Designation: D7949 – 14

Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations[1]

This standard is issued under the fixed designation D7949; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods provide procedures for measuring the temperature profile within a deep foundation element constructed using cast-in-place concrete, such as bored piles, drilled shafts, augered piles, diaphragm walls, barrettes, and dams, and alike. The thermal profile induced by the curing concrete can be used to evaluate the homogeneity and integrity of the concrete mass within the deep foundation element.

1.2 Two alternative procedures are provided:

1.2.1 Method A uses a thermal probe lowered into access ducts installed in the deep foundation element during construction.

1.2.2 Method B uses multiple embedded thermal sensors attached to the reinforcing cage installed in the deep foundation element during construction.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.3.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.4 This standard provides minimum requirements for thermal profiling of concrete deep foundation elements. Plans, specifications, and/or provisions prepared by a qualified engineer, and approved by the agency requiring the test, may provide additional requirements and procedures as needed to satisfy the objectives of a particular test program.

1.5 The text of this standard references notes and footnotes, which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.6 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

NOTE 1—ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

1.7 *Limitations*—Proper installation of the access ducts or thermal sensors is advised for effective testing and interpretation. If a flaw is detected, then the method does not give the exact type of flaw (for example, inclusion, bulge, honeycombing, lack of cement particles, and alike.) but rather only that a flaw exists. The method is limited primarily to testing the concrete during the early curing process.

1.8 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *access ducts, n*—preformed steel pipes or plastic pipes (for example, PVC or equivalent) placed in the concrete to allow thermal probe entry to measure temperature in the concrete.

3.2.2 *access locations, n*—the plan view positions of either access ducts or longitudinally distributed groups of embedded thermal sensors.

3.2.3 *defect, n*—a flaw that, because of either size or location, may detract from the capacity or durability of the deep foundation element.

3.2.4 *depth interval, n*—the maximum incremental spacing along the deep foundation element between embedded thermal sensor levels or probe measurements.

3.2.5 *embedded thermal sensor, n*—a temperature measuring device cast in the concrete that meets the requirements of 6.3.5.

3.2.6 *effective radius, n*—the radius of intact uncompromised concrete that would result in the measured temperature to account for a change in concrete quality or change in section.

3.2.7 *flaw, n*—a deviation from the planned shape or material (or both) of the deep foundation element.

3.2.8 *measurement location, n*—the position of a temperature measurement as defined by depth (or elevation) and the access location.

3.2.9 *sensor level, n*—the depth or elevation where an embedded thermal device is located or where a temperature measurement is taken.

3.2.10 *thermal probe, n*—a slender device inserted into access ducts to measure temperature that meets the requirements of 6.3.1.

3.2.11 *thermal profile, n*—a temperature versus depth plot which can be prepared from a single access location or from the average temperature of all access locations versus depth.

4. Summary of Test Method

4.1 Exothermic chemical processes generate heat as concrete cures within a cast-in-place deep foundation element. The amount of heat generated and the rate of heat dissipation are strongly influenced by the concrete mix and by the size and shape of the deep foundation element. Therefore, temperature measurements within the deep foundation element provide a thermal profile from which to evaluate the consistency of the concrete and the regularity of its shape. Temperature measured at the reinforcing cage, typically near the perimeter, will be lower than the core temperature due to heat dissipation into the surroundings (for example, soil, rock, water or air). If the cage is not concentric within the foundation element, then the portions of the cage closer to the perimeter will be cooler during those times when elevated temperatures exist. Portions closer to the center will be warmer. A flaw in the form of a void, a neck, an inclusion, or poor quality concrete will generate less heat than the normal concrete around it, resulting in lower temperature near the flaw. Conversely, a bulge will have more effective concrete cover, resulting in higher temperature near the bulge. Temperature measurements at access locations equally spaced around the circumference of the reinforcement cage and at regular depth intervals allow the user to identify potentially weak zones of concrete, to estimate the effective size of the foundation, and to check concrete cover and cage alignment along the length of the foundation element.

4.2 Along the axis of a cast-in-place concrete deep foundation element and away from the ends, heat dissipates primarily in the radial direction. However, within approximately one diameter of the top and bottom of the deep foundation element, heat dissipates in both the axial and radial directions, resulting in more rapid cooling and reduced temperature. Analysis of the thermal profile near the bottom may help to evaluate the length of the deep foundation element and its shape at the bottom.

