Designation: D 6760 – 02

Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing[1]

This standard is issued under the fixed designation D 6760; 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 This test method covers procedures for checking the homogeneity and integrity of concrete in a deep foundation such as bored piles, drilled shafts, concrete piles or augercast piles. This method can also be extended to diaphragm walls, barrettes, dams etc. The test measures the propagation time and relative energy of an ultrasonic pulse between parallel access ducts installed in the pile or structure. This method is most applicable when performed between tubes that are installed during pile construction.

1.2 Similar techniques with different excitation sources or single access ducts, or both, exist, but these techniques are outside the scope of this test method.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.3.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.4 *Limitations*—Proper installation of the access ducts is essential for effective testing and interpretation. The method does not give the exact type of defect (for example, inclusion, honeycombing, lack of cement particles, etc.) but rather only that a defect exists. The method is limited primarily to testing the concrete between the access ducts and thus gives little information about the concrete outside the reinforcement cage to which the access ducts are attached when the tubes are attached to the inside of the reinforcement cage.

1.5 *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:*

D 1143 Test Method for Piles Under Static Axial Compressive Load[2]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[2]

D 4945 Test Method High Strain Dynamic Testing of Piles[2]

D 5882 Test Method for Low Strain Integrity Testing of Piles[2]

D 6026 Practice for Using Significant Digits in Calculating and Reporting Geotechnical Test Data[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *access ducts*, *n*—preformed steel or plastic tubes, or drilled boreholes, placed in the concrete to allow probe entry in pairs to measure pulse transmission in the concrete between the probes.

3.1.2 *anomaly*, *n*—irregularity or series of irregularities observed in an ultrasonic profile indicating a possible defect.

3.1.3 *depth interval*, *n*—the maximum incremental spacing along the pile shaft between ultrasonic pulses.

3.1.4 *integrity evaluation*, *n*—the qualitative evaluation of the concrete continuity and consistency between the access ducts or boreholes.

3.1.5 *specifier*, *n*—the party requesting that the tests are carried out, for example, the engineer or client.

3.1.6 *ultrasonic profile*, *n*—a combined graphical output of a series of measured or processed ultrasonic pulses with depth.

3.1.7 *ultrasonic pulse*, *n*—data for one specific depth of a short duration generated by a transmitter probe or sensed by the receiver probe.

4. Principle of the Test Method

4.1 The actual velocity of sound wave propagation in concrete is dependent on the concrete material properties, geometry of the element and wavelength of the sound waves. When ultrasonic frequencies (for example, >20 000 Hz) are generated, Pressure (P) waves and Shear (S) waves travel though the concrete. Because S waves are relatively slow, they are of no further interest in this method. In good quality concrete the P-wave velocity would typically range between

[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] *Annual Book of ASTM Standards*, Vol 04.08.

3600 to 4400 m/s. Poor quality concrete containing anomalies (for example, soil inclusion, gravel, water, drilling mud, bentonite, voids, contaminated concrete, or excessive segregation of the constituent particles) has a comparatively lower P-wave velocity. By measuring the transit time of an ultrasonic P-wave signal between an ultrasonic transmitter and receiver in two parallel water-filled access ducts cast into the concrete during construction and spaced at a known distance apart, such anomalies may be detected. Usually the transmitter and receiver are maintained at equal elevations as they are moved up or down the access ducts. In some cases and for special processing the probes may be deliberately offset in relative elevation and the use of multiple receivers either in the same access duct or in multiple access ducts can also be allowed. The principles and limitations of the test and interpretation of the results are described in the References section.

4.2 Two ultrasonic probes, one a transmitter and the other a receiver, are lowered and lifted usually in unison in their respective water-filled access ducts to test the full shaft length from top to bottom. The transmitter probe generates ultrasonic pulses at frequent and regular intervals during the probes' controlled travel rate. The probe depth and receiver probe's output (timed relative to the transmitter probe's ultrasonic pulse generation) are recorded for each pulse. The receiver's output signals are sampled and saved as amplitude versus time (see Fig. 1).

