Designation: D5882 – 16

Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations[1]

This standard is issued under the fixed designation D5882; 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 the procedure for determining the integrity of individual vertical or inclined piles by measuring and analyzing the velocity (required) and force (optional) response of the pile induced by an (hand held hammer or other similar type) impact device usually applied axially and perpendicularly to the pile head surface. This test method is applicable to long structural elements that function in a manner similar to any deep foundation units (such as driven piles, augeured piles, or drilled shafts), regardless of their method of installation provided that they are receptive to low strain impact testing.

1.2 This standard provides minimum requirements for low strain impact testing of piles. Plans, specifications, and/or provisions prepared by a qualified engineer, and approved by the agency requiring the test(s), may provide additional requirements and procedures as needed to satisfy the objectives of a particular test program.

1.3 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.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

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

1.7 *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.*

NOTE 1—he quality of the result produced by this test method 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 test method 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.

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

D6760 Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing

D7949 Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations

3. Terminology

3.1 *Definitions*—Except as defined in 3.2, the terminology used in this test method conforms with Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *pile integrity, n*—the qualitative evaluation of the physical dimensions, continuity of a pile, and consistency of the pile material.

3.2.2 *pile impedance, n*—the dynamic Young's modulus of the pile material multiplied by the applicable cross sectional area of the pile and divided by the strain wave speed.

3.2.3 *pulse echo method, n*—test in which measurements of the pile head velocity and force (force measurement optional) are evaluated as a function of time.

[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.

***A Summary of Changes section appears at the end of this standard**

3.2.4 *transient response method, n*—test in which the ratio of velocity transform to force transform (force measurement required) are evaluated as a function of frequency.

4. Significance and Use

4.1 Low strain impact integrity testing provides acceleration or velocity and force (optional) data on slender structural elements (that is, structural columns, driven concrete piles, cast in place concrete piles, concrete filled steel pipe piles, timber piles, etc.). The method works best on solid concrete sections, and has limited application to unfilled steel pipe piles, H piles, or steel sheet piles. These data assist evaluation of the pile cross-sectional area and length, the pile integrity and continuity, as well as consistency of the pile material, although evaluation is approximate. This test method will not provide information regarding the pile bearing capacity. It is generally helpful to consider the soil profile, construction method and site records when evaluating data obtained by this method. Other useful information to consider and compare with results of this test includes low strain integrity test results of similar piles at the same site, concrete cylinder or core strength test results, automated monitoring data on equipment placing the concrete when augered piles are used, or information obtained from crosshole sonic logging (Test Method D6760) or thermal integrity profiling (Test Methods D7949) if available.

4.1.1 *Methods of Testing:*

4.1.1.1 *Pulse Echo Method (PEM)*—The pile head motion is measured as a function of time. The time domain record is then evaluated for pile integrity.

4.1.1.2 *Transient Response Method (TRM)*—The pile head motion and force (measured with an instrumented hammer) are measured as a function of time. The data are evaluated usually in the frequency domain.

5. Apparatus

5.1 *Apparatus for Applying Impact:*

5.1.1 *Impact Force Application*—The impact may be delivered by any device (for example, a hand held hammer) that will produce an input force pulse of generally less than 1 ms duration and should not cause any local pile damage due to the impact. A hammer with a very hard plastic tip can induce a short input force pulse without causing local pile damage. The impact should be applied axially to the pile (normally on the pile head).

5.2 *Apparatus for Obtaining Measurements:*

5.2.1 *Velocity Measurement*—Obtain velocity data from integration of signals from (one or more) accelerometers, provided the acceleration signal(s) can be integrated to velocity in the apparatus for reducing data. The accelerometer(s) should be placed at (or near) the pile head and shall have their sensitive axis parallel with the pile axis. Accelerometers shall be linear to at least 50 *g*. Either A/C or D/C accelerometers can be used. If A/C devices are used, the time constant shall be greater than 0.5 s and the resonant frequency shall be at least 30 000 Hz. If D/C devices are used, they shall have frequency response up to 5 000 Hz with less than −3 dB reduction of content. Alternatively, velocity or displacement transducers may be used to obtain velocity data, provided they are equivalent in performance to the specified accelerometers. Calibrate the transducer to an accuracy of 5 % throughout the applicable measurement range. If damage is suspected during use, recalibrate or replace the accelerometer.

