INTERNATIONAL

Designation: ~~D7383 – 10~~ D7383 – 19

Standard Test Methods for Axial ~~Compressive Force Pulse (Rapid)~~ Rapid Load (Compressive Force Pulse) Testing of Deep Foundations[1]

This standard is issued under the fixed designation D7383; 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~~ methods, commonly referred to as Rapid Load Testing, cover procedures for testing an individual vertical or inclined deep foundation element to determine the displacement response to an axial compressive force pulse applied at its top. These non-static foundation test methods apply to all deep foundation units, referred to herein as "piles," that function in a manner similar to driven or cast-in-place piles, regardless of their method of installation.

1.2 Two alternative procedures are provided:

1.2.1 Procedure A uses a combustion gas pressure apparatus to produce the required axial compressive force pulse.

1.2.2 Procedure B uses a cushioned drop mass apparatus to produce the required axial compressive force pulse.

1.3 This standard provides minimum requirements for testing deep foundations under an axial compressive force pulse. Plans, specifications, provisions (or combinations thereof) prepared by a qualified engineer, may provide additional requirements and procedures as needed to satisfy the objectives of a particular deep foundation test program. The engineer in responsible charge of the foundation design, referred to herein as the "Engineer," shall approve any deviations, deletions, or additions to the requirements of this standard.

1.4 The proper conduct and evaluation of ~~force pulse testing~~ the test requires special knowledge and experience. A qualified engineer should directly supervise the acquisition of field data and the interpretation of the test results so as to predict the actual performance and adequacy of deep foundations used in the constructed foundation. A qualified engineer shall approve the apparatus used for applying the force pulse, rigging and hoisting equipment, support frames, templates, and test procedures.

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. The word "shall" indicates a mandatory provision, and the word "should" indicates a recommended or advisory provision. Imperative sentences indicate mandatory provisions.

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

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

1.7.1 The procedures used to specify how data are collected/recorded or calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should 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 be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering data

1.8 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 the design or other uses, or both. How one uses the results obtained using this standard is beyond its scope.

1.9 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.

1.10 *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*

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

Current edition approved ~~July 1, 2010~~March 1, 2019. Published ~~August 2010~~March 2019. Originally approved in 2008 as D7383–08. Last previous edition approved in 2010 as D7383–10. DOI: ~~10.1520/D7383-10.~~10.1520/D7383-19.

~~*safety*~~ *safety, health,* *and* ~~*health*~~*environmental practices and determine the applicability of regulatory limitations prior to use.* Section 7 provides a partial list of specific hazards and precautions.

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

~~D1143~~D1143/D1143M Test Methods for Deep Foundations Under Static Axial Compressive Load

~~D3689~~D3689/D3689M Test Methods for Deep Foundations Under Static Axial Tensile Load

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

D5882 Test Method for Low Strain Impact Integrity Testing of Deep Foundations

D6026 Practice for Using Significant Digits in Geotechnical Data

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

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cast-in-place pile, n*—a deep foundation unit made of cement grout or concrete and constructed in its final ~~location, for example,~~location (such as drilled shafts, bored piles, caissons, augercast piles, and pressure-injected ~~footings, etc.~~footings).

3.2.2 *deep foundation, n*—a load supporting system made up of relatively slender structural ~~element~~elements (length greater than width) that transmits some or all of the load it supports to soil or rock well below the ground surface. It may ~~be a driven pile, a cast-in-place pile, or an alternate structural element having a similar function.~~consist of driven piles, cast-in-place piles, or alternate structural elements having similar functions.

3.2.3 *driven pile, n*—a deep foundation ~~unit~~element made of preformed material with a predetermined shape and size and typically installed by impact hammering, vibrating, or pushing.