4.3 Alternately, the signals may be modulated to a series of black and white lines corresponding respectively to the positive and negative peaks of the signal. In either case, the data are further processed and presented to show the first arrival of the ultrasonic pulse and the relative energy of the signal to aid interpretation. The processed data are plotted versus depth as a graphical representation of the ultrasonic profile of the tested structure. Special test methods to further investigate anomalies are employed where the probes are not raised together. The References section lists further sources of information about these special test techniques.

5. Significance and Use

5.1 This method uses data from ultrasonic probes lowered into parallel access ducts in the pile or structure to assess the homogeneity and integrity of concrete between the probes. The data are used to confirm adequate concrete quality or identify zones of poor quality. If defects are detected, then further investigations should be made by excavation or coring the concrete as appropriate, or by other testing such as Test Method D 1143, D 4945 or D 5882, and measures taken to remediate the structure if a defect is confirmed.

NOTE 1—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 D 3740 are generally considered capable of competent and objective testing and inspection. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

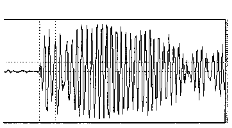

FIG. 1 1 ms Duration Ultrasonic Pulse from Receiver

6. Apparatus

6.1 *Apparatus for Allowing Internal Inspection (Access Ducts)*—To provide access for the probes, access ducts can be preformed tubes, which are preferably installed during the pile or structure installation. The tubes shall preferably be mild steel. Plastic tubes, while not preferred, can be used in special circumstances if approved by the test agency but require more frequent attachment to the reinforcing cage to maintain alignment. The plastic material must not deform during the high temperatures of concrete curing. If no tubes are installed during construction, boreholes drilled into the pile or structure can be installed after installation. The internal diameter of the access ducts shall be sufficient to allow the easy passage of the ultrasonic probes over the entire access duct length. If the access duct diameter is too large it influences the precision of arrival time and calculated concrete wave speed. Access ducts typically have an internal diameter from 38 to 50 mm.

6.2 *Apparatus for Determining Physical Test Parameters*:

6.2.1 *Weighted Measuring Tape*—A plumb bob connected to a 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 100 mm. The plumb bob shall have a diameter similar to the diameter of the probes.

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

6.3 *Apparatus for Obtaining Measurements*:

6.3.1 *Probes*—Probes shall allow a generated or detected pulse within 100 mm of the bottom of the access duct. The weight of each probe shall in all cases be sufficient to allow it to sink under its own weight in the access ducts. The probe housing shall be waterproof to at least 1.5 times the maximum depth of testing.

6.3.2 *Transmitter Probe*—The transmitter probe shall generate an ultrasonic pulse with a minimum frequency of 30 000 Hz.

6.3.3 *Receiver Probe*—The receiver probe shall be of a similar size and compatible design to the transmitter probe and used to detect the arrival of the ultrasonic pulse generated by the transmitter probe.

6.3.4 *Probe Centralizer*—If the receiver or transmitter probes, or both, are less than half the access duct diameter, each probe shall be fitted with centralizers with effective diameter equivalent to at least 50 % of the access duct diameter. It shall be designed to minimize any possible snagging on irregularities in the inner access duct wall.

6.3.5 *Signal Transmission Cables*—The signal cables used to deploy the probes and transmit data from the probes shall be sufficiently robust to support the probes' weight. The cable shall be abrasion resistant to allow repeated field use and maintain flexibility in the range of anticipated temperatures. All cable connectors or splices, if any, shall be watertight.

Where the signal transmission cables exit the access duct, suitable cable guides, pulleys or cushioning material shall be fitted inside the access ducts to minimize abrasion and generally assist with smooth deployment of the probes.