5.2.2 *Force Measurement (optional)*—The impact device shall be capable of measuring the impact force as a function of time. The hammer may have a force load cell between the tip and hammer body. Alternatively, the hammer may have an accelerometer attached and the measured acceleration may be converted to force using the hammer mass. The force calibration shall be within 5 %. The hammer must be tuned such that the fourrier transform of the measured force shall have a smooth spectrum, without any local peaks.

5.2.3 *Placement of Transducers*—The motion sensor should be placed at or near the pile head using a suitable, or temporary, thin layer of bonding material (that is, wax, vaseline, putty etc.) so that it is assured that it correctly measures the axial pile motion (transducer axis of sensitivity aligned with the pile axis). The motion sensor is placed generally near the center of the pile. Additional locations should be considered for piles with diameters greater than 500 mm. The low strain impact should be applied to the pile head within a distance of 300 mm from the motion sensor. If the pile head is not accessible, as when already integral with the structure, the sensor(s) may be attached to the side of the pile shaft.

5.3 *Signal Transmission*—The signals from the sensors shall be conveyed to the apparatus for recording, reducing, and displaying the data, see 5.4, by a low noise shielded cable or equivalent.

5.4 *Apparatus for Recording, Reducing and Displaying Data:*

5.4.1 *General*—The signals from the motion and force (optional) sensors, see 5.2, shall be conveyed to an apparatus for recording, reducing, and displaying data as a function of time. The apparatus shall include a graphic display of velocity (Fig. 1) and force (optional), and a data storage capability for retrieving records for further analysis. . The velocity display can be referenced either to the initial rise, as shown, or to the first peak. The apparatus should be capable of averaging data of

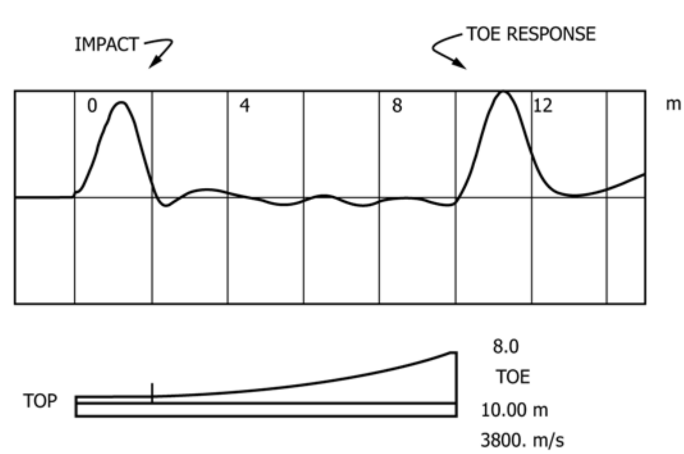

FIG. 1 Typical Velocity Traces for the Pulse Echo Method Generated by the Apparatus for Obtaining Dynamic Measurements (note the orientation of the input pulse is shown as positive in this standard; orientation could also be shown negative)

several blows to reinforce the repetitive information from soil and pile effects while reducing random noise effects. The apparatus shall be able to apply increasing intensity amplification of the motion signal with time after the impact to enhance the interpretation of the measured motions that are reduced by soil and pile material damping. The apparatus must have filtering capability with variable frequency limits for eliminating high frequency, or low frequency signal components, or both. The apparatus shall be capable of transferring all data to a permanent storage medium. The apparatus shall allow for a permanent graphical output of the records. A typical schematic arrangement for this apparatus is illustrated in Fig. 2.

NOTE 2—It is recognized that the velocity signal may be drawn in either downward or upward positive amplitudes. The depth scale may be aligned either at the start of the rise (as shown) or at the initial peak. It is recommended that information be included in the plot showing the magnification function with time.