4.3 Cast-in-place piles with diameters less than 600 mm can be assessed by a single access location adjacent to the center reinforcing rod.

NOTE 2—During the initial concrete hydration period of a deep foundation element, heat production exceeds the rate of dissipation into the surrounding material, and thus it dominates the early thermal profile. Analysis also shows that the degree of saturation in the surrounding material has little effect on the early thermal profile. Interpretation of the thermal profile should consider any significant changes in the thermal diffusivity of the environment around the deep foundation element, for example, when it extends above the ground surface through air or water.

NOTE 3—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Significance and Use

5.1 Temperature measurements taken from a thermal probe lowered into access ducts in the deep foundation element, or from embedded thermal sensors distributed along the length, can be used to assess the homogeneity and integrity of concrete both inside and outside the reinforcing cage, as well as placement of the cage relative to the center of the curing concrete.[3,4]

NOTE 4—If flaws are detected, then further evaluation and potential remediation may be warranted to determine if the flaw is a defect. Any interpretation is qualitative and possibly relative to the particular deep foundation element material, construction characteristics of the tested structure, and the apparatus used. Interpretation therefore should contain proper engineering judgment and experience.

6. Apparatus

6.1 *Method A: Apparatus for Internal Inspection (Access Ducts)*—To provide access for the thermal probe, access ducts made from pipe or round tube shall be installed during construction of the deep foundation element. Access ducts shall have a nominal inside diameter of 38 to 50 mm (38 mm is

[3] Mullins, G., "Thermal Integrity Profiler of Drilled Shafts," DFI Journal Vol 4. No. 2 December 2010: Deep Foundations Institute, Hawthorne, NJ, December, 2010, pp. 54-64.

[4] Mullins, G. and Kranc, S., "Thermal integrity testing of drilled shafts," Final Report, FDOT Project BD544-20, University of South Florida, May 2007.

preferred to reduce cage congestion) and shall be straight, rigid, and strong enough to withstand crushing from fluid concrete pressure. Ducts shall have a regular internal diameter, be free of obstructions, including duct joints, and shall permit the unobstructed passage of the probe. Ducts shall be water-tight. Ducts may be extended using external mechanical couplings.

6.2 *Apparatus for Determining Physical Test Parameters:*

6.2.1 *Weighted Measuring Tape*—A weighted measuring tape shall be used as a dummy probe to check free passage through and determine the unobstructed length of each access duct to the nearest 50 mm. The weight shall have a diameter equal to or greater than the probe and less than the inside diameter of the access duct.

6.2.2 *Magnetic Compass*—A magnetic compass accurate to within 10° shall be used to document the access location designations compared with the site layout plan. Alternately, access locations shall be labeled based on the site plan, structure orientation or other methods to document access location designations assigned and used for reporting test results.

6.3 *Apparatus for Obtaining Measurements:*

6.3.1 *Method A: Thermal Probe*—The thermal probe shall be equipped with a sufficient number of sensors (minimum two, oriented diagonally opposite) to obtain the average temperature around the perimeter of the access duct wall to within 1°C accuracy.

6.3.2 *Method A: Signal Transmission Cable*—The signal cable used to deploy the probe and transmit data from the probe shall be robust to support the probe weight. The cable shall be abrasion resistant to allow repeated field use and maintain flexibility in the range of anticipated temperatures.

6.3.3 *Method A: Probe Depth-Measuring Device*—The location of the probe in the access duct shall be tracked with a depth encoding device throughout the test; for example by engaging the signal cables over a pulley equipped with a depth-encoding device. The design of the depth-measuring device shall be such that cable slippage shall not occur. The depth-measuring device shall be accurate to within 1 % of the access duct length, or 0.15 m, whichever is larger. The depth sensors shall have a readability to the nearest 0.1 m.

6.3.4 *Method A: Container*—A container of sufficient size to hold the expected amount of water from the access tubes (for example, something like a bucket).

