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Standard Test Methods for Deep Foundations Under Lateral Load[1]

This standard is issued under the fixed designation D3966/D3966M; 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.

ε[1] NOTE—Designation was editorially corrected to match units information in June 2013.

1. Scope

1.1 The test methods described in this standard measure the lateral deflection of a vertical or inclined deep foundation when subjected to lateral loading. These methods apply to all deep foundations, referred to herein as "pile(s)," that function in a manner similar to driven piles or cast in place piles, regardless of their method of installation, and may be used for testing single piles or pile groups. The test results may not represent the long-term performance of a deep foundation.

1.2 These test methods provide minimum requirements for testing deep foundations under lateral load. 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 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 these test methods.

1.3 These test methods allow the following test procedures:

Procedure	Test	Section
A	Standard Loading	8.1.2
B	Excess Loading (Optional)	8.1.3
C	Cyclic Loading (Optional)	8.1.4
D	Surge Loading (Optional)	8.1.5
E	Reverse Loading (Optional)	8.1.6
F	Reciprocal Loading (Optional)	8.1.7
G	Specified Lateral Movement (Optional)	8.1.8
H	Combined Loading (Optional)	8.1.9

1.4 Apparatus and procedures herein designated "optional" may produce different test results and may be used only when approved by the engineer. The word "shall" indicates a mandatory provision, and the word "should" indicates a recommended or advisory provision. Imperative sentences indicate mandatory provisions.

1.5 A qualified geotechnical engineer should interpret the test results obtained from the procedures of these test methods so as to predict the actual performance and adequacy of piles used in the constructed foundation. See Appendix X1 for comments regarding some of the factors influencing the interpretation of test results.

1.6 A qualified engineer shall design and approve all loading apparatus, loaded members, support frames, and test procedures. The text of these test methods 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 test methods. These test methods also include illustrations and appendices intended only for explanatory or advisory use.

1.7 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound [lbf] represents a unit of force [weight], while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic [F=ma] calculations are involved.

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

1.10 The method used to specify how data are collected, calculated, or recorded in these test methods 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.

1.11 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

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

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patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

1.12 *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]

A36/A36M Specification for Carbon Structural Steel

A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

A572/A572M Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1143 Test Method for Piles Under Static Axial Compressive Load (Withdrawn 2005)[3]

D3689 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

2.2 *American Society of Mechanical Engineer Standards:*[4]

ASME B30.1 Jacks

ASME B40.100 Pressure Gauges and Gauge Attachments

ASME B46.1 Surface Texture

ASME B89.1.10.M Dial Indicators (For Linear Measurements)

3. Terminology

3.1 *Definitions*—For common definitions of terms used in this standard, see 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, drilled shafts, bored piles, caissons, auger cast piles, pressure-injected footings, etc.

3.2.2 *deep foundation, n*—a relatively slender structural element that transmits some or all of the load it supports to soil or rock well below the ground surface, such as a steel pipe pile or concrete drilled shaft.

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

3.2.4 *failure load, n—for the purpose of terminating a lateral load test*, the test load at which continuing, progressive movement occurs, or as specified by the engineer.

3.2.5 *wireline, n*—a steel wire mounted with a constant tension force between two supports and used as a reference line to read a scale indicating movement of the test pile.

4. Significance and Use

4.1 Field tests provide the most reliable relationship between the lateral load applied to a deep foundation and the resulting lateral movement. Test results may also provide information used to assess the distribution of lateral resistance along the pile shaft and the long-term load-deflection behavior. A foundation designer may evaluate the test results to determine if, after applying an appropriate factor of safety, the pile or pile group has an ultimate lateral capacity and a deflection at service load satisfactory to satisfy specific foundation requirements. When performed as part of a multiple-pile test program, the designer may also use the results to assess the viability of different piling types and the variability of the test site.

4.2 The analysis of lateral test results obtained using proper instrumentation helps the foundation designer characterize the variation of pile-soil interaction properties, such as the coefficient of horizontal subgrade reaction, to estimate bending stresses and lateral deflection over the length of the pile for use in the structural design of the pile.

4.3 If feasible, without exceeding the safe structural load on the pile(s) or pile cap, the maximum load applied should reach a failure load from which the engineer may determine the ultimate lateral load capacity of the pile(s). Tests that achieve a failure load may help the designer improve the efficiency of the foundation by reducing the piling length, quantity, or size.

4.4 If deemed impractical to apply lateral test loads to an inclined pile, the engineer may elect to use lateral test results from a nearby vertical pile to evaluate the lateral capacity of the inclined pile.

NOTE 1—The 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.

5. Test Foundation Preparation

5.1 Excavate or fill the test area to the final grade elevation within a radius of 6 m [20 ft] from the test pile or group using the same material and backfilling methods as for production piles. Cut off or build up the test pile(s) as necessary to permit construction of the load-application apparatus, placement of the necessary testing and instrumentation equipment, and

[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] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

observation of the instrumentation. Remove any damaged or unsound material from the pile top as necessary to properly install the apparatus for measuring movement, for applying load, and for measuring load.