6.3.6 *Probe Depth-Measuring Device*—The signal cables shall be passed over or through a pulley with a depth-encoding device to determine the depth to the location of the transmitter and receiver on the probes in the access ducts throughout the test. The design of the depth-measuring device shall be such that cable slippage shall not occur. Preferably a separate depth-measuring device, such as direct markings on the cables, shall monitor each probe separately so the exact depth of each probe is known at all times. (Alternately a single pulley can be connected to one electronic depth encoder, but then the probes must remain at the same known relative elevation difference for the entire test.) The depth-measuring device shall be accurate to within 1 % of the access duct length, or 0.25 m, whichever is larger.

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

6.4.1 *General*—The signals from the transmitter and receiver probes and the depth-measuring device shall be transmitted to a field rugged, dc battery powered, computerized apparatus for recording, processing and displaying the data in the form of an ultrasonic profile. A typical schematic arrangement for the test apparatus is illustrated in Fig. 2. The apparatus shall generate pulses from the transmitter probe either at fixed depth intervals or at fixed time intervals. In the latter case, the depth shall be recorded and assigned to each pulse captured by the apparatus for the instant of pulse generation. The rate of pulse generation by either method shall generate at least one ultrasonic pulse for every required depth interval, typically 50 mm or less. The apparatus shall have adjustable gain to optimize detection of the transmitted pulse by the receiver probe for the concrete under test.

6.4.2 *Recording Apparatus*—Each transmitted ultrasonic pulse shall immediately start the data acquisition for the receiver probe. Analog signals of an ultrasonic pulse measured by the receiving probe shall be digitized by an analog to digital converter with a minimum amplitude resolution of 12 bits and a minimum sampling frequency of 250 000 Hz. The apparatus shall read the depth-measuring device and assign a depth to each digitized ultrasonic pulse. The apparatus shall store these raw digitized ultrasonic pulses and the processed data from each ultrasonic profile for each pair of access ducts. All stored data shall have identifying header information attached to it describing the test location, profile identifier, date stamp and all pertinent information regarding the test.

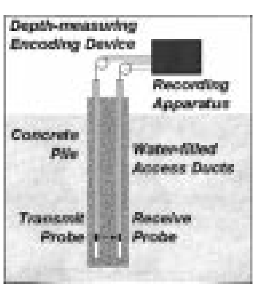

FIG. 2 Test Arrangement

6.4.3 *Apparatus for Processing Data*—The apparatus for processing the data shall be a digital computer or microprocessor capable of analyzing all data to identify at least the first arrival and energy of the transmitted ultrasonic pulse at the receiver probe for each depth interval. The data shall then be compiled into a single ultrasonic profile for each duct pair.

6.4.4 *Apparatus for Display of Measured Data*—The apparatus shall be capable of displaying the raw receiver ultrasonic pulses to confirm data quality during acquisition. After data acquisition, the apparatus shall be capable of displaying the raw data of each ultrasonic pulse along the entire pile length. The apparatus shall also display the processed ultrasonic profile. The apparatus may optionally include a printer for on site output of results.

7. Procedure

7.1 *Installation of Preformed Access Ducts*:

7.1.1 *General*—The access ducts shall be supplied and installed during construction by or in cooperation with the contractor of the pile or structure to be tested. The total number of installed access ducts in the pile or structure should be chosen consistent with good coverage of the cross section. As a guide, the number of access ducts is often selected as one duct for every 0.25 to 0.30 m of pile diameter, with a minimum of three access ducts, spaced equally around the circumference. Typical access duct layout configurations for various structural elements are illustrated in Fig. 3.

7.1.2 *Preformed Access Tube Preparation*—The access tubes shall be straight and free from internal obstructions. The exterior tube surface shall be free from contamination (for example, oil, dirt, loose rust, mill scale, etc.), and for plastic tubes the surface shall be fully roughened by abrasion prior to installation, to ensure a good bond between the tube surface and the surrounding concrete. The ends of the tubes shall be undamaged and suitably prepared for the end caps and coupling system adopted. The access tubes shall be close-ended at the bottom and fitted with removable end caps at the top to prevent entry of concrete or foreign objects, which could block the tubes prior to testing operations.

