

Before analysing the costs of non-destructive shaft integrity methods, it is important to note that each test cost is case specific.

A cost comparison for TWM, TPM, and CSL can still be done in general terms by dividing the whole test cost in four main sub-costs: equipment, equipment installation, data collection, and data elaboration. The main difference among the three methods costs concerns their equipment and installation. For TPM and CSL equipment cost is similar, and is a one-time cost; the equipment can be used on many projects and for many years. Thermal Wire cables for TWM are sacrificial and their cost is higher than the cost of access tubes required for the other two methods.

The installation cost for the three methods is similar.

The data collection cost may be considered the same for the TPM and CSL methods, whereas for the TWM method is simpler and thus less time consuming.

The data elaboration cost has no difference for the three methods.

The PIT test has not been included in this cost analysis, since the quality and reliability of its results is not comparable to the TIP test.

5. Examples

In this paragraph two interesting TIP test examples are illustrated. The tests are all done abroad, since the method has been operative in Italy only since 2017.

5.1. TIP Test, Cleveland, Ohio [Sellountou et al., 2013]

A demonstration shaft, heavily instrumented for integrity and capacity evaluations, was constructed and tested on-site. The shaft is 55 m long and 1.7 m in diameter. The first 8.5 m of the pile top had a temporary steel casing (diameter 2.1 m); the actual concrete volume was 141 m^3. Eight Thermal Wires cables were installed for TIP testing and six PVC tubes were installed for CSL testing.

Figure 12 shows, on the left, the recorded thermal profiles and their average; in the center, the shaft shape 3-D model; on the right, the modeled shaft radius. From these images the entire shape of the pile along its axis may be understood: at the top, for the first 8.5 m, the temporarily casing radius of 1 m can be identified; temperatures of cables 6 and 8 are warmer than the average meaning that there the reinforcing cage is closer to the shaft center; temperatures of cables 2 and 3 are cooler than the average, meaning that there the reinforcing cage is closer to the perimeter of the shaft. However, despite the cage eccentricity, the concrete cover in this section exceeds the nominal 150 mm value,

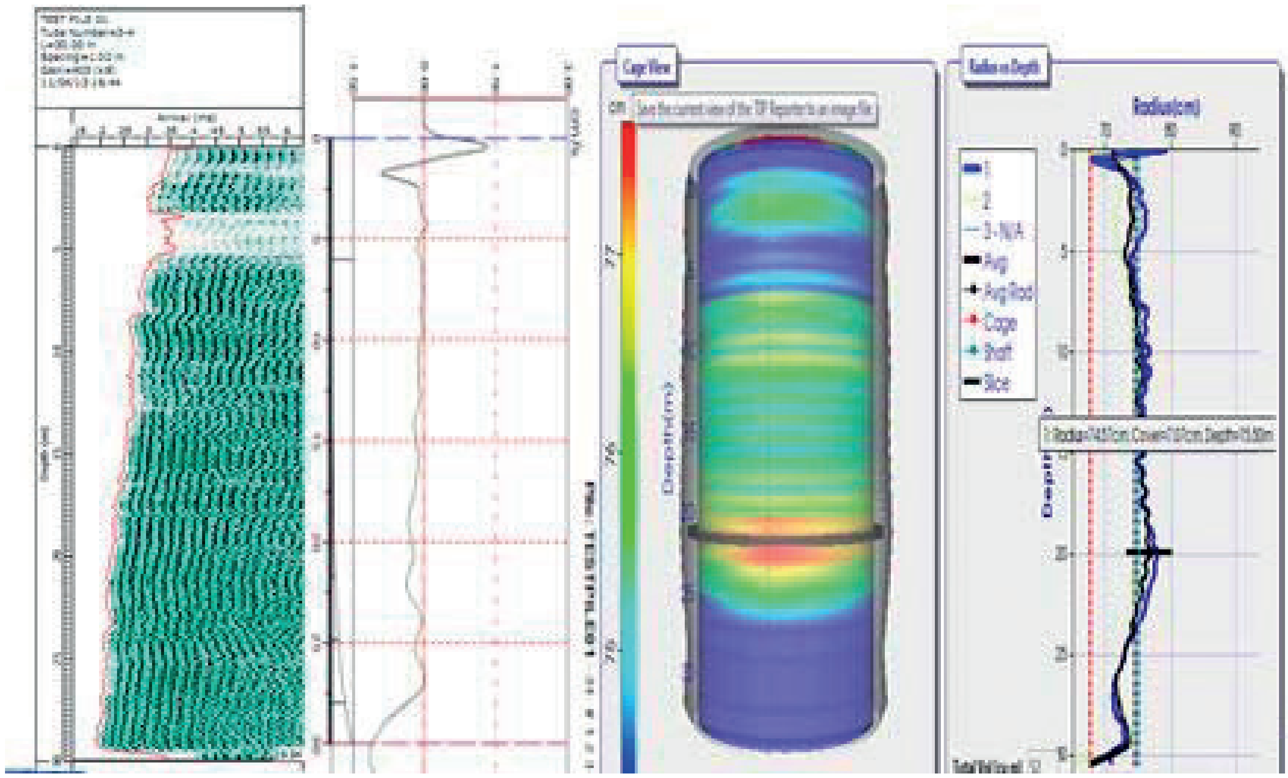

Fig. 13 – Results of the three methods: CSL (left); PIT (center); TIP (rigth).
Fig. 13 – Risultati delle tre prove: Cross-hole (sinistra), PIT (centro), TIP (destra).