5.4.2 *Recording Apparatus*—Analog signals from the motion sensor must be directly digitized using an analog to digital converter with at least 12 bit resolution (16 bit or higher resolution is preferred)such that signal components having a low pass cut-off frequency of 5 000 Hz (−3dB) are retained. When digitizing, the sample frequency, therefore, shall be at least 25 000 Hz each for the motion sensor and the optional instrumented hammer, if used. The uniformity and accuracy of the digital sampling frequency is critical; the clock jitter (sampling frequency accuracy) must be within 0.01 %. Analog data acquisition systems are specifically prohibited. Attached to every digitized event should be identifying information names and descriptions, signal processing enhancement parameters, and date and time stamps. The digital record shall be permanently stored.

5.4.3 *Apparatus for Reducing Data*—The apparatus for reducing signals from the transducers shall be a digital computer or microprocessor capable of at least the following functions:

5.4.3.1 *Velocity Data*—If accelerometers are used (see 5.2.2), the apparatus shall provide signal conditioning and integrate acceleration to obtain velocity. The apparatus shall balance the velocity signal to zero between impact events.

5.4.3.2 *Force Measurements*—The apparatus shall provide signal conditioning and amplification, for the force measurements. The force output shall be balanced to zero between impact events.

5.4.3.3 *Signal Conditioning*—The force and velocity data shall have equal frequency response curves to avoid relative phase shifts and amplitude differences.

5.4.4 *Display Apparatus*—Ensure that the signals from the transducers specified in 5.2.1 and 5.2.2 are displayed by means of an apparatus, such as an LCD graphic display, such that the velocity and force (optional) can be observed as a function of time for each hammer blow. This apparatus may receive the signals after they have been processed by the apparatus for reducing the data. The apparatus shall display the digitized data of the impact event or upon recall by the user of the digitally stored event. Adjust the apparatus to reproduce a signal having a duration greater than 2L/c plus 5 milliseconds, where L is the pile length and c is the material wave speed.

6. Procedure

6.1 *General*—Record applicable project information into the apparatus when appropriate (Section 7). The appropriate motion sensor (see 5.2) shall be attached to or pressed against the pile head. Record the measurements from several impacts. Average the suitable records of at least three impacts and apply necessary amplification to the averaged record. The records from the individual impacts or the averaged record, or both, should then be stored (see 5.4.2). The averaged, amplified record then can be evaluated for integrity.

6.2 *Preparation*—For cast-in-place concrete piles or concrete filled pipe piles, perform the integrity testing no sooner than 7 days after casting or after concrete strength achieves at

