Designation: D3689 – 07

Standard Test Methods for Deep Foundations Under Static Axial Tensile Load[1]

This standard is issued under the fixed designation D3689; 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 The test methods described in this standard measure the axial deflection of a vertical or inclined deep foundation when loaded in static axial tension. These methods apply to all deep foundations, referred to herein as "piles," 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 This standard provides minimum requirements for testing deep foundations under static axial tensile load. Plans, specifications, provisions, or any combination 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 this standard.

1.3 This standard allows the following test procedures:

Procedure	Test	Section
A	Quick Test	8.1.2
B	Maintained Test (optional)	8.1.3
C	Loading in Excess of Maintained Test (optional)	8.1.4
D	Constant Time Interval Test (optional)	8.1.5
E	Constant Rate of Uplift Test (optional)	8.1.6
F	Cyclic Loading Test (optional)	8.1.7

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 this standard 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 this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered requirements of the standard. This standard also includes 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 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.

1.11 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 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.*

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

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

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 National Standards:*

ASME B30.1 Jacks[3]

ASME B40.100 Pressure Gages and Gauge Attachments[3]

ASME B89.1.10.M Dial Indicators (For Linear Measurements)[3]

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, e.g. 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 an axial tensile load test*, the test load at which continuing, progressive movement occurs, or at which the total axial movement exceeds 15 % of the pile diameter or width, or as specified by the engineer.

3.2.5 *telltale rod, n*—an unstrained metal rod extended through the test pile from a specific point to be used as a reference from which to measure the change in the length of the loaded pile.

3.2.6 *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 axial load applied to a deep foundation and the resulting axial movement. Test results may also provide information used to assess the distribution of side shear 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 static capacity and a deflection at service load satisfactory to support a specific foundation. 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 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 axial static tensile 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.

4.3 If deemed impractical to apply axial test loads to an inclined pile, the engineer may elect to use axial test results from a nearby vertical pile to evaluate the axial capacity of the inclined 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/sampling/inspection/etc. 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. Test Foundation Preparation

5.1 Excavate or add fill to the ground surface around the test pile or pile group to the final design elevation unless otherwise approved by the engineer.

5.2 Design and construct the test pile(s) so that any location along the depth of the pile will safely sustain the maximum anticipated axial compressive and tensile load to be developed at that location. 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 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.

5.3 For tests on pile groups, cap the pile group with steel-reinforced concrete or a steel load frame designed to safely sustain the anticipated loads.

5.4 Install structural tension connectors extending from the test pile or pile cap, constructed of steel straps, bars, cables, and/or other devices bolted, welded, cast into, or otherwise firmly affixed to the test pile or pile cap to safely apply the maximum required tensile test load without slippage, rupture, or excessive elongation. Carefully inspect these tension members for any damage that may reduce their tensile capacity. Tension members with a cross-sectional area reduced by corrosion or damage, or material properties compromised by

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

fatigue, bending, or excessive heat, may rupture suddenly under load. Do not use brittle materials for tension connections.

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.

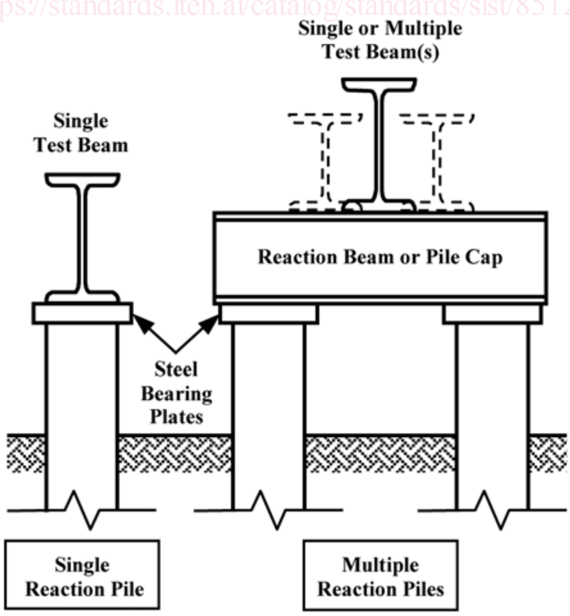
6. Apparatus for Applying and Measuring Loads

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. The method in 6.3 is recommended. The method in 6.5 can develop high tensile loads with relatively low jacking capacity, but does not perform well for tests to failure or for large upward movements.

