



Designation: D3689/D3689M – 22

## Standard Test Methods for Deep Foundation Elements Under Static Axial Tensile Load<sup>1</sup>

This standard is issued under the fixed designation D3689/D3689M; 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 ( $\epsilon$ ) 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 an individual vertical or inclined deep foundation element or group of elements when loaded in static axial tension. These methods apply to all types of deep foundations, or deep foundation systems, as they are practical to test. The individual components of which are referred to herein as elements that function as, or in a manner similar to, drilled shafts; cast-in-place piles (augered cast-in-place piles, barrettes, and slurry walls); driven piles, such as pre-cast concrete piles, timber piles or steel sections (steel pipes or wide flange beams); or any number of other element types, regardless of their method of installation. Although the test methods may be used for testing single elements or element groups, the test results may not represent the long-term performance of the entire deep foundation system. A summary of the test methods is contained in Section 4.

1.2 This standard provides minimum requirements for testing deep foundation elements under static axial tensile load. Project plans, specifications, provisions, or any combination thereof may provide additional requirements and procedures as needed to satisfy the objectives of a particular test program. The engineer in charge of the foundation design, referred to herein as the foundation engineer, shall approve any deviations, deletions, or additions to the requirements of this standard. (Exception: the test load applies to the testing apparatus shall not exceed the rated capacity established by the engineer who designed the testing apparatus.)

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

1.4 The foundation engineer should interpret the test results obtained from the procedures of this standard to predict the

actual performance and adequacy of elements used in the constructed foundation.

1.5 An engineer qualified to perform such work shall design and approve all loading apparatus, loaded members, and support frames. The foundation engineer shall design or specify the 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.

1.6 *Units*—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.

1.7 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 slug. The rationalized slug unit is not given, unless dynamic [ $F=ma$ ] calculations are involved.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026. The procedure used to specify how data are collected, recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally 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.

1.9 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.

1.10 *This standard offers an organized collection of information or a series of options and does not recommend a*

<sup>1</sup> 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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specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this standard may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

1.11 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.12 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:<sup>2</sup>

**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 and Data Records 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**

**D8169/D8169M Test Methods for Deep Foundations Under Bi-Directional Static Axial Compressive Load**

### 2.2 ASME Standards:<sup>3</sup>

**ASME B30.1 Jacks**

**ASME B40.100 Pressure Gages and Gauge Attachments**

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

## 3. Terminology

3.1 *Definitions*—For definitions of common technical terms used in this standard, refer to Terminology **D653**.

### 3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cast in-place pile, n*—a deep foundation element made of cement grout or concrete and constructed in its final

location, for example, drilled shafts, bored piles, caissons, augered cast-in-place piles, pressure-injected footings, etc.

3.2.2 *deep foundation element, 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 or concrete-filled drilled shaft.

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

3.2.4 *failure load, n*—the test load at which continuing, progressive movement occurs, or at which the total axial movement exceeds the value specified by the foundation engineer.

3.2.5 *gage or gauge, n*—an instrument used for measuring load, pressure, displacement, strain or such other physical properties associated with load testing as may be required.

3.2.6 *reaction, n*—a device or deep foundation element or elements designed to provide resistance in the opposite direction of the test load.

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

3.2.8 *toe, n*—the bottom of a deep foundation element, sometimes referred to as tip or base.

3.2.9 *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 element.

## 4. Summary of Test Method

4.1 This standard provides minimum requirements for testing deep foundation elements under static axial tensile load. The test is a specific type of test, most commonly referred to as deep foundation load testing or static load testing. This standard is confined to test methods for loading a deep foundation element or elements from the top, in the upward direction. The loading requires devices or structural elements be constructed that resist downward movement, often referred to collectively as a reaction system. The principal measurements taken in addition to load are displacements.

4.2 This standard allows the following test procedures:

Method A	Quick Test	<b>10.1.2</b>
Method B	Maintained Test	<b>10.1.3</b>
Method C	Constant Rate of Uplift Test	<b>10.1.4</b>

## 5. Significance and Use

5.1 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 element and the long-term load-deflection behavior. The foundation engineer may evaluate the test results to determine if, after applying appropriate factors of safety, the element or group of elements has a static capacity, load response and deflection at service load satisfactory to support the foundation. When performed as part of a multiple-element test program, the foundation engineer may also use the results

<sup>2</sup>For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup>Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.



to assess the viability of different sizes and types of foundation elements and the variability of the test site.

5.2 If feasible and without exceeding the safe structural load on the element or element cap (hereinafter unless otherwise indicated, “element” and “element group” are interchangeable as appropriate), the maximum load applied should reach a failure load from which the foundation engineer may determine the axial static tensile load capacity of the element. Tests that achieve a failure load may help the foundation engineer improve the efficiency of the foundation design by reducing the foundation element length, quantity, and/or size.

5.3 If deemed impractical to apply axial test loads to an inclined element, the foundation engineer may elect to use axial test results from a nearby vertical element to evaluate the axial capacity of the inclined element. The foundation engineer may also elect to use a bi-directional axial test on an inclined element (D8169/D8169M).

5.4 Different loading test procedures may result in different load-displacement curves. The Quick Test (10.1.2) and Constant Rate of Uplift Test (10.1.4) typically can be completed in a few hours. Both are simple in concept, loading the element relatively quickly as load is increased. The Maintained Test (10.1.3) loads the element in larger increments and for longer intervals, which could cause the test duration to be significantly longer. Because of the larger load increments the determination of the failure load can be less precise, but the Maintained Test is thought to give more information on creep displacement. Although control of the Constant Rate of Uplift Test is somewhat more complicated (and uncommon for large diameter or capacity elements), the test may produce the best possible definition of capacity. The foundation engineer must weigh the complexity of the procedure and other limitations against any perceived benefit.

5.5 The scope of this standard does not include analysis for foundation capacity in tension, but in order to analyze the test data appropriately it is important that information on factors that affect the derived mobilized static axial tensile capacity are properly documented. These factors may include, but are not limited to, the following:

5.5.1 Potential residual loads in the element which could influence the interpreted distribution of load along the element shaft.

5.5.2 Possible interaction of friction loads from test element with downward friction transferred to the soil from reaction elements obtaining part or all of their support in soil at levels above the tip level of the test element.

5.5.3 Changes in pore water pressure in the soil caused by element driving, construction fill, and other construction operations which may influence the test results for frictional support in relatively impervious soils such as clay and silt.

5.5.4 Differences between conditions at time of testing and after final construction such as changes in grade or groundwater level.

5.5.5 Potential loss of soil supporting the test element from such activities as excavation and scour.

5.5.6 Possible differences in the performance of an element in a group or of an element group from that of a single isolated element.

5.5.7 Effect on long-term element performance of factors such as creep, environmental effects on element material, negative friction loads not previously accounted for, and strength losses.

5.5.8 Type of structure to be supported, including sensitivity of structure to settlements and relation between live and dead loads.

5.5.9 Special testing procedures which may be required for the application of certain acceptance criteria or methods of interpretation.

5.5.10 Requirement that non-tested element(s) have essentially identical conditions to those for tested element(s) including, but not limited to, subsurface conditions, element type, length, size and stiffness, and element installation methods and equipment, so that application or extrapolation of the test results to such other elements is valid. For concrete elements, it is sometimes necessary to use higher amounts of reinforcement in the test elements in order to safely conduct the test to the predetermined required test load. In such cases, the foundation engineer shall account for the difference in stiffness between the test elements and non-tested elements.

5.5.11 Tension tests are sometimes used to validate element compression capacity in addition to tension capacity. When subjected to tension loads, elements may have different stiffness and structural capacity compared to elements subjected to compression loads.

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.