7.1.3 *Preformed Access Tube Extensions*—If extension of the access tubes is necessary due to long tube lengths, access tube couplings shall be used which prevent slurry or grout ingress during construction. Butt welding for steel tube couplings shall not be permitted. For coupling plastic tubes,

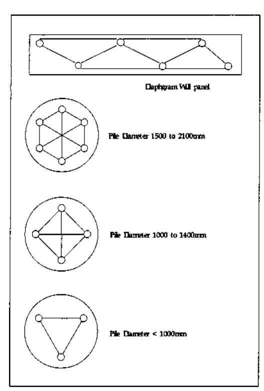

FIG. 3 Typical Access Duct Configurations

threaded or glued plastic couplings shall be used. Wrapping the joints with tape or other compounds is strictly forbidden.

7.2 *Preformed Access Tube Installation*—The access tubes shall be installed such that their bottom is as close as possible to the bottom of the concrete pile or structure so that the bottom condition can be tested. The access tubes shall have a minimum concrete cover of 1 tube diameter. Access tubes shall be secured to the inside of the main axial reinforcement of the steel cage at frequent and regular intervals along their length to maintain the tube alignment during cage lifting, lowering and subsequent concreting of the pile or structure. During tube installation, care should be taken to ensure that all access tubes are as parallel to each other as possible. After installation of the reinforcement cage into the pile or structure, the top end caps shall be temporarily removed and the tubes shall be inspected to verify they are clear of obstructions. Access tubes should be filled with water prior to, or within one hour of, concrete placement to assure good bonding of the concrete to the tube after the concrete cools.

7.2.1 *Preformed Access Tube Installation Records*—Lengths and separation of the access tubes at intervals not exceeding two meters along the length shall be recorded to the nearest 10 mm. Joint details and their nominal position shall be recorded. Records of the access tube installation details shall be made and kept by the organization installing the tubes.

7.3 *Installation of Drilled Access Ducts (Boreholes)*—In cases where structures to be tested have no preformed access tubes, drilled boreholes may be used to provide probe access. Normal procedures for concrete drilling or coring, or both, can be used to form the access ducts, selecting a borehole diameter consistent with the probes and drilling equipment capable of drilling an essentially straight borehole. Where critical, the alignment of each borehole can be checked by independent means. The borehole cores shall be inspected for additional insight.

7.4 *General Test Procedures*:

7.4.1 Check that the apparatus is functioning correctly prior to mobilizing to site.

7.4.2 *Date of Testing*—The tests shall be performed no sooner than 3 to 7 days after casting depending on concrete strength and shaft diameter (larger diameter shafts may take closer to 7 days) unless agreed with client. In the case of plastic access tubes, testing should be completed as soon as practical to prevent loss of data caused by debonding of the concrete from the tube.

7.4.3 *Preparing Access Ducts for Testing*—The access ducts shall be exposed and the protective top caps removed. Use a weighted measuring tape to measure and record the length of each access duct to the nearest 10 mm. If the access duct is blocked, record the depth of the blockage from the access duct top. The access ducts shall be filled to the top with clean water.

7.4.4 *Access Duct Documentation*—Assign a systematic reference label to each access duct and prepare a reference sketch of the access duct layout using the magnetic compass or a site plan diagram. The as-built details of the access duct layout shall be recorded including measuring the center-to-center separations of the exposed access ducts to the nearest 10 mm using a measuring tape and measuring the access duct length exposed above the concrete, if any, to the nearest 100 mm.

7.4.5 *Probe Preparation*—To obtain a good acoustic coupling between the probes and the water in the access ducts, the probes shall be clean and free from all contaminants.

7.4.6 Check that test equipment and probes are functioning correctly prior to actual testing by placing the probes in two adjacent water filled access ducts of one pile just below the level of the shaft concrete and verifying that ultrasonic pulses are received in the recording apparatus.