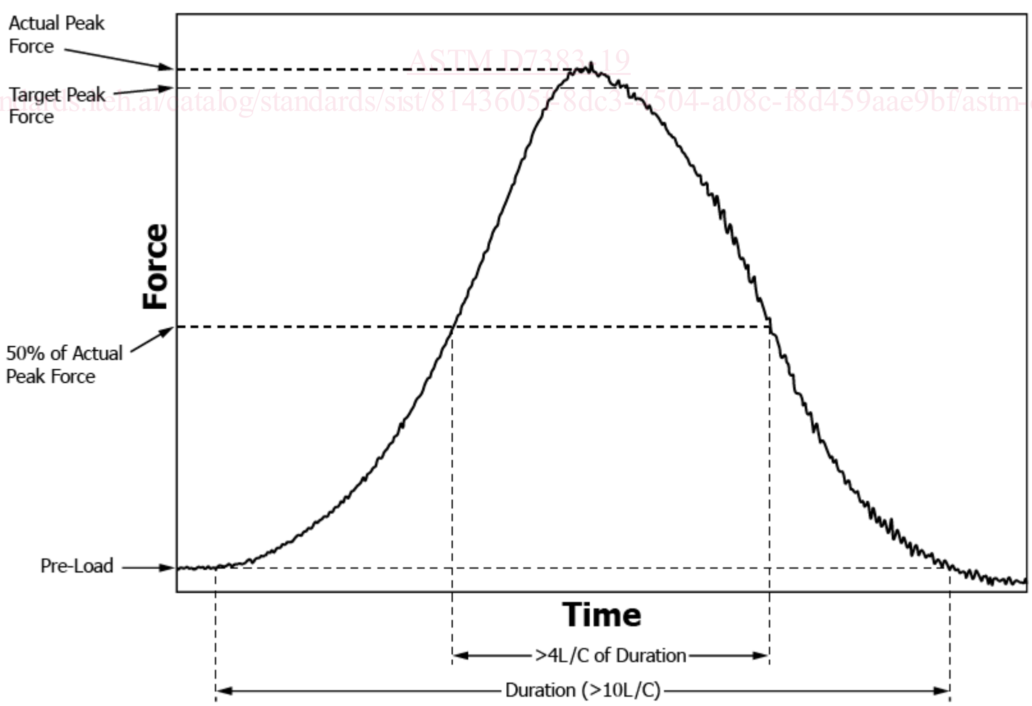

FIG. 1 Typical Axial Compressive Force Pulse

[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.

3.2.4 *force pulse, n*—~~for the purposes of this standard, a "force pulse" shall result~~ a force that increases smoothly and continuously to the peak force and then decreases smoothly and continuously, and results in a force-time event similar to Fig. 1~~, typically reaching a target peak force. The applied force shall exceed the pre-load for a duration time of at least twelve times the test pile length (.L) divided by the strain wave speed (c), or 12L/c. The applied force shall also exceed 50 % of the actual peak force for a minimum duration time of four times L/c. The force pulse shall increase smoothly and continuously to the peak force and then decrease smoothly and continuously. Typical force pulse durations range from 90 to 250 ms.~~

~~NOTE 1—A force pulse duration of less that 12*L/c* may be acceptable to the Engineer when using supplemental transducers as described in 5.4.~~

3.2.5 *pre-load, n*—the load applied to the pile head ~~due to the static weight of the test apparatus~~ prior to the ~~test, possibly negligible depending on the design of the test apparatus.~~test.

3.2.5.1 *Discussion—*

Depending on the design of the test apparatus, this pre-load may be negligible (which is generally the case when Procedure B is used) or not (which is generally the case when Procedure A is used).

3.2.6 *target peak force, n*—a pre-determined ~~target~~ minimum required value for the ~~desired amplitude of the force pulse~~ Actual Peak Force as defined by the project ~~requirements. This value should typically exceed the sum of the required ultimate axial compressive static capacity plus the dynamic resistance of the pile by an amount determined by the Engineer based on factors including, but not limited to, pile type, soil type, structural strength of the pile, type of structural load, physical restrictions, or other project requirements (see Section~~requirements as illustrated ~~4).~~in Fig. 1.

3.2.6.1 *Discussion—*

This value should typically exceed the sum of the required ultimate axial compressive static capacity plus the dynamic resistance of the pile by an amount determined by the Engineer based on factors including, but not limited to, pile type, soil type, structural strength of the pile, type of structural load, physical restrictions, or other project requirements (see Section 4).