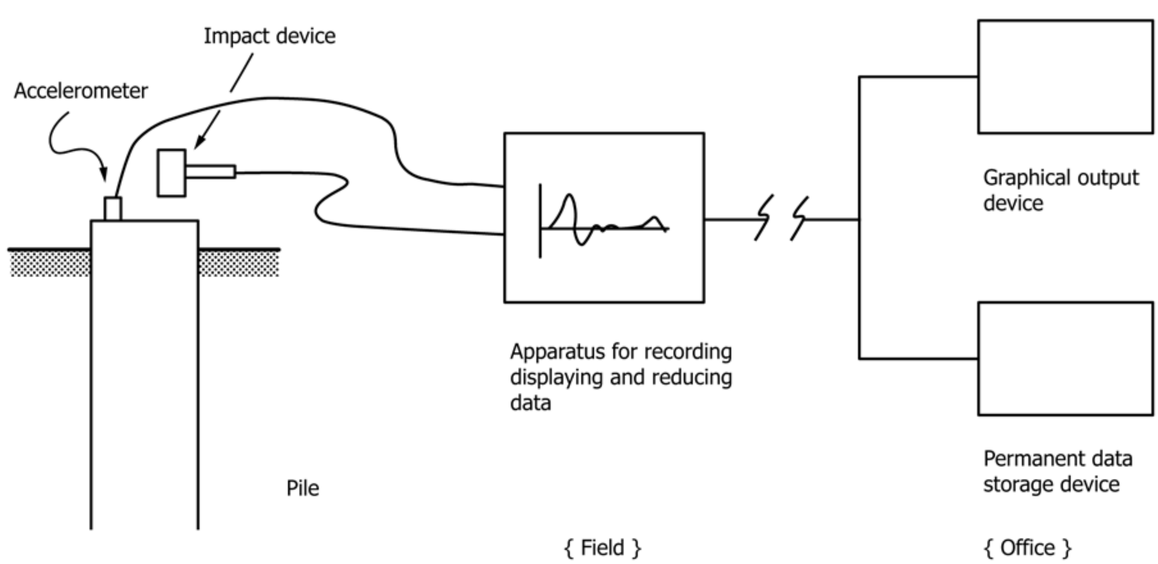

FIG. 2 Schematic Diagram of Apparatus for Integrity Testing

least 75 % of its design strength, whichever occurs earlier. Ensure that the pile head surface is accessible, above water, and clean of loose concrete, soil or other foreign materials resulting from construction. If the pile head is contaminated, remove a sufficient pile section to reach sound concrete. Because proper pile top preparation is critical to the successful application of this method, if necessary, prepare small areas by a hand grinder to provide a smooth surface for motion sensor attachment and impact. Attach the motion sensor firmly to pile (i.e. solid contact) at selected locations away from the edge of the pile head. For piles with diameters larger than 500 mm, attach the accelerometer at a minimum of three locations so that an integrity evaluation near the pile head may be made for each localized section of pile. Position the apparatus for applying the impact force so that the impact is applied axially with the pile and at a distance no larger than 300 mm from the accelerometer. Set up the apparatus for recording, reducing, and displaying data so that it is operational and the force and velocity signals are zeroed.

6.3 *Field Notes*—Include the following information in detailed records, as available, for each pile tested.

6.3.1 Pile identification, nominal and actual pile head diameter and length;

6.3.2 Date and method of concrete placement;

6.3.3 As-built geometry that is, total concrete volume, nominal or actual diameter versus length, permanent or temporary casing, steel reinforcement, etc.;

6.3.4 Soil stratigraphy;

6.3.5 Any specific observation related to each pile tested that affects the pile construction, excavation, integrity, etc.;

6.3.6 Location of transducers at pile head and corresponding measurements; and,

6.3.7 Date pile is tested.

6.4 *Taking Measurements*—Apply several impacts and record each individual impact or the average, if required, or both. If only the individual impacts are recorded, ensure that the apparatus for recording, reducing, and displaying data is capable of averaging up to at least 10 individual records. Record the number of impacts for a specific averaged record. Take, record, and display a series of velocity and force (optional) measurements.

6.5 *Data Quality Checks*—For confirmation of data quality, the operator shall monitor the velocity and force (optional) from several impact events for consistency. Ensure that the apparatus for recording, reducing, and displaying data is capable of determining the measurement device overload threshold. Do not use the records of impacts that cause the measurement device to overload. Consistent records are the result of uniform impacts on sound concrete, transducer systems that are properly functioning, motion sensors that are firmly attached, and the apparatus for recording, reducing, and displaying data properly functioning. If records are not repeatable, do not use the data. If the cause of poor data is not a motion sensor attachment problem but rather is found to be a transducer malfunction, repair or recalibrate it before further use.

NOTE 3—It is generally recommended that all components of the apparatus for obtaining dynamic measurements and the apparatus for recording, reducing, and displaying data be calibrated if any signs of system malfunctions become apparent or if required by project specifications. No amplitude calibration for the sensors beyond the initial manufacturer's calibration is usually necessary. The amplitude for a single motion measurement is not even relevant since it is normalized. The time base can be checked by testing the system on rods of known length, L, and known wave speed, c (e.g. steel) and observing whether the reflection from the rod end returns at the expected time 2L/c (within 2%).

6.6 *Analysis of Measurements:*

6.6.1 With the Pulse Echo Method (PEM), pile head velocity (either integrated from acceleration or directly measured) is analyzed as a function of time. In most cases, this method gives sufficient information for integrity evaluation. Alternately, the pile head force can be measured as well. The combination of force and velocity may give additional information regarding the pile integrity near the pile head. The Transient Response Method (TRM) requires measurement of both the pile head velocity and force. For both methods, data may be evaluated in both time domain and frequency domain.