6.3.5 *Method B: Embedded Thermal Sensors*—When using Method B, embedded thermal sensors shall be installed at prescribed access locations defined by 3.2.2 and further specified by 7.3.1 where the sensor levels at one access location correspond to the same depth (or elevation) of the other access locations. The sensors may be installed individually or connected together in an array of sensors that may be individually polled to measure the temperature at each sensor. The thermal sensors shall have an accuracy of 1°C. The thermal sensors shall have a readability to the nearest 0.1°C. The wire(s) connected to the sensors shall be abrasion resistant and remain operational in the range of anticipated temperatures.

6.4 *Apparatus for Recording, Processing and Displaying Data:*

6.4.1 *Recording Apparatus*—The recording apparatus shall record depth and temperature data from each access duct or group of embedded thermal sensors at a depth interval no greater than 500 mm. Typical schematic arrangements for the test apparatus are illustrated in Figs. 1 and 2. For Method A, the apparatus shall read the depth-measuring device and assign a depth to each probe temperature reading. The apparatus shall store the temperature data versus depth from each access location (access duct or group of embedded thermal sensors). For either Procedure, all stored data (temperature versus depth) shall have identifying header information attached to it describing the test location, measurement location identifier, time/date stamp, and all pertinent information regarding the test.

6.4.2 *Processing and Display Apparatus*—The apparatus for processing the data shall be a computer or microprocessor capable of graphically displaying results as average temperature versus depth at each measurement location.

7. Procedures

7.1 *General*—The access ducts or embedded thermal sensors shall be installed during construction of the foundation element. Access ducts for probe-type testing equipment shall be spaced uniformly throughout the foundation cross-section, separated by no more than 1 m. For cylindrical foundation elements, the location plan shall provide in most cases one access duct for every 300 mm of diameter, with a preferred minimum of four access ducts for elements with diameters 1 m or larger. An even number of plan access locations is preferred to simplify interpretation. Access ducts shall be spread equally around the perimeter and spaced at an equal distance from the axis. Access locations for embedded thermal sensors shall conform to the same location plan requirements as access ducts, and the sensor levels shall be the same for all of the