## 6. Test Foundation Preparation

6.1 Excavate or add fill to the ground surface around the test element to the final design elevation unless otherwise approved by the foundation engineer. Type of fill and compaction requirements shall be as specified by the foundation engineer.

6.2 Design and construct the test element so that any location along the depth of the element will safely sustain the maximum anticipated loads to be developed at that location. Cut off or build up the test element 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 element top as necessary to properly install the apparatus for measuring movement, for applying load, and for measuring load.

6.3 For tests on element groups, cap the element group with steel-reinforced concrete or a steel load frame designed for the anticipated loads by the structural engineer.

6.4 Install structural tension connectors extending from the test element or element cap, constructed of steel straps, bars, cables, and/or other devices bolted, welded, cast into, or

otherwise firmly affixed to the test element or element cap to safely apply the maximum required 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 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, ultrasonic crosshole integrity tests as described in Test Method D6760, and thermal integrity profiling as described in Test Methods D7949 may provide a useful pre-test evaluation of the test foundation. While the former two methods can be done at any time, including after the load test, thermal integrity profiling must be done relatively soon after the concrete element is cast.

NOTE 3—When testing a cast-in-place concrete element such as a drilled shaft, the size, shape, material composition and properties of the element can influence the element capacity and the interpretation of strain measurements described in Section 8.

## 7. Safety Requirements

7.1 All operations in connection with element load testing shall be carried out in such a manner to minimize, avoid, or eliminate the exposure of people to hazard. The following safety rules are in addition to general safety requirements applicable to construction operations:

7.1.1 Keep all test and adjacent work areas, walkways, platforms, etc. clear of scrap, debris, small tools, and accumulations of snow, ice, mud, grease, oil, or other slippery substances.

7.1.2 Provide timbers, blocking and cribbing materials made of quality material and in good serviceable condition with flat surfaces and without rounded edges.

7.1.3 Hydraulic jacks shall be equipped with hemispherical bearings or shall be in complete and firm contact with the bearing surfaces and shall be aligned with axis of loading to avoid eccentric loading.

7.1.4 Loads shall not be hoisted, swung, or suspended over any person and shall be controlled by tag lines.

7.1.5 For tests on inclined elements, all inclined jacks, bearing plates, test beam(s), or frame members shall be firmly fixed into place or adequately blocked to prevent slippage upon release of load.

7.1.6 All test beams, reaction frames, platforms, and boxes shall be adequately supported at all times.

7.1.7 Only authorized personnel shall be permitted within the immediate test area, and only as necessary to monitor test equipment. The overall load test plan should include all provisions and systems necessary to minimize or eliminate the need for personnel within the immediate test area. All reasonable effort shall be made to locate pumps, load cell readouts, data loggers, and test monitoring equipment at a safe distance away from jacks, loaded beams, weighted boxes, dead weights, and their supports and connections.

7.1.8 The requirements in this section have been developed to assist in the preparations for the testing process, but should not be considered completely comprehensive of all safety issues. Safety matters should be carefully considered with the list above being a starting point for any safety planning.

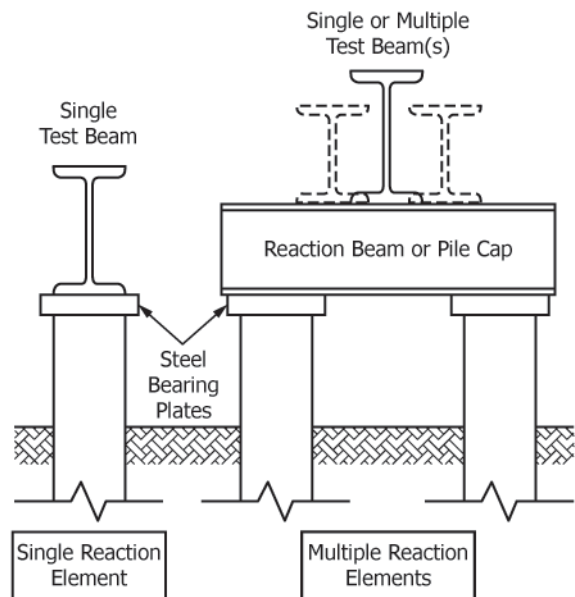
## 8. Apparatus for Applying and Measuring Loads

### 8.1 General:

8.1.1 The apparatus for applying tensile loads to a test element shall conform to one of the methods described in 8.3 – 8.6. The apparatus for applying and measuring loads described in this section shall be designed in accordance with recognized standards by a qualified engineer who shall clearly define the maximum allowable load that can be safely applied. The method in 8.3 is recommended. The method in 8.5 can develop high tensile loads with relatively low jacking capacity, but does not perform well for tests to failure or for large upward movements. All described methods require careful setup to ensure a safe test environment.

8.1.2 Reaction elements, if used, shall be of sufficient number and installed to safely provide adequate reaction capacity without excessive movement. When using two or more reaction elements at each end of the test beam(s), cap them with reaction beams (Fig. 1). Locate reaction elements so that resultant test beam load supported by them acts at the center of the reaction element 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.

8.1.3 Cut off or build up reaction elements as necessary to place the reaction or test beam(s). Remove any damaged or unsound material from the top of the reaction elements, 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 elements 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 element at the time of the test. For steel reaction



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

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

elements, weld a bearing plate to each element, or weld the cap or test beam(s) directly to each element. For timber reaction elements, set the bearing plate(s) directly on the cleanly cut top of the element, or in grout as described for concrete elements.

8.1.4 Provide a clear distance between the test element(s) and the reaction elements or cribbing of at least five times the maximum diameter of the largest test or reaction element(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 affect the test results.

NOTE 4—Excessive vibrations during reaction element installation in non-cohesive soils may affect test results. Reaction elements that penetrate deeper than the test element may affect test results. Reaction elements nearest to the test element should be installed first to help reduce installation effects. A clear distance of five (5) times the maximum element diameter may be impractical for larger elements.

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

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

8.1.7 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 element(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 elements 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.

8.1.8 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 central axis at a maximum angle of 45 degrees, or per manufacturer recommendations.

8.1.9 Align the test load apparatus with the longitudinal axis of the test element 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.

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

8.1.11 Qualified engineers shall design and approve all aspects of the loading apparatus, including loaded members, support frames, tension connections (material, diameter, weld

or embedment length, etc.), reaction elements, instruments and loading procedures. The apparatus for applying and measuring loads (except for hydraulic jacks and load cells), including all structural members, shall have sufficient size, strength, and stiffness to safely prevent excessive deflection and instability up to the maximum anticipated test load.

NOTE 5—Rotations and lateral displacements of the test element, reaction elements, cribbing support(s), or element cap may occur during loading, especially for elements extending above the soil surface or through weak soils. Support reactions, loading apparatus and equipment should be designed and constructed to resist any undesirable or possibly dangerous rotations or lateral displacements. These displacements should be monitored during the test so the test can be immediately halted if undesirable rotations or lateral displacements occur.

## 8.2 Hydraulic Jacks, Gages, Transducers, and Load Cells:

8.2.1 The hydraulic jack(s) and their operation shall conform to ASME B30.1. Jack(s) and load cell(s) shall have a nominal load capacity exceeding the maximum anticipated test 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.

8.2.2 The hydraulic jack(s) shall have a ram (piston, rod) travel greater than the sum of the anticipated maximum axial movement of the element plus the deflection of the reaction system and the elongation of the tension connection, but not less than 15 % of the average element diameter or width (or any other specified and approved displacement requirement). 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, and operated by a single hydraulic pump. Fit the manifold and each jack with a pressure gage to detect malfunctions and imbalances.