6.6.2 Obtain velocity and force (optional) from the readout of the apparatus for reducing data (see 5.4.3) or from the display apparatus (see 5.4.4) The displayed data should include the velocity and force (optional) records with time, an indication of the pile length and assumed material wave speed and a representation of the shape and magnitude of the amplification function when used. The motion during the impact event is normalized usually and is associated with the pile head. The amplification is used generally to scale the pile toe response to a similar magnitude.

NOTE 4—In the time domain analysis (PEM), base the pile integrity evaluation on relative increases and decreases of velocity after the initial impact pulse (Fig. 3, Fig. 4). Apparent reflections occurring prior to the toe response that are of the same sign as the input are due to a relative decrease of impedance. Reflections of the opposite sign are due to a relative increase of impedance. Comparison of results from several piles from the site with similar construction is recommended to assess the typical response with the same amplification factor being applied to all piles of similar lengths. Visual interpretation may be qualitative and possibly relative to other tested piles and a matter of proper engineering judgment.

6.6.3 The recorded data may be subjected to further analysis in a computer to quantify better the extent of an apparent

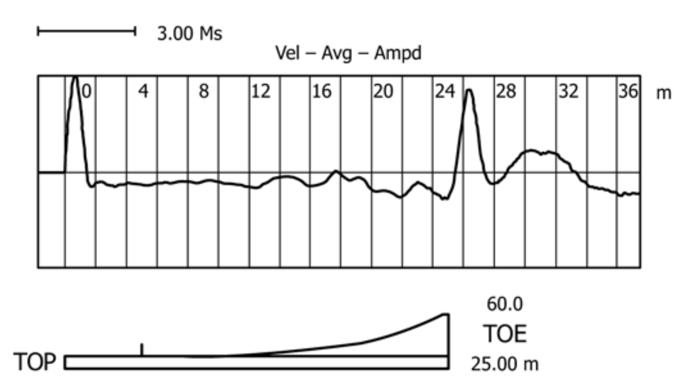

FIG. 3 Typical Velocity Record Indicating Pile of Generally Uniform Nature (Gradual Impedance Changes or Soil Friction) (note the orientation of the input pulse is shown as positive in this standard; orientation could also be shown negative)

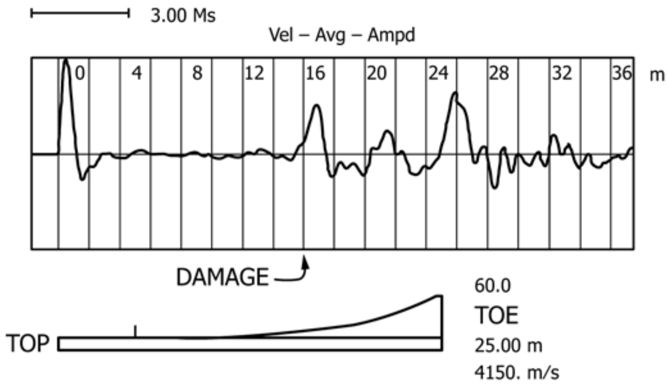

FIG. 4 Typical Velocity Record Indicating Major Changes in Impedance (Severe Damage or a Cracked Pile (note the orientation of the input pulse is shown as positive in this standard; orientation could also be shown negative))

anomaly. The results of the analysis may include a quantitative assessment of pile integrity. Such further use and interpretation of the data is a matter of engineering judgment and experience.

6.6.4 Engineers with specialized experience in this field are to make final integrity evaluation. Use integrity evaluation from low strain impact integrity tests together with other information, including pile installation procedures and observations, soil information, loading requirements, etc., to assess the pile's acceptance. The low strain impact integrity test evaluation should not be used as the sole factor in establishing pile acceptance or rejection. A contingency plan should be formed that allows the engineer to possibly perform further tests or dictate pile repair or replacement prior to the low strain impact integrity testing, in case a serious defect is indicated. Pile lengths contain uncertainties since they are obtained by the low strain impact integrity test using an assumed wave speed.