5.2 For tests of single piles, install solid steel test plate(s) at least 50 mm [2 in.] thick against the side of the pile at the point(s) of load application and perpendicular to the line of the load action. The test plate shall have side dimensions not more than, and not less than one half of, the diameter or side dimension of the test pile(s). The test plate(s) shall span across and between any unbraced flanges on the test pile.

5.3 For tests on pile groups, cap the pile group with steel-reinforced concrete or a steel load frame designed and constructed to safely sustain and equally distribute the anticipated loads. The connection between the piles and the cap shall simulate in-service conditions. Pile caps shall be cast above grade unless otherwise specified and may be formed on the ground surface.

5.4 For each loading point on a pile cap, provide a solid steel test plate oriented perpendicular to the axis of the pile group with a minimum thickness of 50 mm [2 in.], as needed to safely apply load to the pile cap. Center a single test plate on the centroid of the pile group. Locate multiple test plates symmetrically about the centroid of the pile group.

5.5 To minimize stress concentrations due to minor irregularities of the pile surface, set test plates bearing on precast or cast-in-place concrete piles in a thin layer of quick-setting, non-shrink grout, less than 6 mm [0.25 in.] thick and having a compressive strength greater than the test pile at the time of the test. Set test plates designed to bear on a concrete pile cap in a thin layer of quick-setting, non-shrink grout, less than 6 mm [0.25 in.] thick and having a compressive strength greater than the pile cap at the time of the test. For tests on steel piles, or a steel load frame, weld the test plates to the pile or load frame. For test piles without a flat side of adequate width to mount the test plate, cap the head of the pile to provide a bearing surface for the test plate or set the test plate in high-strength grout. In all cases, provide full bearing for the test plate against the projected area of the pile.

5.6 *Elimination of Pile Cap Friction (Optional)*—Provide a clear space beneath the pile cap as specified by the engineer. This option isolates the lateral response of the piles from that of the pile cap.

5.7 *Passive Soil Pressure Against Pile Cap (Optional)*—Develop passive soil pressure against the pile cap by constructing the pile cap below the ground surface and backfilling with compacted fill on the side opposite the point of load application, or by constructing the pile cap above the ground surface against an embankment. If specified, place compacted against the sides of the pile cap to the extent practicable.

NOTE 2—Deep foundations sometimes include hidden defects that may go unnoticed prior to static testing. Low strain integrity tests as described in Test Method D5882 and ultrasonic crosshole integrity tests as described in Test Method D6760 may provide a useful pre-test evaluation of the test foundation.

6. Apparatus for Applying and Measuring Loads

6.1 *General:*

6.1.1 The apparatus for applying tensile loads to a test pile or pile group shall conform to one of the methods described in 6.3 – 6.6. Unless otherwise specified, construct the test apparatus so that the resultant loads are applied horizontally, at approximately pile cut-off elevation, and in line with the central vertical axis of the pile or pile group so as to minimize eccentric loading and avoid a vertical load component.

NOTE 3—For lateral tests on inclined pile frames or pile groups involving inclined piles, consider applying the lateral test loads at the actual or theoretical point of intersection of the longitudinal axis of the piles in the frame or group.

6.1.2 *Struts and Blocking*—Struts shall be of steel and of sufficient size and stiffness to transmit the applied test loads without bending or buckling. Blocking used between reaction piles or between the hydraulic jack and the reaction system shall be of sufficient size and strength to prevent crushing or other distortion under the applied test loads.

6.1.3 Reaction piles, if used, shall be of sufficient number and installed so as to safely provide adequate reaction capacity without excessive movement. When using two or more reaction piles at each end of the test beam(s), cap or block them as needed to develop the reaction load. Locate reaction piles so that resultant test beam load supported by them acts at the center of the reaction pile group. Cribbing or deadmen, if used as a reaction, shall be of sufficient plan dimensions and weight to transfer the reaction loads to the soil without excessive lateral movement that would prevent maintaining the applied loads.

6.1.4 Provide a clear distance between the test pile(s) and the reaction piles or cribbing of at least five times the maximum diameter of the largest test or reaction pile(s), but not less than 2.5 m [8 ft]. The engineer may increase or decrease this minimum clear distance based on factors such as the type and depth of reaction, soil conditions, and magnitude of loads so that reaction forces do not significantly effect the test results.

NOTE 4—Excessive vibrations during reaction pile installation in non cohesive soils may affect test results. Reaction piles that penetrate deeper than the test pile may affect test results. Install the anchor piles nearest the test pile first to help reduce installation effects.

6.1.5 Each jack shall include a lubricated hemispherical bearing or similar device to minimize lateral loading of the pile or pile group. The hemispherical bearing(s) should include a locking mechanism for safe handling and setup.

6.1.6 Provide bearing stiffeners as needed between the flanges of test and reaction beams.

6.1.7 Provide steel bearing plates to spread the load to and between the jack(s), load cell(s), hemispherical bearing(s), test beam(s), reaction beam(s), and reaction pile(s). Unless otherwise specified by the engineer, the size of the bearing plates shall be not less than the outer perimeter of the jack(s), load cell(s), or hemispherical bearing(s), nor less than the total width of the test beam(s), reaction beam(s), reaction piles so as to provide full bearing and distribution of the load. Bearing plates supporting the jack(s), test beam(s), or reaction beams on timber or concrete cribbing shall have an area adequate for safe bearing on the cribbing.