7.5 *Obtaining Measurements with the Apparatus*:

7.5.1 Pay due regard to safety and any special instructions or manufacturer's procedures pertaining to the particular apparatus employed.

7.5.2 Document the pair of access ducts being tested. Place the probe cable pulley guides into the access ducts. Insert the transmitter and receiver probes into these access ducts ensuring that the cables are engaged over the respective cable pulley guides fixed at the access duct tops. If the access duct tops are not level, then hold the probes at the level of the lower access duct top.

7.5.3 Zero the depth-measuring device if required by the recording apparatus.

7.5.4 Carefully lower the probes down the access ducts at a steady rate not exceeding 0.5 m/s, always keeping them at the same level, until one probe reaches the bottom of the duct or encounters an obstruction (for example, because one access duct is shorter, bent or blocked). Temporarily secure the cables at that level with the cables remaining in equal tension.

7.5.5 Adjust the test apparatus, if necessary, selecting the power settings required for the access duct separation distance and concrete characteristics encountered such that an ultrasonic pulse with good amplitude can be consistently obtained in a portion of pile shaft of good quality.

NOTE 2—The pile top and bottom are more likely to contain contaminated concrete than at intermediate locations. Setting the signal conditioning gains should be done at an intermediate location along the pile shaft. The gain settings may be manually or automatically adjusted (as per apparatus system used) to adapt to different spacings between tested access duct pairs so that good signal strength is maintained.

7.5.6 Begin recording the ultrasonic pulses as the probes are raised. Lift both probes by steadily pulling the probe cables simultaneously at a speed of ascent slow enough to capture one ultrasonic pulse for each depth interval specified. If an ultrasonic pulse is not obtained for any depth interval, then the probes shall be lowered past that depth and the test repeated until all depth intervals have an associated ultrasonic pulse.

NOTE 3—Data collection in some systems may proceed from the top down, or during both downward and upward probe travel.

NOTE 4—In some cases it is advantageous to place the probes at different levels during pulling. The differences can be at either fixed or variable distances depending on the application.

7.6 *Data Quality Checks*:

7.6.1 After completing data acquisition, view the ultrasonic profile obtained. Check the ultrasonic profile quality. The modulated graphics (4.3) should be of good resolution and contrast.

7.6.2 Compare the length of the measured ultrasonic 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 transmitter and receiver on the probe. The difference between the corrected measurements shall not exceed 1 % of the measured length or 0.25 m, whichever is larger.

7.6.3 Ensure that the captured data is labeled with the pile identification, identification of the two access ducts for the data set, date of test, identification of the test operator, and any further necessary project information such as site and location details as requested by the specifier. Store the data and information safely.

7.7 *Completing the Test*:

7.7.1 If the ultrasonic profile indicates an anomaly, then the suspect anomaly zone may be further investigated by special test procedures such as fan shaped tests, tests with the probes raised at a fixed offset distance, or other tomographical techniques **(2, 3)**. The probes shall be lowered to a depth of at least 1 m below the anomaly and raised to a depth of at least 1 m above the anomaly.

7.7.2 Repeat 7.5-7.7 for the remaining pairs of access ducts.

NOTE 5—If specified, the access ducts may be grouted upon completion of the testing.

7.8 *Analysis of Measurements*:

7.8.1 A hard copy of the ultrasonic profiles shall be clearly presented and annotated. The ultrasonic profiles shall be collated separately for each test pile or structure. As a minimum, the profile shall include the calculated relative energy and the arrival time or calculated wave speed derived from the arrival time and tube spacing. The left edge of the traditional "waterfall" diagram also defines the arrival time. Fig. 4 illustrates both this traditional "waterfall" diagram shown on right and processed signals on left. This data shows a special test pile with purposely installed anomalies at depths of 1.8, 8.2 and 14.2 m below the top of the access ducts, showing both arrival time delay and loss of signal strength at each anomaly location.