6.6.5 Certain limitations are inherent in low-strain integrity testing. These limitations must be understood and taken into consideration in making the final integrity evaluation. Integrity evaluation of a pile section below a crack that crosses the entire pile cross-sectional area or a manufactured mechanical joint is not normally possible since the impact wave likely will reflect completely at the discontinuity. Piles with highly variable cross sections or multiple discontinuities may be difficult to evaluate. In some cases, it may be difficult to distinguish the soil response from the pile response. The method is generally not suitable for testing steel sheet, H-section or unfilled pipe piles. If the reflection from the pile toe is not evident in the records, the integrity evaluation may not be conclusive and may be limited to a certain unknown depth. This limitation may apply to long or highly variable piles or piles in soils that exhibit relatively high friction. Piles that are rigidly connected to a footing or superstructure are sometimes tested successfully although the evaluation often may be more difficult and may be inconclusive. Some cases involving integral superstructures, may require use of two motion measuring devices attached at two different locations along the pile shaft.

6.6.6 Integrity testing may not identify all imperfections, but it can be a useful tool in identifying major defects within the effective length. Also, the test may identify minor impedance variations that may not affect the intended use of the pile. For piles having minor impedance variations, the engineer should use judgement as to the acceptability of these piles considering other factors such as load redistribution to adjacent piles, load transfer to the soil above the defect, applied safety factors, and structural load requirements.

7. Report

7.1 Background information and descriptions helpful to pile evaluation may include the following when available, or applicable, or both:

7.1.1 *General:*

7.1.1.1 Project identification/location; and,

7.1.1.2 Log of nearby or typical test boring(s).

7.1.2 *Pile Installation Equipment*—Description of pile installation equipment used for either driving piles or drilling piles, as appropriate if related to the integrity investigation, including size, type, operating performance levels or pressures, pump sizes, and any special installation equipment and their description such as for predrilling or jetting.

7.1.3 *Test Piles:*

7.1.3.1 Identification (name and designation) of test pile(s);

7.1.3.2 Type and dimensions of pile(s) including nominal or actual length and diameter, or both;

7.1.3.3 Date test piles made, cast, or installed or concrete cylinder/core strength, or both;

7.1.3.4 Description of internal and external reinforcement used in test pile (size, length, number and arrangement of longitudinal bars; casing or shell size and length);

7.1.3.5 Description and location, where applicable, of splices; and,

7.1.3.6 Observations of piles including spalled areas, cracks, and head surface condition.

7.1.4 *Pile Installation:*

7.1.4.1 Date of installation;

7.1.4.2 For drilled shafts, include the size of the auger, volume of concrete or grout placed in pile (volume versus depth, if available), grout pressure used, and a description of special installation procedures used, such as pile casing installation or extraction, or both;

7.1.4.3 For driven piles (when the driving process is the suspect cause of damage), include hammer cushion and pile cushion information; include driving records, including blow count and hammer stroke or operating level for final unit penetration;

7.1.4.4 Cause and duration of interruptions in pile installation, if applicable and related to the investigation; and,

7.1.4.5 Notation of any unusual occurrences during installation or excavation, or both, that may relate to the integrity investigation.

7.1.5 *Integrity Testing:*

7.1.5.1 Description of the apparatus for obtaining impact measurements and apparatus for recording, reducing and displaying data, and of test procedure including description and location of the motion sensor attachment;

7.1.5.2 Date tested;

7.1.5.3 Test pile identification;

7.1.5.4 Graphical presentation of motion and force (optional) measurements in the time domain which shall include data enhancements used in the evaluation; frequency domain presentation is optional for PEM evaluation but required for TRM evaluation;

7.1.5.5 The wave speed of test pile, and how determined or estimated;

7.1.5.6 Length of pile, as driven or cast, embedded, or below apparatus for obtaining dynamic measurements,

7.1.5.7 Method(s) used to evaluate data; and,

7.1.5.8 Comments on the integrity of the pile, including when appropriate how the soil stratigraphy or installation methods, or both, have influenced the constructed shape as determined by the measurements.

8. Precision and Bias

8.1 *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.

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

9. Keywords

9.1 force; impact; integrity; low-strain; nondestructive; piles; pulse echo; velocity; sonic echo

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2007 (Reapproved 2013)) that may impact the use of this standard. (July 1, 2016)

(1) Revised 4.1 and 7.1.3.3.

(2) Added Test Methods D6760 and D7949 to 2.1.