8.2.3 Unless otherwise specified, the hydraulic jack(s), pressure gage(s), and pressure transducer(s) shall each be calibrated 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. Each report shall include the ambient temperature and individual calibrations shall be performed for multiple discrete ram strokes up to the maximum stroke of the jack.

8.2.4 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. 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.

8.2.5 Pressure gages and pressure transducers shall have minimum resolutions 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  $\pm 1$  % of the span. When used for control of the test, pressure transducers shall include a real-time display.

8.2.6 Place a properly positioned load cell or equivalent device in series with each hydraulic jack. Unless otherwise

specified the load cell 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 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.

8.2.7 Do not leave the hydraulic jack pump unattended at any time during the test. Automated jacking systems shall include a clearly marked mechanical override to safely reduce hydraulic pressure in an emergency.

8.3 *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 elements or cribbing, using reaction beams as needed to cap multiple reaction elements 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 6.4) extending from the test element. Design and construct the test beam(s), reaction frame, and reaction elements or cribbing, and arrange the jack(s) symmetrically to apply the resultant tensile load at, and parallel to, to the longitudinal axis of the test element. 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 element plus the deflection of the test beam(s).

8.4 *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 element. Support the jacks on reaction elements or cribbing, using reaction beams as needed to cap multiple reaction elements. Center a reaction frame over the test beam(s) and anchor it to the tension connections (see 6.4) extending from the test element. Place a single load cell and hemispherical bearing between the reaction frame and the test

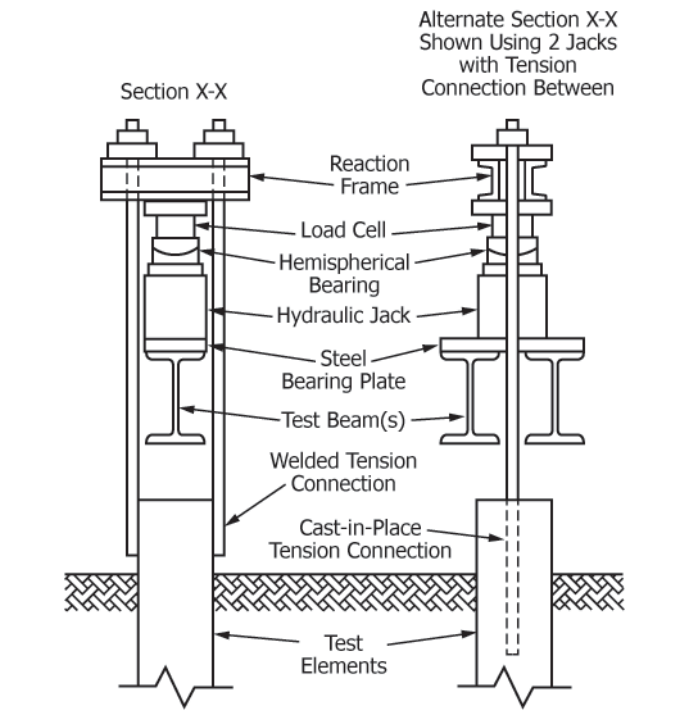


FIG. 3 Typical Section X-X (Fig. 2) of Test Beam(s) at Test Element(s)

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 elements or cribbing, and arrange the jack(s) symmetrically to apply the resultant tensile load at, and parallel to, the longitudinal axis of the test element.

8.5 *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

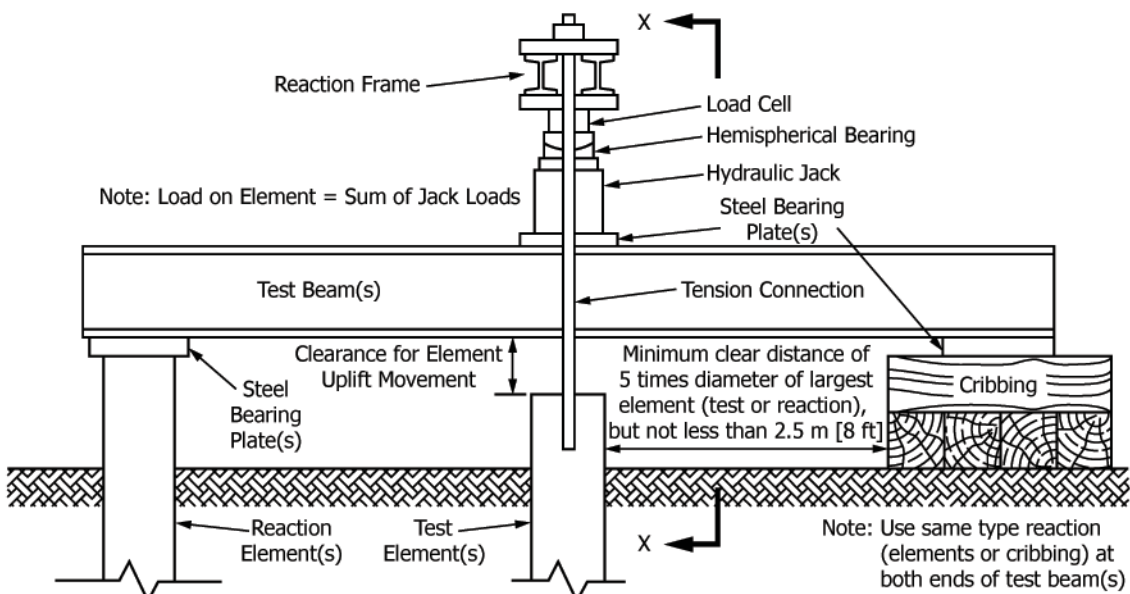


FIG. 2 Typical Setup for Load Test Using Hydraulic Jack(s) Supported on Test Beam(s)

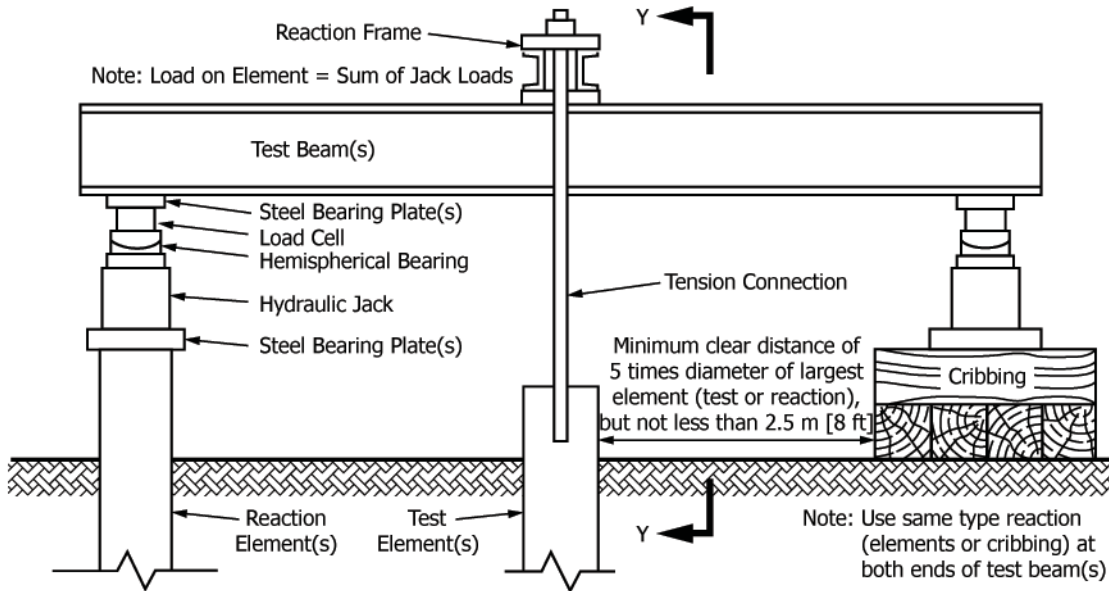


FIG. 4 Typical Setup for Load Test Using Hydraulic Jacks Acting Upward on Both Ends of Test Beam(s)