6.1.2 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 them with reaction beams (Fig. 1). Locate reaction piles so that resultant test beam load supported by them acts at the center of the reaction pile group. Cribbing, if used as a reaction, shall be of sufficient plan dimensions to transfer the reaction loads to the soil without settling at a rate that would prevent maintaining the applied loads.

6.1.3 Cut off or build up reaction piles as necessary to place the reaction or test beam(s). Remove any damaged or unsound material from the top of the reaction piles, and provide a smooth bearing surface parallel to the reaction or test beam(s). To minimize stress concentrations due to minor surface irregularities, set steel bearing plates on the top of precast or cast-in-place concrete reaction 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 reaction pile at the time of the test. For steel reaction piles, weld a bearing plate to each pile, or weld the cap or test beam(s) directly to each pile. For timber reaction piles, set the bearing plate(s) directly on the cleanly cut top of the pile, or in grout as described for concrete piles.



Note: Bearing Plates not Required when Reaction Beam Welded Directly to Steel Reaction Piles, or Reaction Piles Cast into Concrete Pile Cap

FIG. 1 Typical End Views of Test Beam(s) and Reaction Pile(s)

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 3—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.

6.1.8 Unless otherwise specified, where using steel bearing plates, provide a total plate thickness adequate to spread the bearing load between the outer perimeters of loaded surfaces at a maximum angle of 45 degrees to the loaded axis. For center hole jacks and center hole load cells, also provide steel plates adequate to spread the load from their inner diameter to the their central axis at a maximum angle of 45 degrees, or per manufacturer recommendations.

6.1.9 Align the test load apparatus with the longitudinal axis of the test pile or pile group to minimize eccentric loading. Align bearing plate(s), jack(s), load cell(s), and hemispherical bearing(s) on the same longitudinal axis. Place jacks to center the load on the test beam(s). Place test beam(s) to center the load on reaction beams or cribbing, and reaction beams to center the load on reaction piles or cribbing. These plates, beams, and devices shall have flat, parallel bearing surfaces. Set bearing plates on cribbing in the horizontal plane.

6.1.10 When testing inclined piles, align the test apparatus and reaction piles parallel to the inclined longitudinal axis of the test pile(s) and orient the test beam(s) perpendicular to the direction of incline.

6.1.11 A qualified engineer shall design and approve all loading apparatus, loaded members, support frames, and loading procedures. Unless otherwise specified by the engineer, the apparatus for applying and measuring loads, including all structural members, shall have sufficient size, strength, and stiffness to safely prevent excessive deflection and instability up to 120 % of the maximum anticipated test load.

NOTE 4—Rotations and lateral displacements of the test pile or test pile group, reaction piles, cribbing support(s), or pile cap(s) may occur during loading, especially for sites with weak soils. The user should design and construct the support reactions to prevent instability and to limit undesired rotations or lateral displacements.

6.2 *Hydraulic Jacks, Gages, Transducers, and Load Cells:*

6.2.1 The hydraulic jack(s) and their operation shall conform to ASME B30.1 and shall have a nominal load capacity exceeding the maximum anticipated jack load by at least 20 %. The jack, pump, and any hoses, pipes, fittings, gages, or transducers used to pressurize it shall be rated to a safe pressure corresponding to the nominal jack capacity.

6.2.2 The hydraulic jack ram(s) shall have a travel greater than the sum of the anticipated maximum axial movement of the pile plus the deflection of the test beam and the elongation of the tension connection, but not less than 15 % of the average pile diameter or width. Use a single high capacity jack when possible. When using a multiple jack system, provide jacks of the same make, model, and capacity, and supply the jack pressure through a common manifold with a master pressure gage. Fit the manifold and each jack with a pressure gage to detect malfunctions and imbalances.

6.2.3 Unless otherwise specified, the hydraulic jack(s), pressure gage(s), and pressure transducer(s) shall have a calibration to at least the maximum anticipated jack load performed within the six months prior to each test or series of tests. Furnish the calibration report(s) prior to performing a test, which shall include the ambient temperature and calibrations performed for multiple ram strokes up to the maximum stroke of the jack.