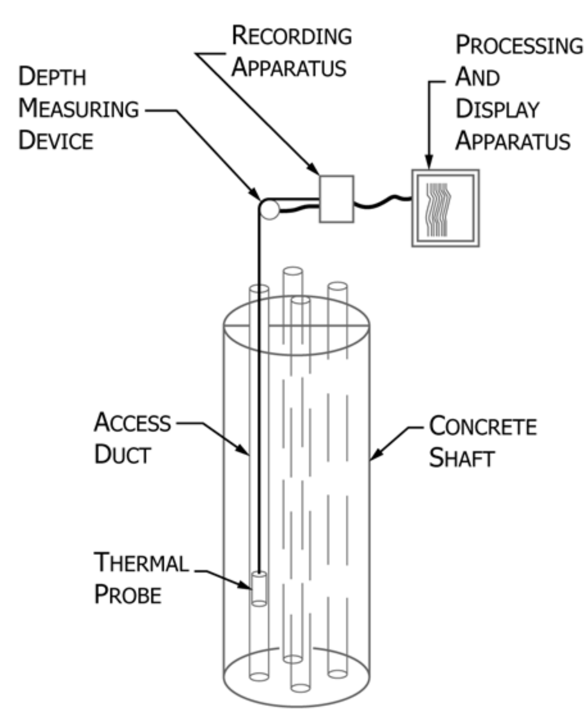

FIG. 1 Method A Test Schematic

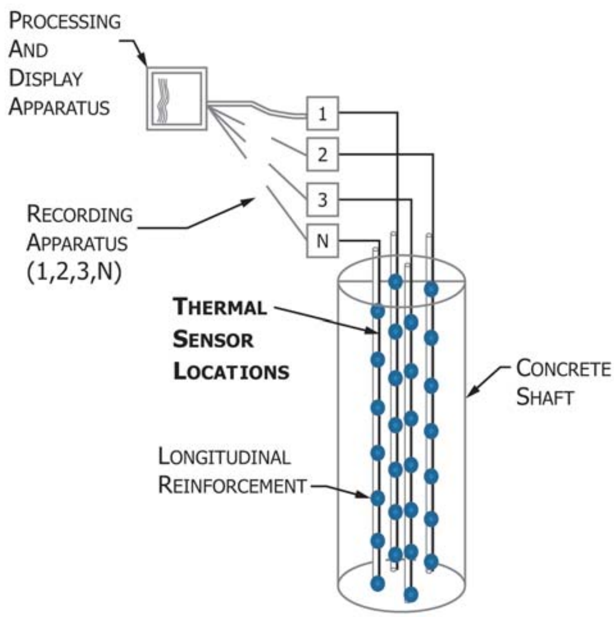

FIG. 2 Method B Test Schematic

access locations with a maximum depth interval between levels of 500 mm. Fig. 3 illustrates several plan layout configurations for the access locations. If a drilled or augered deep foundation element less than 1 m in diameter has only a center bar, attach the access duct or embedded sensors to the center bar, but it should incorporate at least two access locations when there is a reinforcing cage.

NOTE 5—More access locations improve the definition of thermal variation. For non-cylindrical foundations, the placement of the measuring locations should provide adequate coverage of the concrete volume. Spacing should not exceed 1 m for walls.

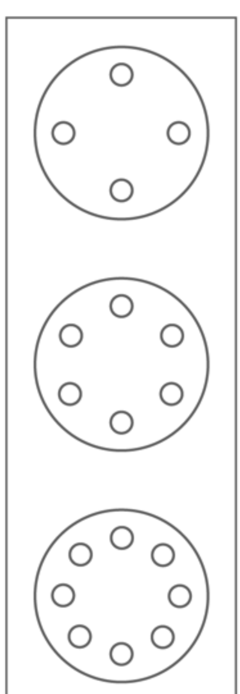

FIG. 3 Plan View of Circular Shafts Showing Thermal Sensing Pattern for 4, 6, or 8 Measurement Locations (Method A using access ducts; Method B using embedded thermal sensors)

7.1.1 Check that the apparatus is functioning correctly according to the manufacturer's operation instructions both prior to mobilizing to site and again upon arrival at the site.

7.1.2 *Date and Time of Testing*—The tests should be performed near the time of peak temperature in the concrete.

NOTE 6—The optimal thermal test time occurs when the core temperature reaches a peak and provides the maximum contrast to the surrounding material, which depends on the foundation cross-sectional area and the concrete mix. The recommended testing window extends from 12 hours after concrete placement until the number of days equivalent to foundation diameter in meters divided by 0.3 m. The 12 hour minimum would apply to testing the center of small diameter augered piles. For cylindrical foundations, a minimum wait of 18 to 24 hours is more common. When retarders are used to slow the onset of hydration, that retardation time should be added to the testing time window. Larger foundation elements require longer to reach the peak temperature and retain their heat longer, and may allow testing up to several days after concrete placement. Either computations or direct measurements can be used to predict or determine the hydration time versus temperature response for a given foundation size and mix design. If using direct measurements (such as thermocouples in the access ducts), measurements should be taken from a location more than 1 diameter away from the ends.

7.1.3 *Measurement Location Documentation*—Lengths of each access duct (or the longitudinal location of all embedded thermal sensors) and lateral separation of the access locations at the top and bottom, and preferably at the midpoint along the length shall be recorded to the nearest 50 mm using a measuring tape. Joint details and their nominal position shall be recorded. Records of all measurements, locations and installation details shall be made and kept by the organization installing the access ducts or embedded thermal sensors. A systematic reference label shall be assigned to each access location (access duct or group of embedded thermal sensors) and a reference sketch prepared of the plan access location layout using the magnetic compass or a site plan diagram. If applicable, note and document bends in the reinforcing cage or access ducts.

7.1.4 *Concrete Volume Installation Records*—Record the volume of concrete installed versus depth to the nearest 0.1 m^3. As a minimum this consists of the volume of concrete supplied by each truck and the depth to top of concrete before and after each truck has transferred its concrete into the excavation.

7.1.5 *Concrete Mix Design Records*—If the thermal characteristics of the deep foundation element are to be modeled, collect the as-built mix design parameters and cementitious constituent fractions.