3.2.7 *wave speed, c, n*—the speed with which a strain wave propagates through a pile. ~~It is a property of the pile composition and is represented herein by c. For one-dimensional wave propagation, c is equal to the square root of Elastic Modulus divided by mass density: c = (E/ρ) $^{1/2}$. Typical values of c are 4000 m/s for concrete piles and 5100 m/s for steel piles.~~

3.2.7.1 *Discussion—*

For this test, one-dimensional, strain-wave propagation is generally assumed to occur along the axis of an elastic pile, so that the wave speed equals the square root of the ratio of the dynamic elastic modulus, *E*, to the mass density, ρ: or $c = (E/\rho)^{1/2}$. Variations in material down the pile and discontinuities may affect the overall wave speed of the pile.

4. Significance and Use

4.1 Based on the measurements of force and displacement at the pile top, possibly combined with those from ~~acceleration~~accelerometers or strain transducers located further down the pile, these test methods measure the pile top deflection in response to an axial compressive force pulse. The relatively long duration of the force pulse compared to the natural period of the test pile causes the pile to compress and translate approximately as a unit during a portion of the pulse, simultaneously mobilizing compressive axial static ~~capacity~~resistance and dynamic resistance at all points along the length of the pile for that portion of the test. ~~The Engineer may analyze the acquired data using engineering principles and judgment to evaluate the performance of the force pulse apparatus, and the characteristics of the pile's response to the force pulse loading.~~

4.2 The compressive axial static resistance is derived from the test data and is therefore an indirect result. Test Method D1143/D1143M provides a direct and therefore more reliable measurement of static resistance.

4.3 The Engineer should ensure that the test as specified will generate the required peak force to meet the purpose of the test. In case that purpose is to establish geotechnical failure, the Engineer should also ensure that peak force results in significant permanent axial movement during the axial force pulse event.

4.4 The Engineer may analyze the acquired data using engineering principles and judgment to evaluate the performance of the force pulse apparatus, and the characteristics of the pile's response to the force pulse loading. This analysis typically includes a reduction factor to account for the loading rate effect, that is, additional load resistance that occurs as a result of a faster rate of loading than used during a static test. Test results from piles installed in cohesive soils generally require a greater reduction. The Engineer should determine how the type, size, and shape of the pile, and the properties of the soil or rock beneath and adjacent to the pile, affect the rate-of-loading reduction factors and the amount of movement required to mobilize and accurately assess the static resistance by eliminating the dynamic component of the response.

4.5 If significant permanent axial movement occurs during the axial force pulse event, the Engineer may analyze the results of the test to estimate, after assessing inertial effects and the dynamic soil and rock response along the side and bottom of the pile, the ultimate axial static compression capacity (see Note 2). The scope of this standard does not include analysis for either ultimate or design foundation capacity. Factors that may affect the foundation capacity, but in order to analyze the test data appropriately it is important that information on factors that affect the derived axial static capacity estimated from force pulse tests is properly documented. These factors may include, but are not limited to, the: ((1)*1*) pile installation equipment and procedures, ((2)*2*) elapsed time since initial installation, ((3)*3*) pile material properties and dimensions, ((4)*4*) type, density, strength, stratification, and saturation of the soil, or rock, or both adjacent to and beneath the pile, ((5)*5*) quality of force pulse test data, (6) foundation settlement, (7) analysis method, and ((8)*6* engineering judgment and experience. If the Engineer does not have adequate previous experience with these factors, and with the analysis of force pulse test data, then a static load test carried out according to Test Method) final foundation settlement.D1143 should be used to verify estimates of static capacity and its distribution along the pile length. Test Method D1143 provides a direct and more reliable measurement of static capacity.

NOTE 2—If a force pulse test produces insufficient axial movement, subsequent analysis may overestimate the static capacity because of difficulty in separating the static and dynamic components of the response. The analysis of a force pulse test to estimate static capacity also typically includes a reduction factor to account for the additional load resistance that occurs as a result of a faster rate of loading than used during a static test. Force pulse test results from cohesive soils generally require a greater reduction factor due to the rate of loading effect, chosen conservatively to produce a lower static capacity estimate. The Engineer should determine how the type, size, and shape of the pile, and the properties of the soil or rock beneath and adjacent to the pile, affect the rate-of-loading reduction factors and the amount of movement required to mobilize and accurately assess the static capacity. Correlations between actual measurements and force pulse estimates of the ultimate axial static compression capacity generally improve when using additional transducers embedded in the pile. Static capacity may also change over time after the pile installation, especially for driven piles. Both static and force pulse tests represent the capacity at the time of the respective test, and correlation attempts should provide results for a similar time of testing after pile installation or include analysis to account for changes in the soil strength during the time between the two tests.