6.2.4 Each complete jacking and pressure measurement system, including the hydraulic pump, should be calibrated as a unit when practicable. The hydraulic jack(s) shall be calibrated over the complete range of ram travel for increasing and decreasing applied loads. If two or more jacks are to be used to apply the test load, they shall be of the same make, model, and size, connected to a common manifold and pressure gage, and operated by a single hydraulic pump. The calibrated jacking system(s) shall have accuracy within 5 % of the maximum applied load. When not feasible to calibrate a jacking system as a unit, calibrate the jack, pressure gages, and pressure transducers separately, and each of these components shall have accuracy within 2 % of the applied load.

6.2.5 Pressure gages shall have minimum graduations less than or equal to 1 % of the maximum applied load and shall conform to ASME B40.100 with an accuracy grade 1A having a permissible error ±1 % of the span. Pressure transducers shall have a minimum resolution less than or equal to 1 % of the maximum applied load and shall conform to ASME B40.100 with an accuracy grade 1A having a permissible error ±1 % of the span. When used for control of the test, pressure transducers shall include a real-time display.

6.2.6 If the maximum test load will exceed 900 kN (100 tons), place a properly constructed load cell or equivalent device in series with each hydraulic jack. Unless otherwise specified the load cell(s) shall have a calibration to at least the maximum anticipated jack load performed within the six months prior to each test or series of tests. The calibrated load cell(s) or equivalent device(s) shall have accuracy within 1 % of the applied load, including an eccentric loading of up to 1 % applied at an eccentric distance of 25 mm (1 in.). After calibration, load cells shall not be subjected to impact loads. A load cell is recommended, but not required, for lesser load. If not practicable to use a load cell when required, include embedded strain gages located in close proximity to the jack to confirm the applied load.

6.2.7 Do not leave the hydraulic jack pump unattended at any time during the test. An automatic regulator is recommended to help hold the load constant as pile movement occurs. Automated jacking systems shall include a clearly marked mechanical override to safely reduce hydraulic pressure in an emergency.

6.3 *Tensile Load Applied by Hydraulic Jack(s) Supported on Test Beam(s) (Figs. 2 and 3)* —Support the ends of the test beam(s) on reaction piles or cribbing, using reaction beams as needed to cap multiple reaction piles as shown in Fig. 1. Place the hydraulic jack(s), load cell(s), hemispherical bearing(s), and bearing plates on top of the test beam(s). Center a reaction frame over the jack(s), and anchor it to the tension connections (see 5.4) extending from the test pile or pile group. Design and construct the test beam(s), reaction frame, and reaction piles or cribbing, and arrange the jack(s) symmetrically so as to apply the resultant tensile load at, and parallel to, to the longitudinal axis of the test pile or pile group. Leave adequate clear space beneath the bottom flange(s) of the test beam(s) to allow for the maximum anticipated upward movement of the test pile or pile cap plus the deflection of the test beam(s).

6.4 *Tensile Load Applied by Hydraulic Jacks Acting Upward at Both Ends of Test Beam(s) (Figs. 4 and 5)*—Support each end of the test beam(s) on hydraulic jack(s) centered beneath the beam web(s) and placed equidistant from the longitudinal axis of the test pile or pile group. Support the jacks on reaction piles or cribbing, using reaction beams as needed to cap multiple reaction piles. Center a reaction frame over the test beam(s) and anchor it to the tension connections (see 5.4) extending from the test pile or pile group. Place a single load cell and hemispherical bearing between the reaction frame and the test beam(s) (preferred), or alternatively, place a load cell and hemispherical bearing with each jack beneath the test beam(s). Design and construct the test beam(s), reaction frame, and reaction piles or cribbing, and arrange the jack(s) symmetrically so as to apply the resultant tensile load at, and parallel to, to the longitudinal axis of the test pile or pile group.