7.2 *Method A: Installation of Preformed Access Ducts:*

7.2.1 *Preparation*—Access ducts shall be straight and free from internal obstructions. The access ducts shall be closed at the bottom end, threaded at the top to assist in dewatering process if necessary, and fitted with removable end caps to prevent entry of concrete or foreign objects which could block the ducts prior to testing operations.

NOTE 7—Threaded ends at the top of the access ducts provides the most preferable means to connect de-watering systems when filled with water as a standard construction method. When no water is used, non-threaded caps are sufficient.

7.2.2 *Extensions*—If extension of the access ducts is necessary due to long duct lengths, access duct couplings shall be used which prevent slurry or grout ingress during construction. Butt welding for steel duct couplings shall not be permitted. For coupling plastic ducts, threaded or glued plastic couplings shall be used.

7.2.3 *Installation*—Ducts shall be secured to the reinforcement cage as described above and capped on both ends. Ducts shall be extended to within 150 mm of the bottom of the foundation element, to in most cases 1.00 m above the top of the concrete, and to usually between 600 mm and 1.50 m above the ground surface. The access ducts shall have a planned minimum radial concrete cover of one duct diameter. After access duct installation, care shall be taken to make sure that all access ducts are as parallel to each other as practicable. After placement of the reinforcement cage into the deep foundation element, the top end caps of the ducts shall be temporarily removed and the ducts shall be inspected to verify they are clear of obstructions. Ducts shall not be damaged during installation of the reinforcement cage.

7.2.4 *Preparing Access Ducts for Testing*—After placing concrete, the access ducts shall be exposed and the protective top caps removed. Preferably, use a weighted measuring tape to measure and record the length of each access duct to the nearest 50 mm. If the access duct is blocked, record the depth of the blockage from the access duct top. When necessary, remove water from tubes prior to testing.

NOTE 8—If water is to be removed to perform the test and other test methods which require water in the tubes are to be performed later, remove the water, store it temporarily in a container taking reasonable precautions to keep the water as warm as practicable during the extraction period, and return the warm water as soon as practicable to the access duct after testing has been completed.

7.3 *Method B: Embedded Thermal Sensor Installation:*

7.3.1 *Installation*—Embedded thermal sensors shall be attached to the reinforcing cage and aligned with the longitudinal reinforcement of the foundation element corresponding to a given measurement location. The wire(s) connected to the embedded thermal sensors shall be adequately secured to the reinforcing cage such that the sensor locations are not altered during concrete placement. Embedded thermal sensors shall be placed within 150 mm of the bottom of the foundation element. Embedded thermal sensors and wires connected to the sensors shall not be damaged during installation of the reinforcement cage.

7.4 *Obtaining Measurements with the Apparatus (Method A)*—A typical arrangement is shown in Fig. 1.

7.4.1 Follow project health and safety regulations and special instructions or manufacturer's procedures pertaining to the particular apparatus employed.

7.4.2 Document the access duct being tested (duct has to be empty). Place the depth-measuring device and thermal probe onto an access duct. Follow all manufacturer recommended procedures such that temperature measurements are accurate.

7.4.3 Connect the encoder and the probe to the Recording Apparatus and then to the Processing and Display Apparatus.

7.4.4 With the probe at the top of the access duct, zero the depth-measuring device if advised by the Recording Apparatus.

7.4.5 Carefully lower the probe down to the bottom of the access duct until the probe reaches the bottom of the duct or encounters an obstruction (for example, because the access duct is bent or blocked). Record the temperatures to the nearest 0.1°C versus depth as the probe is lowered. Make sure that the probe cable is in firm contact with the pulley and does not slip. The probe shall be steadily lowered from the top at a rate not to exceed the manufacturer's recommendation to allow a stable temperature measurement, typically 150 mm/s, with temperature measurements taken at prescribed depth intervals (typically intervals of 150 to 500 mm), but not to exceed an interval of 500 mm.

7.4.6 The temperature data from the recording apparatus shall be transferred to the processing and display apparatus. The recording apparatus and the processing and display apparatus shall be connected during data collection, and results displayed during data collection.

7.4.7 The test for each access duct shall be repeated and temperature versus depth compared to a previous test in the same access duct so that results are consistent within ±2°C. If it is determined that repeat tests of 7.4.5 in the same access duct are consistent to within 1°C, then the confirmation tests of 7.4.5 can be eliminated.