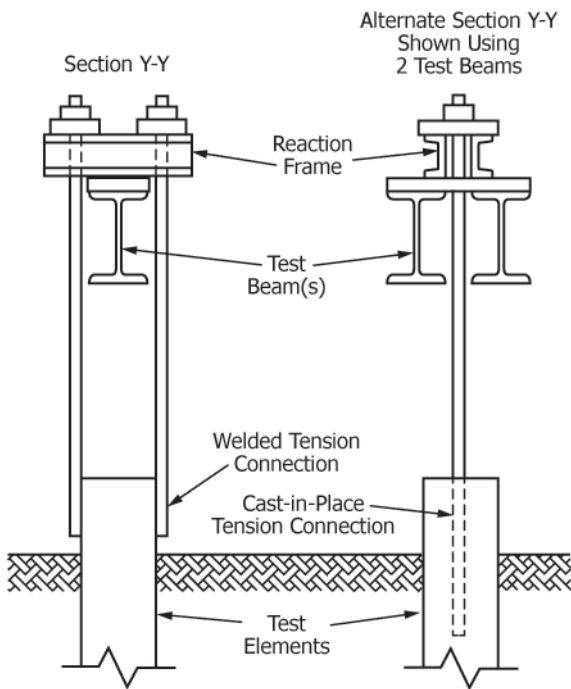


FIG. 5 Typical Section Y-Y (Fig. 4, Fig. 6) of Test Beam(s) at Test Element(s)

If using the latter arrangement, obtain accurate measurements of the plan locations of the jack(s), test element, 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 elements or cribbing, and arrange the jack(s) symmetrically to apply the resultant tensile load at, and parallel to, the longitudinal axis of the test element.

8.6 *Load Applied 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 element on concrete footings, reaction elements, or cribbing, using reaction beams as needed to cap multiple reaction elements. Using tension members, tie together the bottoms or supports of the A frame or tripod legs 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 6.4) extending from the test element. Design and construct the A frame or tripod, reaction frame, and footings, reaction elements or cribbing, and arrange the jack(s) symmetrically to apply the resultant tensile load at, and parallel to, the longitudinal axis of the test element. Leave adequate clear space beneath the A frame or tripod members to allow for the maximum anticipated upward movement of the test element or element cap plus the deflection of the A frame or tripod.

8.7 *Other Types of Loading Apparatus (optional)*—The engineer may specify another type of loading apparatus satisfying the basic requirements of 8.3 – 8.6.

web(s). Support the jacks on reaction piles or cribbing, using reaction beams as needed to cap multiple reaction elements. Support the other end of the test beam(s) on a steel fulcrum or similar device placed on a steel plate supported on a reaction element(s) or cribbing, using reaction beams as needed to cap multiple reaction elements. Center a reaction frame over the test beam(s) and anchor it to the tension connections (see 6.4) extending from the test element. 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).

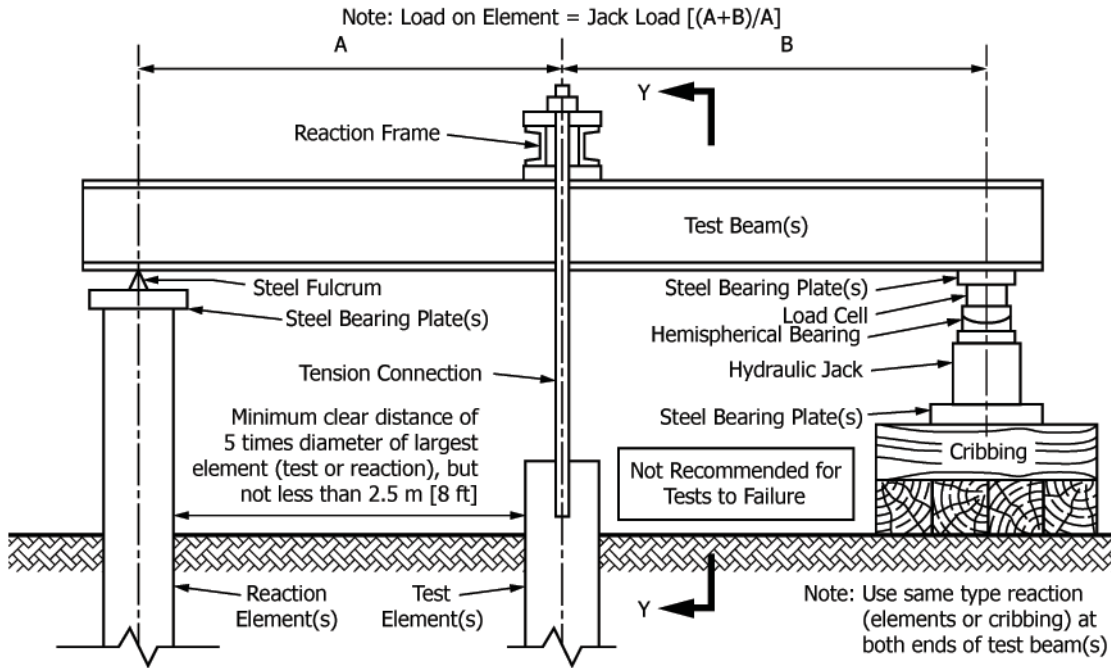


FIG. 6 Typical Setup for Load Test Using Hydraulic Jack(s) Acting Upward on One End of Test Beam(s)

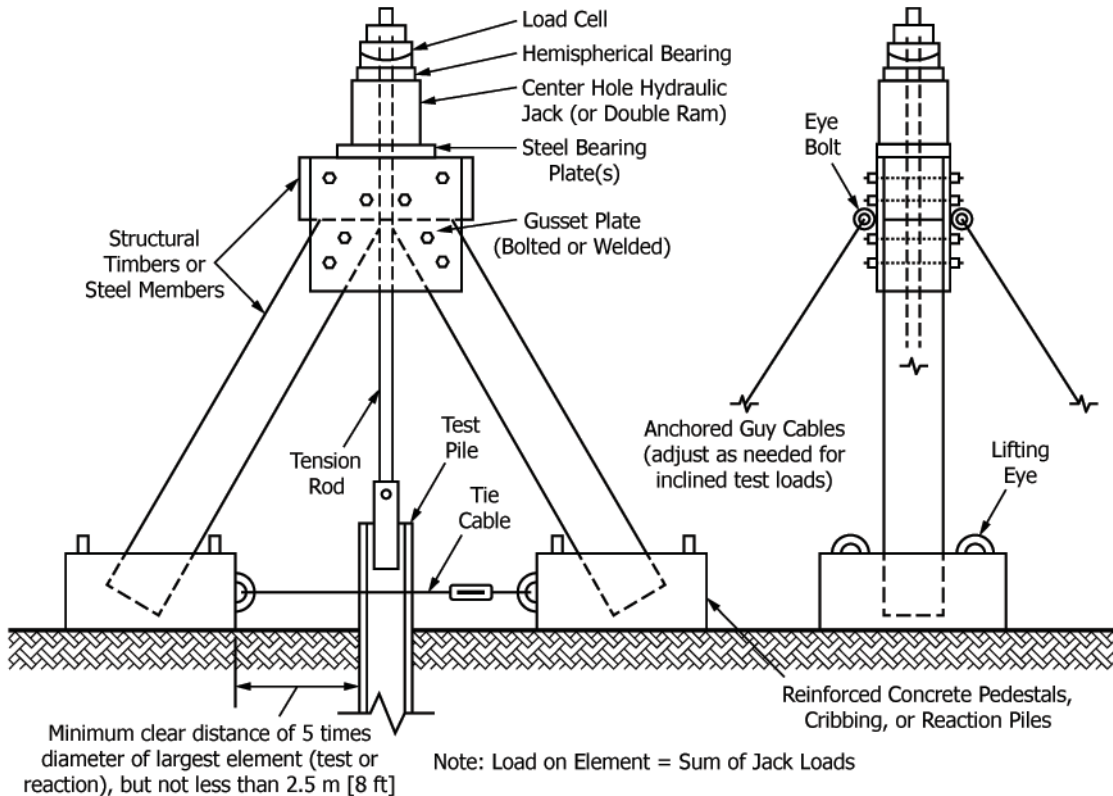


FIG. 7 Typical Setup for Tensile Load Test Using Hydraulic Jack(s) Acting at Top of an A-frame