NOTE 6—It is strongly suggested that the waterfall diagram (which is a nesting of ultrasonic pulses in an ultrasonic profile) be included in the data presentation. If the waterfall diagram is not presented in the report, the original data must be kept permanently and be accessible to construct the waterfall diagram if requested during a possible future review.

NOTE 7—Filtering or smoothing of the processed results shall be kept to an absolute minimum since excessive smoothing or filtering can hide defects and thus lead to improper interpretation of results. Therefore, if any filtering or smoothing of the data is performed for the processed results, then the waterfall diagram must also be presented in the report.

7.8.2 The results of the analysis shall include the time of first arrival of the ultrasonic pulses (or calculated wave speed) and the relative energy plotted relative to the pile depth to quantify the extent and location of any apparent anomaly. Any further interpretation is qualitative and possibly relative to the particular pile material, construction characteristics of the tested structure, and the apparatus used. Interpretation therefore must contain proper engineering judgment and experience. Any evaluation of integrity is to be made by an engineer with specialized experience in this field, and is beyond the scope of this standard.

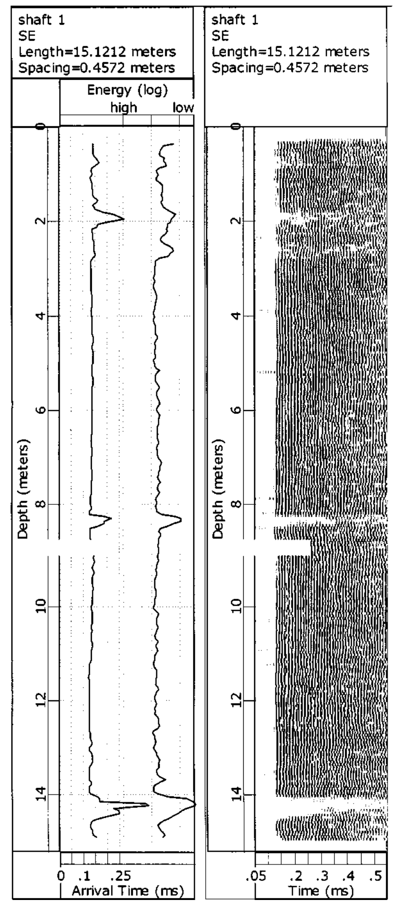

FIG. 4 Typical Ultrasonic Profile

8. Report

8.1 *General*—The test report shall contain the following information when available or applicable:

8.1.1 Identification of testing agency,

8.1.2 Project and client identification,

8.1.3 Date of test,

8.1.4 Description of the testing apparatus unit and probes, and

8.1.5 Identification of test staff and of person responsible for the validity of the test report.

8.2 *Test Pile(s)*:

8.2.1 Identification and location of test pile,

8.2.2 As-built geometry of test pile including nominal and/or actual diameter and length,

8.2.3 Test pile installation date and method, with any specific installation observations,

8.2.4 Arrangement and identification of access ducts, relative separation of ducts, and identifying designation documentation,

8.2.5 Any failure of the probes to penetrate the full depth of the access ducts shall be reported,

8.2.6 Cut-off and ground elevation of the pile, elevation of each access duct top, or length of access duct above pile top at time of test, and

8.2.7 Any other specific observation or given information relevant to each pile tested (for example, excavation, soil boring, pile construction, other integrity testing, etc.) that relate to the pile tested.

8.3 *Ultrasonic Profiles*:

8.3.1 The ultrasonic profiles shall be presented logically and clearly for each structure tested and relevant information shall accompany the profiles or be clearly associated with the profiles by cross-referencing, including the access ducts for each profile with time and depth axes and scales allowing clear data interpretation.

8.4 The test report shall contain comments on the integrity of the pile tested, including locations of suspected anomalies and, when appropriate, the influence of soil stratigraphy and construction techniques on the results, and

8.4.1 Comments on information for boreholes (drilled for access ducts) or coring (to confirm anomaly), if available.

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; crosshole testing; drilled shaft; integrity test; ultrasonic logging; ultrasonic testing

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