6.5 *Tensile Load Applied by Hydraulic Jack(s) Acting Upward at One End of Test Beam(s) (Figs. 5 and 6)*—Support one end of the test beam(s) on hydraulic jack(s) centered beneath the beam web(s). Support the jacks on reaction piles or cribbing, using reaction beams as needed to cap multiple reaction piles. Support the other end of the test beam(s) on a steel fulcrum or similar device placed on a steel plate supported

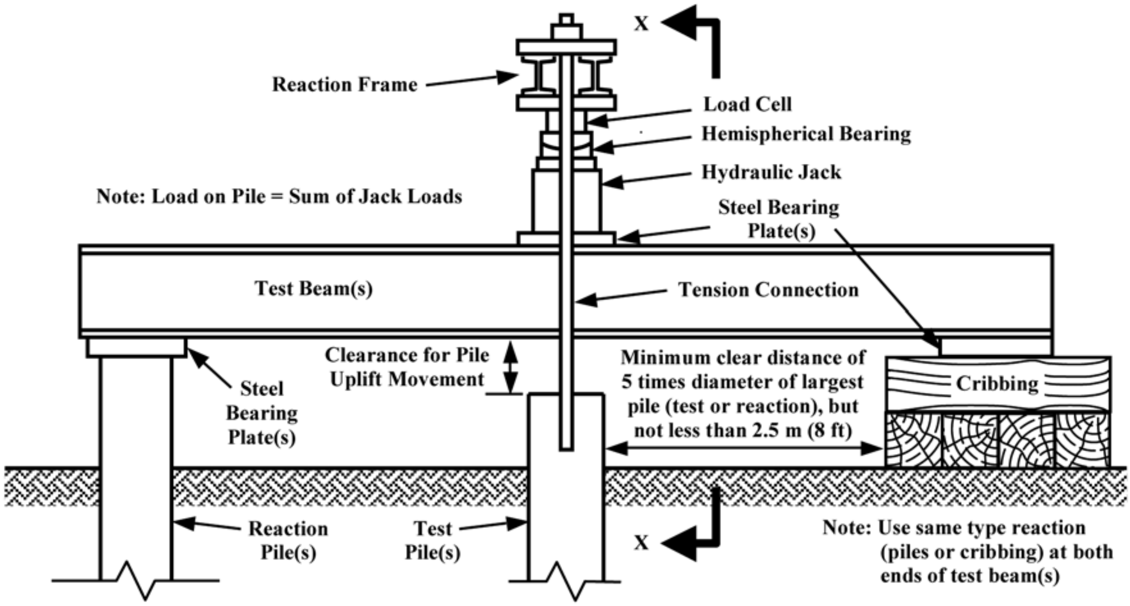


FIG. 2 Typical Setup for Tensile Load Test Using Hydraulic Jack(s) Supported on Test Beams