## 9. Apparatus for Measuring Movement and Strain

### 9.1 General:

9.1.1 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 element of at least five times the diameter of the test element, and at least five times the diameter of the reaction element(s), but not less than 2.5 m [8 ft] clear distance from any test or



reaction element. Reference supports shall also be located as far as practicable from any cribbing supports not less than a clear distance of 2.5 m [8 ft].

NOTE 6—The clear distance between the test element and reference supports may be decreased to no less than three test element diameters under certain circumstances, if the foundation engineer considers the possible negative effects.

9.1.2 Reference beams may be monolithic, such as a wide flange section, or composed of many materials, such as wood in the form of a wood truss. However, any reference beam shall be designed to minimize vertical movement of its center during the test due to heat or moisture (humidity changes or periodic rain). Reference beams shall have adequate strength, stiffness, and cross bracing to support the test instrumentation and minimize vibrations and movement that may degrade measurement of the test element 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 systems and reference systems. In order to verify beam stability, monitor the gages affixed to the beam for an appropriate period of time prior to loading. To avoid delay, begin this monitoring as soon as practical prior to setting up other testing components. Make adjustments as needed.

9.1.3 Dial and electronic displacement indicators shall conform to ASME B89.1.10.M. Indicators used to measure top of element displacement should generally have a travel of 150 mm [6 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. All of the electronic indicators shall have a real-time display of the movement available during the test, whether directly on each indicator or collectively through a data logger, multiplexor output or computer. 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. Indicators used to measure top of element displacement shall have minimum graduations of 0.25 mm [0.01 in.] or less, with similar accuracy. 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].

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

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

9.1.6 Indicators, scales, or reference points attached to the test element, element cap, reference beam, or other references shall be firmly affixed to prevent movement relative to the test element or element cap during the test. Unless otherwise approved by the foundation engineer, verify that reference beam and wireline supports do not move during the test by using a surveyor’s level to take readings on a survey rod or a

scale with reference to a permanent benchmark located outside of the immediate test area, for example, in excess of ten times the largest cross-sectional dimension of the test element, as practical.

9.2 Top of Element Axial Movements (Fig. 8):

9.2.1 Unless otherwise specified, all axial tensile load tests shall include apparatus for measuring the axial movement of the test element top, or elements within a group, or the element group cap. This apparatus as described herein shall include a primary measurement system and at least one redundant, secondary system, using at least two of the systems described herein. If loading elements within a test group, either with a minimal cap or no cap, it may be necessary to measure some or all individual element tops.

NOTE 7—When possible use displacement indicators as the primary system to obtain the most precise measurements. Use the redundant system(s) to check top movement data and provide continuity when the measuring system is disturbed or reset for additional movement.

NOTE 8—Element top movements measured directly on the test element have superior accuracy to measurements on the test plate, but with negligible difference when using a thin layer of grout on a sound test element, or with a test plate welded to the element. However, users may

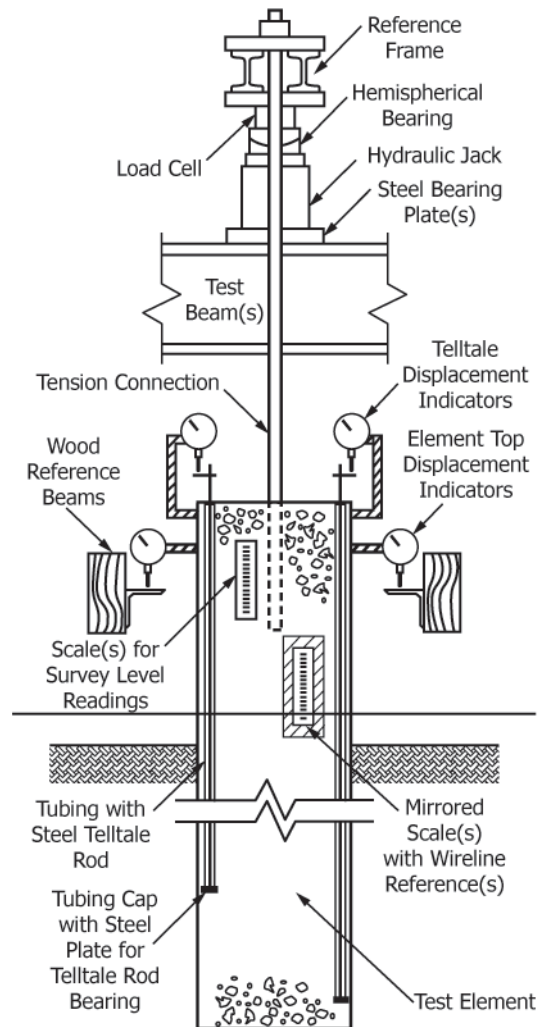


FIG. 8 Schematic of Suggested Instrumentation for Measuring Axial Displacements of Deep Foundation Element

wish to verify that the test plate and element top do not move relative to each other using additional indicators (Fig. 7).

**9.2.2 Displacement Indicators**—Mount a minimum of two displacement indicators on each reference beam to bear on the element top at axisymmetric points equidistant from the center of the test element, or element cap, with stems parallel to the longitudinal axis of the element, inclined element, or element group. Orient two parallel reference beams, one on each side of the test element or element cap, in a direction that permits placing their supports as far as feasible from reaction elements or cribbing. Alternatively, mount the two indicators on axisymmetric points equidistant from the center of the test element, or element cap, with the stems parallel to the longitudinal axis of the element or element group to bear on the reference beams. For elements without good lateral support near the top, and when deemed necessary, use additional displacement indicators to compensate for lateral movement or rotation of the element top. These indicators may also be vertical or may be orthogonal (one in each axis) to the direction of loading to compensate for lateral movement or rotation of the element top.

NOTE 9—For tests on inclined elements, monitor lateral element movements as described in 9.3 to detect instability that may result from gravitational forces during the test.

NOTE 10—For test elements having a width or diameter greater than 2.5 m [8 ft], and when deemed necessary, four displacement indicators should be used to compensate for non-vertical movement of the element top. Indicators should be located around the pile perimeter at axisymmetrical points spaced equidistant from the centroid of the test pile.

**9.2.3 Wireline, Mirror, and Scale**—Orient two wirelines parallel to each other and perpendicular to and located on opposite sides equidistant from the axis of the test element, in a direction that permits placing the wireline supports as far as practicable from reaction elements or cribbing. The wirelines shall include a weight or spring to maintain a constant tension force in the wire, so that, when plucked or tapped, the wireline will return to its original position. Use clean, uncoated steel wire with a diameter of 0.25 mm [0.01 in.] or less for the wirelines. Each wireline shall pass across, and remain clear of, a scale mounted on the test element or element cap parallel to the axis of the element. Mount the scale on a mirror affixed to the test element or element cap and use the wireline as a reference line to read the scale. Use the mirror to eliminate parallax error in the scale reading by lining up the wire and its image in the mirror. Align the wire not more than 13 mm [0.5 in.] from the face of the scale.