7.4.8 Repeat the procedure of 7.4.2 through 7.4.7 for each access duct.

7.4.9 If specified, the access ducts shall be grouted upon acceptance of the test results and acceptance of the deep foundation element.

7.5 *Obtaining Measurements with the Apparatus (Method B)*—A typical arrangement is shown in Fig. 2.

7.5.1 Follow project health and safety regulations and special instructions or manufacturer's procedures pertaining to the particular apparatus employed.

7.5.2 Document the measurement location (sensor level and access location) in the deep foundation element of each embedded thermal sensor being tested.

7.5.3 Connect each embedded thermal sensor to the Recording Apparatus. Start recording temperature data to the nearest 0.1°C as soon after concrete placement as practical. Record temperatures periodically at intervals not to exceed one hour. Testing shall be terminated only after the peak temperature has been recorded.

7.5.4 Temperature data shall be transferred to the Processing and Display Apparatus upon completion of the data collection.

7.6 *Data Quality Checks:*

7.6.1 If using Method A, compare the length of the measured temperature profile with the measured access duct length. In comparing these measurements a correction should be made to account for the length between the bottom of the probe assembly to the exact point of the thermal sensor in the probe. The difference between the corrected measurements shall not exceed 1 % of the measured length of the access duct (from weighted tape) or 0.15 m, whichever is larger. If the difference exceeds these tolerances, discard the data and re-run the test or recalibrate the depth measuring device.

7.6.2 Make sure that the captured data are labeled with the deep foundation element identification, identification of the measurement location (access duct or thermal sensor) for each data set, date of test, identification of the test operator, and when applicable further necessary project information such as site and location details as requested by the party requesting that the tests are carried out, for example, the engineer or client. Store the data and information safely.

7.7 *Presentation of Measurements:*

7.7.1 The temperature profiles for each access location shall be clearly presented and annotated. The temperature profiles shall be collated separately for each deep foundation element tested. As a minimum, the temperature profile for each access location and the average temperature profile of all access locations shall be included (Figs. 4 and 5).

8. Report: Test Data Sheet(s)/Form(s)

8.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.3.

8.2 Record as a minimum the following general information (data):

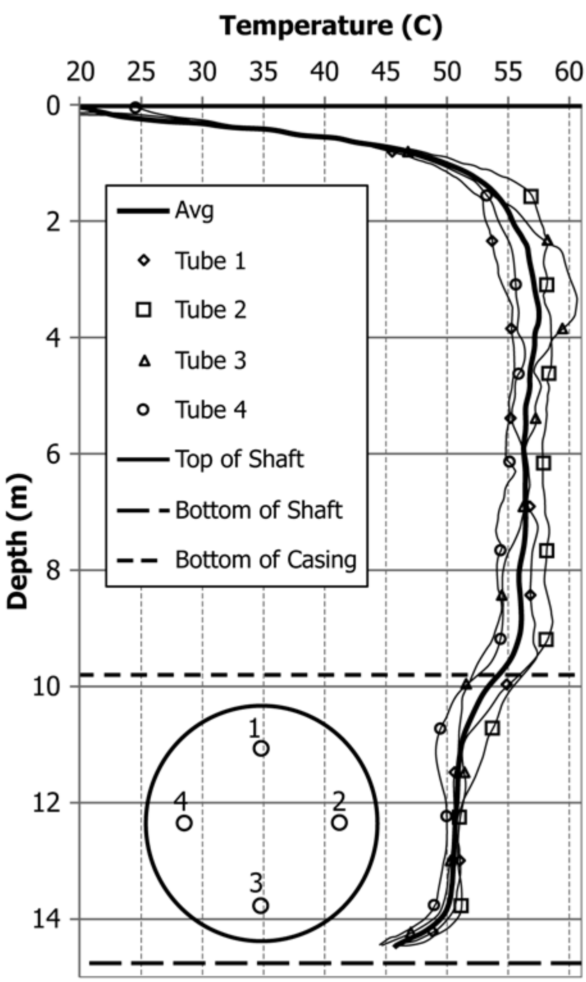

FIG. 4 Thermal Measurements for a Shaft Constructed with Temporary Surface Casing Where the Larger Diameter, Cased Portion with More Cover Exhibited Higher Temperatures