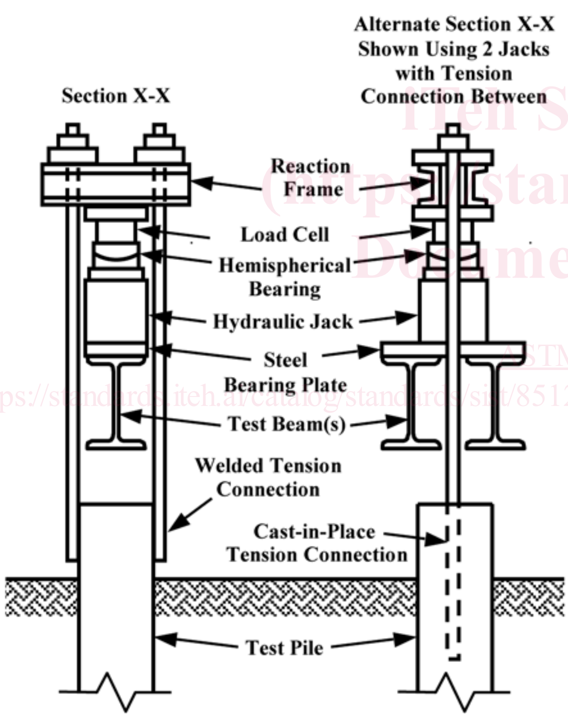


FIG. 3 Typical Section X-X (Fig. 1) of Test Beam(s) at Test Pile

on a reaction pile(s) or cribbing, using reaction beams as needed to cap multiple reaction piles. Center a reaction frame over the test beam(s) and anchor it to the tension connections (see 5.4) extending from the test pile or pile group. Place a single load cell and hemispherical bearing between the reaction frame and the test beam(s) (preferred), or alternatively, place a load cell and hemispherical bearing with each jack beneath the test beam(s). If using the latter arrangement, obtain accurate measurements of the plan locations of the jack(s), test pile or pile group, and the fulcrum to determine the magnification factor to apply to the measured loads to determine the resultant tensile load. Design and construct the test beam(s), reaction frame, and reaction piles or cribbing, and arrange the jack(s) symmetrically so as to apply the resultant tensile load at, and parallel to, to the longitudinal axis of the test pile or pile group.

6.6 *Load Applied to Pile by Hydraulic Jack(s) Acting at Top of an A-Frame or a Tripod* (Fig. 7) *(optional)*—Support an A frame or tripod centered over the test pile or pile group on concrete footings, reaction piles, or cribbing, using reaction beams as needed to cap multiple reaction piles. Using tension members, tie together the bottoms or supports of the A frame or tripod legs so as to prevent them from spreading apart under load. Secure the top of an A frame against lateral movement with not less than four guy cables anchored firmly to the ground. Place the hydraulic jack(s), load cell(s), hemispherical bearing(s), and bearing plates on top of the A frame or tripod. Center a reaction frame over the jack(s), and anchor it to the tension connections (see 5.4) extending from the test pile or pile group. Design and construct the A frame or tripod, reaction frame, and footings, reaction piles or cribbing, and arrange the jack(s) symmetrically so as to apply the resultant tensile load at, and parallel to, to the longitudinal axis of the test pile or pile group. Leave adequate clear space beneath the A frame or tripod members to allow for the maximum anticipated upward movement of the test pile or pile cap plus the deflection of the A frame or tripod.

6.7 *Other Types of Loading Apparatus (optional)*—The engineer may specify another type of loading apparatus satisfying the basic requirements of 6.3-6.6.

7. Apparatus for Measuring Movement

7.1 *General:*

7.1.1 Reference beams and wirelines shall be supported independent of the loading system, with supports firmly embedded in the ground at a clear distance from the test pile of at least five times the diameter of the test pile(s) but not less

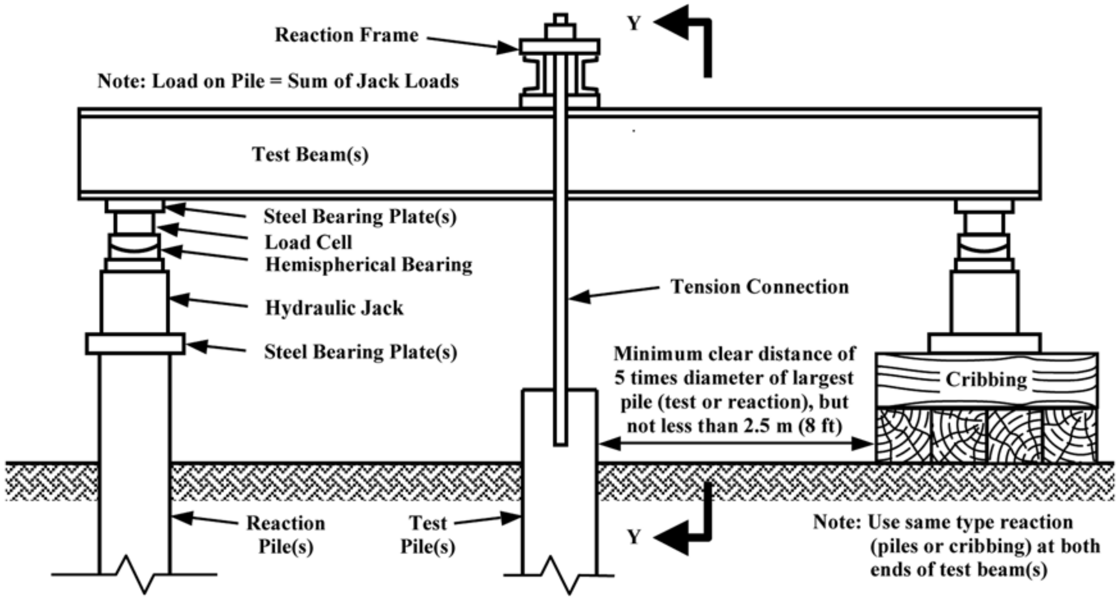


FIG. 4 Typical Setup for Tensile Load Test Using Hydraulic Jacks Acting Upward on Both Ends of Test Beam(s)