and in fact is larger than 230 mm. The radius below the depth of 8.5 m is practically constant until the depth of 39 m, with a generally well-centered cage (as it is evident by the overlapping of temperature measurements of the various wires) and concrete cover of about 200 mm. Between the depths of 38.7 m and 40.8 m a small bulge is observed.

From 40.8 m to about 48.8 m depth, the shaft returns to the radius observed above and the concrete cover exceeds 180 mm.

Concluding, even if some anomalies are observed, no major defect has been detected; the reinforcing cage results eccentric at some depths, but the concrete cover can be considered acceptable for the entire pile length. The top 4.6 m of the shaft were later excavated, bringing to light the bulge as well as the cage eccentricity located near the top, so clearly predicted by the Thermal Integrity Profiling.

CSL results did not show any decrease in First Arrival Time or energy, which would be an indication of a defect, and it cannot estimate the as-built shape of the shaft like TIP does. Finally, no defects were found by CSL nor TIP.

5.2. TIP Test, Jakarta, Indonesia [Piscsalko et al., 2015]

TIP, CSL and PIT testing were performed on a test shaft for the Jet Monorail project in Jakarta, Indonesia. The shaft is 30 m long and 1.5 m in diameter. For the TIP test, four Thermal Wire cables were installed and the test started as soon as the shaft construction was completed. The TIP results showed a sharp temperature reduction less than 1 m below the pile top (circled section in Fig. 13) that indicates a severe necking. Six days after the completion of the shaft, PIT and CSL testing were also performed but no defect was found. The pile top was excavated and the defect became clearly visible

Fig. 14 – Shaft excavated to show the defect identified by the TIP.
Fig. 14 – Palo scavato per mettere in luce il difetto.

(Fig. 14), confirming the TIP results. The defect was repaired, saving the project from a potentially costly foundation failure.

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Prova di integrità del palo col metodo del profilo termico – Thermal Integrity Profiling (TIP)

Il Thermal Integrity Profiler (TIP) sfrutta la temperatura generata dal calcestruzzo in fase di presa (energia di idratazione) per valutare la qualità e l'integrità dei pali di fondazione. E' in grado di superare i limiti delle metodologie fino ad oggi impiegate (es. CSL, PIT); in particolare, offre il vantaggio di permettere l'analisi dell'intera sezione trasversale del palo e la conoscenza della forma e delle caratteristiche meccaniche della parte corticale, quella più importante a contatto col terreno. In aggiunta, il TIP permette un rapido proseguimento dei lavori di costruzione concludendosi nelle ore successive alla realizzazione del palo, e offre una raccolta e valutazione dei dati veloce e oggettiva, lasciando poco spazio alle interpretazioni.

Il metodo TIP è basato sulla misurazione dell'andamento della temperatura lungo il fusto del palo, rilevata durante la fase di maturazione del getto quando si attiva il fenomeno esotermico il cui calore viene disperso nel terreno circostante. Durante questa fase, la presenza di inclusioni, riduzioni di diametro, vespai, basso contenuto di cemento è registrata da relative regioni fredde; invece la presenza di calcestruzzo in eccesso, come nel caso di aumenti di diametro, è registrata da relative regioni calde. Un apposito software, partendo dal profilo termico registrato in campo, costruisce un modello 3-D della forma del palo e ne evidenzia i difetti, quali ingrossamenti, restringimenti, cavità, interruzioni di profilo, e valuta inoltre la posizione esatta della gabbia d'armatura e lo spessore del copriferro.

La strumentazione impiegata prevede due alternative. La Sonda Termica, sonda che viene calata in appositi tubi di ispezione; e i Cavi Termici, cavi strumentati con sensori termici posizionati ogni 30 cm e fissati alla gabbia di armatura prima del getto. Questi Cavi Termici registrano automaticamente dati in continuo, permettendo di monitorare la temperatura del calcestruzzo per l'intera durata di presa.

Il metodo TIP è stato sviluppato inizialmente dalla University of South Florida a partire dagli anni '90 e rappresenta oggi il metodo di indagine di integrità più impiegato negli Stati Uniti.