**9.2.4 Surveyor's Level or Laser Beam**—Movement readings obtained using a surveyor's level or laser beam shall be taken using a survey rod or a scale and shall be referenced to a permanent benchmark located outside of the immediate test area (at least ten times the largest cross-sectional dimension of the test element). The surveyor's level shall be mounted on a tripod designed for that purpose or an object of fixed elevation (for example, a driven steel section) at a distance of at least five times the largest cross-sectional dimension of the test element or any reaction element from the test. Reference points or scales used in taking displacement readings shall be mounted on the sides of the test element or element cap and located on opposite sides except that reference points may be located on

top of the element cap or readings may be taken on a single fixed point in the center of the test element top, test plate or element cap.

**9.2.5 Other Types of Measurement Systems (optional)**—The foundation engineer may specify another type of measurement system satisfying the basic requirements of 9.2.

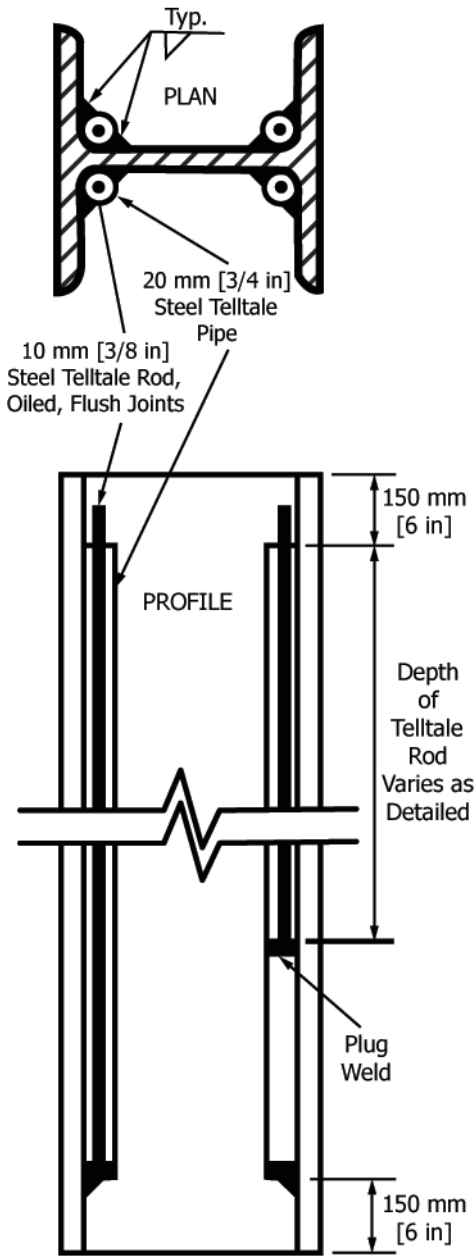
**9.3 Lateral Movements (optional)**—Measure the lateral movements of the top of the test element to within an accuracy of 2.5 mm [0.1 in.] using either of the following methods: (a) two displacement indicators oriented in orthogonal directions, mounted with their stems perpendicular to the longitudinal axis of the test element(s) and bearing against lubricated glass plates affixed to the sides of the test element or element cap, or (b) a surveyor's transit reading from scales mounted laterally on two perpendicular sides of the test element or element cap with readings referenced to fixed foresights or backsights. For tests on inclined elements, orient the indicators or scales parallel and perpendicular to the vertical plane of the incline and perpendicular to the longitudinal axis of the test element(s).

**9.4 Element Extension and Strain Measurements (Optional):**

**9.4.1** Measure the extension or strain of the test element(s) during loading at locations specified by the foundation engineer to help evaluate the distribution of load transfer from the element to the surrounding soil.

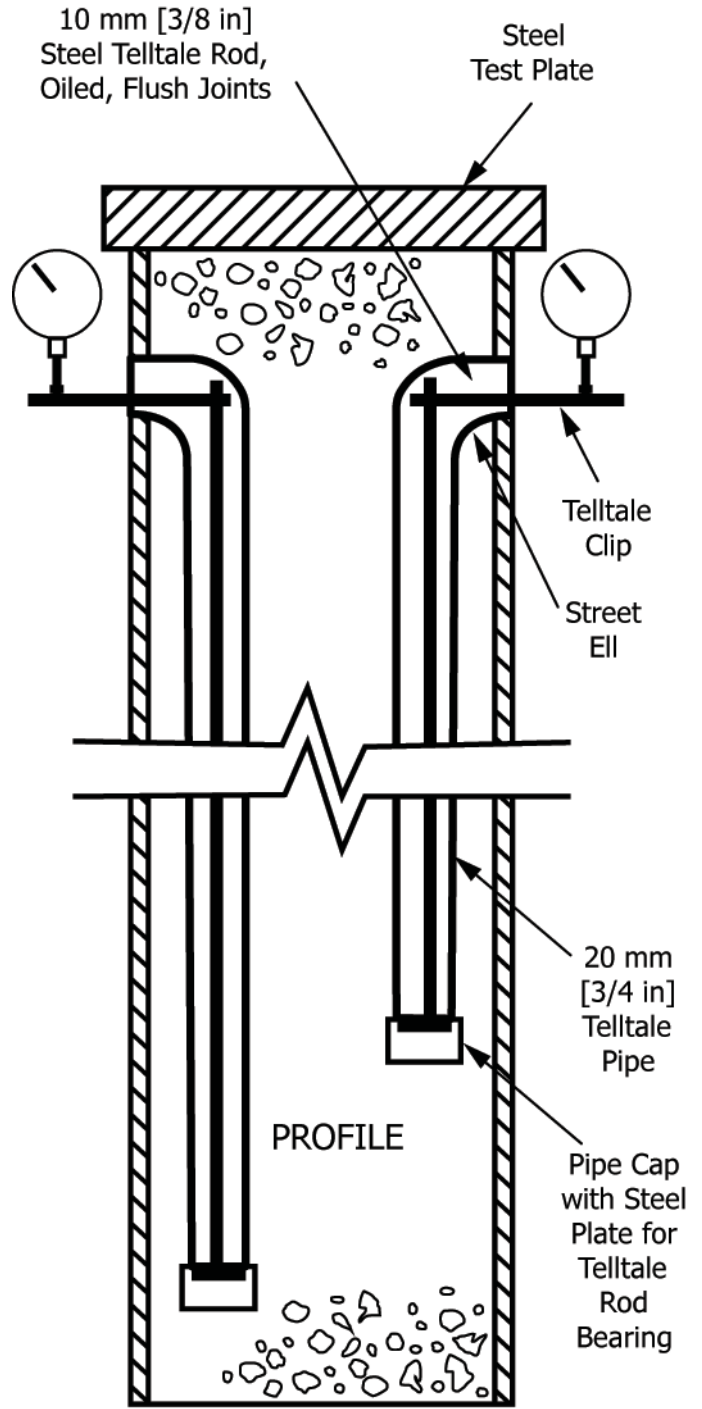
**9.4.2** Determine element extension using displacement indicators to measure the relative movement between the element top and an unstrained telltale rod (Figs. 8-11) bearing at a point within the element, typically at the toe. Unless located on the element central axis, install paired telltales in the element with the rods in each pair oriented symmetrically opposite each other and equidistant from, and parallel to, the element axis. Terminate telltale pairs near the element bottom and at other points along the element as required. Measure and record the distance from the element top to the telltale termination point(s) to the nearest 10 mm [0.5 in.]. Install the telltales in a sheath or casing (typically small diameter steel pipe) to insure free rod movement during the test. The rods shall have a rounded or pointed tip that bears on a clean steel plate at the termination point(s) or shall be mechanically affixed to the termination point(s) within the element. Clean the telltale rods prior to installation, oil them during or after installation, and provide centralizers to restrain lateral movement but not axial movement at the element top if needed. The displacement indicators shall have a travel of at least a 5 mm [0.2 in.] and minimum graduations of 0.01 mm [0.0001 in.] or less, with similar accuracy. Mount a smooth bearing surface for the indicator stem on the telltale rod perpendicular to the direction of stem travel, such as a small, lubricated, glass plate clamped or glued in place. Or, use an indicator that is in line and connected directly to the rods. The gage type and installation shall be as specified by the foundation engineer and shall include temperature compensation as recommended by the gage manufacturer.