4.6 When used in conjunction with additional The accuracy of the derived results may improve when using additional strain transducers embedded in the pile, these test methods may also be used to measure the pile response to the axial force pulse along the pile length. pile. When combined with an appropriate method of analysis, the Engineer may use data from these optional transducers to estimate the relative contribution of side shear and end bearing to the mobilized axial static compressive capacityresistance of the pile, or to infer the relative contribution of certain soil layers to the overall mobilized axial compressive capacityresistance of the pile.

NOTE 1—The quality of the result produced by these test methods 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 and inspection. Users of these test methods 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.

NOTE 3—When used in conjunction with additional transducers embedded in the pile the force pulse test analysis may provide an estimate of the pile's tension (uplift) capacity. Users of this standard are cautioned to interpret the estimated side resistance conservatively. If the Engineer does not have adequate previous experience for the specific site and pile type with the analysis of force pulse test data for tension capacity, then a static load test carried out according to Test Method D3689 should be used to verify tension capacity estimates. Test Method D3689 provides a direct and more reliable measurement of static tension capacity.

NOTE 4—The quality of the result produced by these test methods 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 and inspection. Users of these test methods 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. Apparatus

5.1 *General*—The test requires that the equipment applies a force pulse, which shall exceed the pre-load for a duration time of at least ten times the test pile length (*L*) divided by the strain wave speed (*c*), or 10*L/c,* unless supplemental transducers are used in accordance with 5.4.4. The applied force shall also exceed 50 % of the actual peak force for a minimum duration time of four times *L/c*. The force pulse shall increase smoothly and continuously to the Actual Peak Force, which shall exceed the Target Peak Force in accordance with Fig. 1, and then decrease smoothly and continuously. Any apparatus capable of applying such a force pulse to a pile foundation that is in accordance with Section 3shall be considered acceptable. The apparatus selected shall be capable of applying a target peak force in accordance with the project requirements. This section describes two specific types of equipment used to generate an axial compressive force pulse: a combustion gas pressure apparatus as shown in Fig. 2 and a cushioned drop-mass apparatus as shown in Fig. 3.

5.2 *Combustion Gas Pressure Apparatus (for Procedure A):*

5.2.1 Piston and cylinder jack capable of confining the operating pressure, and capable of centering the force pulse application to the pile.

5.2.2 Fuel and ignition mechanism to create gas pressure in the combustion chamber.

5.2.3 Reaction beam, supported by cylinder portion of jack to transfer the combustion force to the inertial or other reaction system.

5.2.4 Reaction mass or other means to resist the combustion forces. A reaction mass system will typically weigh between 5 and 15 % of the target peak force and will be comprised of concrete, steel or contained water.