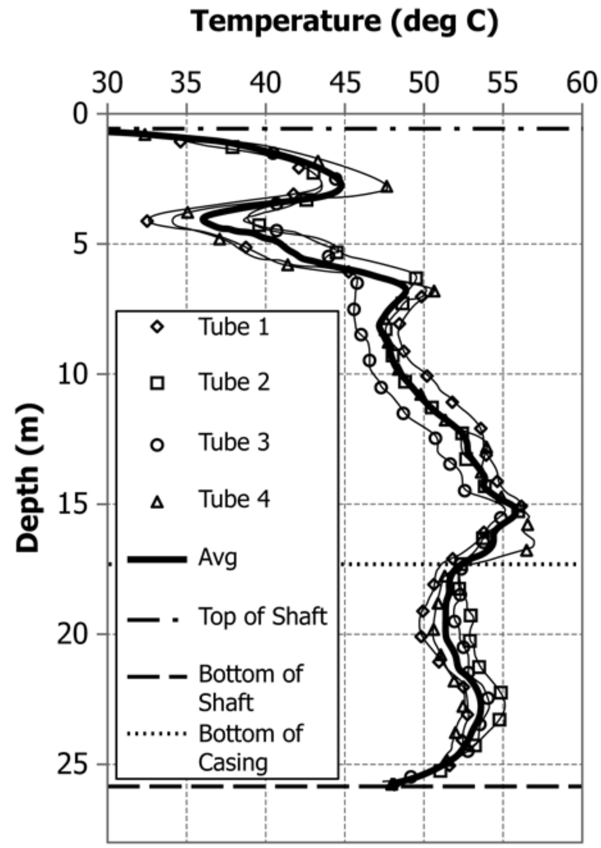

FIG. 5 Thermal Measurements for a Shaft Constructed with Temporary Surface Casing (similar to Fig. 4) Where the Upper 15 m Registered Lower Temperatures and Where the Upper Concrete was Subsequently Cored and Found to Be Flawed

8.2.1 Identification of testing agency,
8.2.2 Project and client identification,
8.2.3 Date and time of test,
8.2.4 Description of the testing apparatus unit, and
8.2.5 Identification of test staff and of person responsible for the validity of the test report.

8.3 Record as a minimum the following Tested Deep Foundation Element(s):

8.3.1 Identification and location of tested deep foundation element,

8.3.2 As-built geometry of tested deep foundation element including nominal diameter and length or other applicable dimension (for example, wall length, width, depth, or similar),

8.3.3 Tested deep foundation element installation date and method, with specific installation observations, including casting information for each concrete truck (for example, date/time, volume, depth to top of concrete),

8.3.4 Arrangement and identification and relative separation of access locations (access ducts or vertically aligned groups of embedded thermal sensors), and identifying designation documentation,

8.3.5 Cut-off and ground elevation of the deep foundation element and, if applicable, elevation of each access duct top, or length of access duct above top of concrete at time of test, and

8.3.6 If appropriate, other specific observation or given information relevant to each deep foundation element tested (for example, excavation, soil boring, construction information, ambient soil temperature at depth, water table, other integrity testing, and alike.) that relate to the deep foundation element tested.

8.3.7 Documentation of water removal and replacement in access tubes, if applicable.

8.3.8 Present the thermal profiles logically and clearly for each structure tested. Relevant information shall accompany the profiles or be clearly associated with the profiles by cross-referencing, including the access location for each profile with temperature and depth axes and scales allowing clear data interpretation.

8.4 *Record Management*—Maintain a record of measurements for future reference or transmit the records, including at a minimum, each temperature measurement to the nearest 0.1°C, its depth within the deep foundation element to the nearest 10 mm, its location within the deep foundation element, and the time and date of the measurement to the nearest minute.

NOTE 9—Record comments on the homogeneity and integrity of the concrete mass within the deep foundation element tested on the data sheet(s), as appropriate.

9. Precision and Bias

9.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

9.1.1 The Subcommittee D18.11 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

9.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

10. Keywords

10.1 barrette; bored pile; concrete curing; drilled shaft; heat of hydration; integrity test; thermal testing