**9.4.3** Measure element strain directly using strain gages installed axially along the length of the test element at regular intervals or at points of significant change in the subsurface



Note: Install Telltale Rods After Driving The Test Element

FIG. 9 Possible Installation of Telltales for Driven Steel Section or Wide Flange Beam



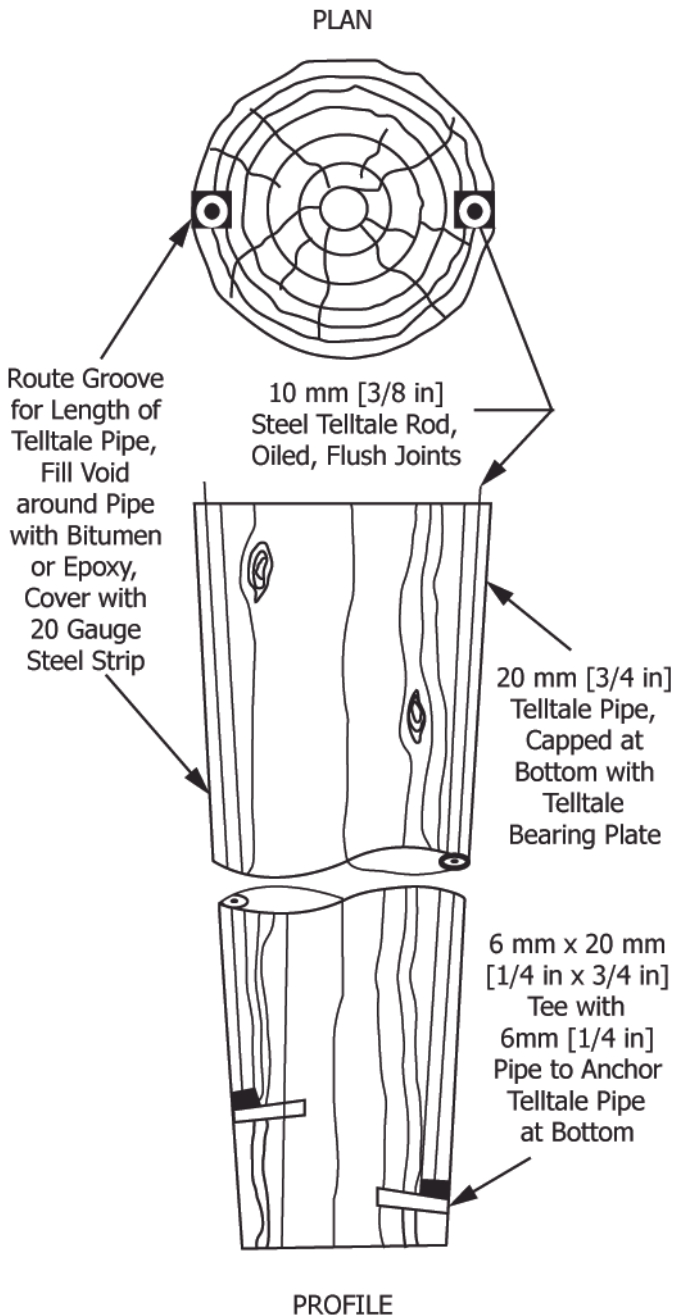
Note: Install Telltale Pipes, Install Telltale Rods, and Fill Pipe with Concrete After Driving

FIG. 10 Possible Installation of Telltales for Driven Concrete Element

stratigraphy. Gages should also be placed near, but not at, changes in the element itself such as changes in diameter or presence of casings, etc. Install single gages along the element axis, or gage pairs or multiple pairs with the gages in each pair oriented symmetrically opposite each other and equidistant from and parallel to, the element axis. Measure and record the distance from the element top to the gages to the nearest 10 mm [0.5 in.]. The gage type and installation shall be as specified or approved by the foundation engineer and shall include temperature compensation as recommended by the gage manufacturer. Where feasible, include calibrations for all gages in the

fully instrumented element and a complete history of gage readings starting before their installation in the element.

NOTE 11—To interpret strain measurements and estimate element stresses, the foundation engineer should require a depth profile describing the variation of element constituents and their strength, cross sectional area, and stiffness. Stiffness properties may vary with the applied stress,



Note: Install Telltale Rods After Driving

FIG. 11 Possible Installation of Telltales for Timber Elements

especially for grout or concrete. Obtain this information from installation records and separate material property tests as needed. For elements constructed with concrete or grout, cracking of concrete or grout can greatly impact strain measurements.

## 10. Test Procedures

### 10.1 Loading:

#### 10.1.1 General:

10.1.1.1 Apply test loads following one of the procedures described below for each test method, or as modified by the foundation engineer. If feasible, the maximum applied load

should reach failure of the test element. Do not exceed the safe structural capacity of the element or the loading apparatus. Do not leave a loaded element unattended.

10.1.1.2 To avoid excessive creep and possible structural failure of cast-in-place concrete elements, delay load testing after concrete placement to permit the fresh concrete to gain adequate strength and stiffness. Use test cylinders or cores of the element concrete to determine the appropriate wait time, recognizing that the test cylinders will generally cure more quickly than concrete in the element.

10.1.1.3 The static axial capacity of elements typically changes as time elapses after element installation, possibly increasing (setup) or decreasing (relaxation), depending on the soil or rock properties and the pore water pressure and soil structure disturbance induced by installation. This behavior may affect both driven elements and cast-in-place elements. The foundation engineer may specify a waiting period between element installation and static testing to investigate time effects. The waiting period may range from 3 to 30 days, or longer, based on testing (for example redriving elements) or prior experience.

10.1.1.4 When temporarily dewatering a test site with elements installed in granular soils, maintain the groundwater level as near to the ground surface as possible and record the groundwater surface elevation during the test. Correct the axial element capacity for the difference in groundwater level as judged appropriate, but generally only when the difference exceeds 1.5 m [5 ft].

10.1.2 *Method A: Quick Test*—Apply the test load in increments of no less than 5 % of the predetermined required test load as defined by the foundation engineer, but not to exceed the capacity of the loading apparatus or structural capacity of the element. Preferably the element should be loaded to geotechnical failure. In that case, load increments may be between 5 % and 10 % of that expected failure load. The foundation engineer should use care to specify a load step size that will result in 10 to 20 load steps. Add each load increment in a continuous fashion and immediately following the completion of movement readings for the previous load interval. During each load interval, keep the load constant for a time interval of not less than 4 min and not more than 15 min, using the same time interval for all loading increments throughout the test. Remove the load in three to six approximately equal decrements, keeping the load constant for a time interval of not less than 4 min and not more than 15 min, using the same time interval for all unloading decrements. The foundation engineer may consider a longer time interval at a specific load increment to assess creep behavior and for the final zero load to assess rebound behavior.