5.2.5 Accumulator or plenum to receive the combustion gas.

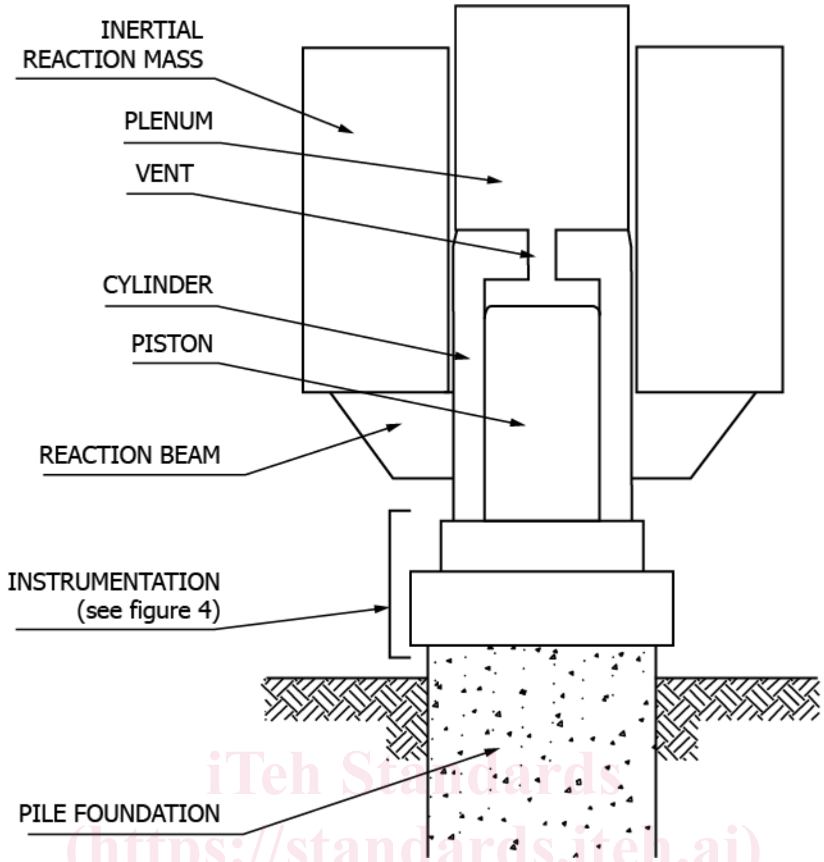

FIG. 2 Schematic of a Combustion Gas Pressure Test Apparatus

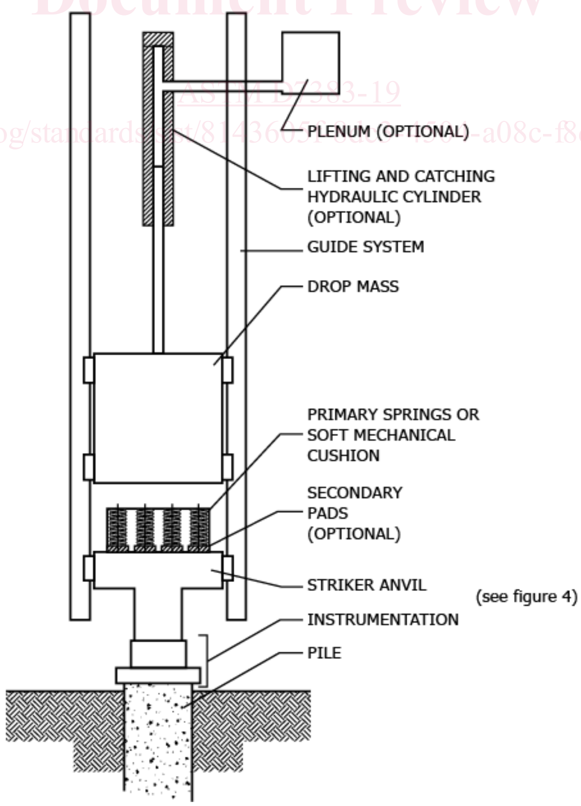

FIG. 3 Schematic of a Cushioned Drop Mass Test Apparatus

5.2.6 Venting apparatus for the release of combustion gas from the plenum.

5.2.7 Silencer apparatus to muffle the noise of the venting combustion gas.

5.2.8 Means or mechanism to protect the pile from damage caused by the fall of the reaction mass system (this will typically consist of a gravel-filled enclosure or a mechanism for arresting the reaction mass such as a hydraulic or mechanical system).

5.2.9 Means or mechanism such as a rupture valve or disk to release the combustion gas in the event of an accidental increase in system pressure or malfunction of the system.

5.3 *Cushioned Drop Mass Apparatus (for Procedure B):*

5.3.1 A drop mass comprised of concrete, steel or another material, typically weighing between 5 and 15 % of the target peak force.

5.3.2 A cylinder jack, crane, or winch, capable of lifting the drop mass to the required height.

5.3.3 Release mechanism for the drop mass.

5.3.4 A guiding system for the fall of the drop mass to properly center the force pulse application to the pile.

5.3.5 Springs or cushion material of sufficient strength and stiffness to transfer a force pulse to the test pile.

5.3.6 Optional secondary springs or cushion material to further cushion the force pulse at the beginning and end of the force pulse application.