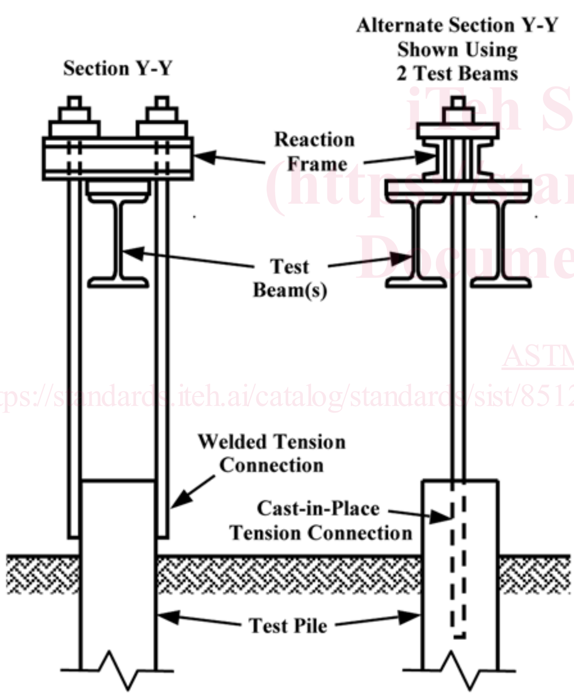


FIG. 5 Typical Section Y-Y (Fig. 4, Fig. 6) of Test Beam(s) at Test Pile

than 2.5 m (8 ft), and at a clear distance from any anchor piles of at least five times the diameter of the anchor pile(s) but not less than 2.5 m (8 ft). Reference supports shall also be located as far as practicable from any cribbing supports but not less than a clear distance of 2.5 m (8 ft).

7.1.2 Reference beams shall have adequate strength, stiffness, and cross bracing to support the test instrumentation and minimize vibrations that may degrade measurement of the pile movement. One end of each beam shall be free to move laterally as the beam length changes with temperature variations. Supports for reference beams and wirelines shall be isolated from moving water and wave action. Provide a tarp or shelter to prevent direct sunlight and precipitation from affecting the measuring and reference systems.

7.1.3 Dial and electronic displacement indicators shall conform to ASME B89.1.10.M and should generally have a travel of 100 mm (4 in.), but shall have a minimum travel of at least 50 mm (2 in.). Provide greater travel, longer stems, or sufficient calibrated blocks to allow for greater movement if anticipated. Electronic indicators shall have a real-time display of the movement available during the test. Provide a smooth bearing surface for the indicator stem perpendicular to the direction of stem travel, such as a small, lubricated, glass plate glued in place. Except as required in 7.4, indicators shall have minimum graduations of 0.25 mm (0.01 in.) or less, with similar accuracy. Scales used to measure pile movements shall have a length no less than 150 mm (6 in.), minimum graduations of 0.5 mm (0.02 in.) or less, with similar accuracy, and shall be read to the nearest 0.1 mm (0.005 in.). Survey rods shall have minimum graduations of 1 mm (0.01 ft) or less, with similar accuracy, and shall be read to the nearest 0.1 mm (0.001 ft).

7.1.4 Dial indicators and electronic displacement indicators shall be in good working condition and shall have a full range calibration within three years prior to each test or series of tests. Furnish calibration reports prior to performing a test, including the ambient air temperature during calibration.

7.1.5 Clearly identify each displacement indicator, scale, and reference point used during the test with a reference number or letter.

7.1.6 Indicators, scales, or reference points attached to the test pile, pile cap, reference beam, or other references shall be firmly affixed to prevent movement relative to the test pile or pile cap during the test. Unless otherwise approved by the engineer, verify that reference beam and wireline supports do not move during the test by using a surveyor's level to take