5.3.7 Optional clamping or catching mechanism on the drop mass, guide system, or lift cylinder to catch the rebounding drop mass after the application of the force pulse, preventing the application of additional force and improving the verification of the permanent pile head displacement by means of an elevation check as described in 6.4.4. This clamping or catching mechanism is preferred but not required.

5.3.8 Accessibility for the measurement of the drop height.

5.3.9 ~~Accumulator~~ Optional accumulator or plenum to receive the hydraulic fluids used to raise and to catch the drop mass.

5.4 ~~*Force*~~ *Force, Acceleration and Displacement Measurements:*

5.4.1 The apparatus for measuring the force pulse applied to the pile shall consist of a calibrated force transducer mounted directly between the test apparatus and the pile head and in alignment with the central longitudinal axis of the test pile. The force transducer shall have a rated service capacity at least 10 % greater than the target peak force and shall be calibrated to a minimum of the target peak force plus 10 %. The force transducer shall be calibrated to an accuracy of 2 % throughout the applicable measurement range. Calibration of the force transducer shall demonstrate linearity to within 2 %. Hysterisis shall not exceed 2 %. The force transducer shall have a response time of less than 0.1 ms.

5.4.2 The primary apparatus for measuring the vertical acceleration shall consist of at least one calibrated accelerometer attached parallel to the central longitudinal pile axis. The resonant frequency of the accelerometers shall be greater than 5 kHz, and the accelerometers shall be linear to at least the anticipated peak acceleration plus 10 %. The accelerometers shall be calibrated to an accuracy of 3 % throughout the applicable measurement range. Bolt-on, glue-on, or weld-on accelerometers are acceptable. The accelerometers may also be attached to a force-distribution plate or another part of the testing apparatus that is firmly attached to the pile head.

NOTE 2—An accelerometer that is linear to at least 50 g is likely to meet the linearity requirement.

5.4.3 The ~~primary~~ apparatus for measuring the axial displacement at the pile head shall consist of a calibrated displacement transducer(s). The device shall be capable of measuring displacements directly and continuously over a range of not less than the larger of: *(a)* 50 mm plus the theoretical elastic shortening of the pile; or *(b)* $D/20$ plus the theoretical elastic shortening of the pile, where D is the pile diameter. The transducer shall have a precision of at least 0.25 mm and a response time of less than 0.1 ms. The transducer shall be calibrated to an accuracy of 2 % throughout the applicable measurement range. The displacement transducer shall be positioned at and parallel to the central longitudinal axis of the pile. If a single transducer cannot be located at the central axis, then ~~position~~ two or more transducers shall be positioned parallel to and at symmetrical locations with respect to the central longitudinal axis so that the average of their measurements cancels ~~the~~any rotational movement of the pile head. The displacement shall be measured using a stationary reference, such as shown in Fig. 4. ~~Position the displacement reference~~ This stationary reference shall be positioned at a sufficient ~~distance~~ distance, but no less than 15 m from the test pile such that the measurements are not influenced by test-induced ~~disturbances (typically 20 to 30 m),~~ disturbances, considering the expected force pulse duration and wave speed in the surrounding soil and surface material.

NOTE 3—To ensure that the stationary reference is not influenced by test-induced disturbances it may have to be placed at such a distance from the pile that is not practical. In that case displacement of the pile head may be derived by double integrating the signals of accelerometers as described in 5.4.4.

5.4.4 ~~A secondary~~ The accelerometer specified in 5.4.2 can be used as an alternate apparatus for measuring axial pile head displacement ~~is required, and shall consist~~ by performing double integration of the measured acceleration signal in time. This result shall be cross-checked with the direct displacement measurement specified in 5.4.3~~of accelerometers, redundant displacement transducers, or other apparatus as approved by the Engineer. Accelerometers indicate pile head displacement by doubly integrating the acceleration signal. Securely attach~~ . In situations where this cross-check cannot be done (for example, where physical restrictions prevent the use of a stationary reference), accelerometers can be used as the main displacement measurement system, with appropriate redundancy in the measurements, notation in the report, and independent verification of final set. Where