10.1.3 *Method B: Maintained Test*—Apply the test load in increments of 10 % of the predetermined required test load as defined by the foundation engineer, preferably to geotechnical failure, but not to exceed the capacity of the loading apparatus or structural capacity of the element. Maintain each load increment until the rate of axial movement is less than 0.25 mm [0.01 in.] per hour, with a minimum time of 30 minutes, and a maximum time of 2 hours. After the axial movement first exceeds 0.25 mm [0.01 in.] per hour within the specified

maximum time of 2 h and if the element has not reached its predetermined required test load or geotechnical failure, apply the additional test load in increments of 5 % of the maximum test load as defined by the foundation engineer and hold each load step for at least 10 minutes but no longer than 1 hour. If geotechnical failure occurs, after the load step is held for 10 minutes if practical, remove the load in decrements of 25 % of the maximum test load keeping the load constant for a time interval of 10 minutes using the same time interval for all unloading decrements. If geotechnical failure does not occur after reaching the predetermined required test load, or if the test is halted for any reason (other than safety or structure failure of the load reaction system), hold the final load for 2 h and then remove the load in decrements of 25 % of the maximum test load keeping the load constant for a time interval of 10 minutes, using the same time interval for all unloading decrements. Consider a longer time interval, not to exceed 1 h, for the final zero load to assess rebound behavior.

NOTE 12—If negligible permanent axial movement occurs after unloading the test element, consider reloading the element to a greater load or use the procedure in 10.1.4.

10.1.4 *Method C: Constant Rate of Uplift Test*—Apply a continuously increasing load to maintain an element uplift rate of 0.25 to 1.25 mm [0.01 to 0.05 in.] per minute for cohesive soil or 0.75 to 2.5 mm [0.03 to 0.10 in.] per minute for granular soils, or as specified by the foundation engineer. Continue loading the element at the specified constant uplift rate until achieving preferably the geotechnical failure, or the predetermined required test load, but not to exceed the capacity of the loading apparatus or structural capacity of the element. Control the rate of uplift by checking the incremental uplift every 15 seconds and then adjusting the jacking accordingly to maintain the selected uplift rate. After completing the test, gradually remove the load.

## 10.2 Recording Test Readings:

### 10.2.1 General:

10.2.1.1 For the required time intervals described below for each test method, record the time, applied load, and movement readings (displacement, and strain if measured) for each properly identified gage, scale, or reference point taken as nearly simultaneously as practicable. The foundation engineer may specify different reading intervals from those given below as needed to satisfy the objectives of a particular test element program. Obtain additional test readings as specified by the foundation engineer, or as convenient for testing purposes, that is, when using a datalogger to record readings at a constant time interval. Clearly record and explain any field adjustments made to instrumentation or recorded data.

10.2.1.2 Verify the stability of the reference beams and load reaction system (including reaction elements) using a surveyor's level or transit and target rod or scales to determine movement. Record readings taken before applying any test load, at the proposed design load, at the maximum test load, and after the removal of all load. Intermediate readings for each load increment are recommended to provide additional quality assurance and detect potential failure of the load reaction system.

10.2.1.3 When using embedded strain gages to obtain incremental strain measurements as in 9.4, record strain readings just before starting the test and, as a minimum, during the test whenever recording readings of time, load, and movement. The foundation engineer may also require gage readings taken before and after the element installation to obtain a complete strain history and investigate residual stress behavior.

10.2.2 *Method A: Quick Test*—Record test readings at least once per minute (or 30 seconds, if possible) after completing the application of each load increment. If taking readings every minute is impossible due to the number of gages and/or lack of automatic data logging systems, record readings one minute after completing the application of each load increment and at the end of that increment. Alternately, take only critical (as specified by the foundation engineer) displacement and load readings once per minute. Record the load, element top displacement and compression readings once per minute and record strain and redundant backup readings less frequently. Follow the same procedures for unloading decrements.

NOTE 13—The movement measured between readings for a given load increment provides an indication of creep behavior.

10.2.3 *Method B: Maintained Test*—Record test readings taken before and after the application of each load increment or decrement. During each load interval, record additional readings taken at 5, 10, and 20 min following application of the load increment, and every 20 min thereafter as needed and as applicable depending on the length of the increment. If element failure occurs, record readings taken immediately before removing any load. During each unloading decrement, record readings taken at time intervals of 2 min following partial removal of load, for up to 10 min and every 10 min thereafter as needed and as applicable depending on the length of the decrement (assuming that hold times exceed those described in 10.1.3). Record final readings 1 h after removing all load.

NOTE 14—Modern data loggers and data acquisition systems often make it practical to take readings of some or all instrumentation (depending on gage types) every 30 seconds.

10.2.4 *Method C: Constant Rate of Uplift*—Record test readings taken at least every 30 s or at sufficient intervals to determine the actual rate of uplift. Operate any automatic monitoring and recording devices continuously during each test. When the test element has achieved its specified rate of uplift, continue to take and record readings for the duration of the loading, and determine the maximum load applied. Take and record readings during unloading, immediately after unloading, and again 1 h after removing all load.

## 11. Report: Test Data Sheet(s)/Form(s)

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.8 and in Practice D6026.

11.2 *General*—Record at a minimum the following test information as required by the engineer and as appropriate to the test apparatus.

11.2.1 Project identification and location.

11.2.2 Identification, installation date and location of test element.

11.2.3 Type and dimensions of test element (nearest 0.03 m [0.1 ft] or less).

11.2.4 Date and type of test.

11.2.5 Personnel performing the test and preparing the report.

11.2.6 Brief description of the apparatus used for the test, possibly with photographs of the test instrumentation and set-up.

11.2.7 Target test load.

11.2.8 Description of all instrumentation used to measure movement and force, including location with respect to element top.

11.3 *Reaction Element Details*—Record as a minimum the following:

11.3.1 Identification, installation date and location of reaction element.

11.3.2 Type, dimensions of reaction element (nearest 0.03 m [0.1 ft] or less).

11.3.3 Reaction element material including basic specifications and observed condition (including, as applicable, spalled areas, cracks, head surface of deep foundations, and slope deviation from vertical axis).

11.3.4 Reported embedded length of the reaction element (nearest 0.03 m [0.1 ft] or less).

11.3.5 Design load of reaction element.

11.4 *Test Element Details*—Record as a minimum the following project and test element information (as available), as appropriate to the element type.

11.4.1 Nearest test boring or sounding, and its location with reference to test location.

11.4.2 For cast-in-place elements, the volume of concrete or grout placed in deep foundation (volume versus depth, if available).

11.4.3 Test element material including basic specifications and observed condition (including, as applicable, spalled areas, cracks, head surface of deep foundations, and slope deviation from vertical axis).

11.4.4 Tested top and bottom elevations of the test element, and ground elevation referenced to a datum (nearest 0.03 m [0.1 ft] or less).

11.4.5 Reported embedded length of the test element (nearest 0.03 m [0.1 ft] or less).

11.4.6 As-built sketch of the element cross section indicating, as applicable, the depth from the test element top to the nearest 0.03 m [0.1 ft] or less to changes in dimensions, splices, special tip protection or materials, and to any instrumentation.

11.4.7 Results of integrity checks performed before or after the test.

11.5 *Test Data*—Record as a minimum the following as required by the engineer.

11.5.1 Measured force versus displacement plot for each load cycle, including a representation of the theoretical elastic stiffness of the element.

11.5.2 An electronic record in an open format of the applied force and displacement versus time, plus any intermediate quantities used in their calculation, with three significant digits or more, but not to exceed the precision of their measurement.

11.5.3 Relevant field notes, including notations of any interruptions or unusual occurrences during testing.

11.5.4 Calibration reports for the instrumentation.

## 12. Precision and Bias

12.1 *Precision*—Test data on precision is not presented due to the nature of these test methods. 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. Each test pile is unique due to the variable nature of the ground in which it is embedded. Furthermore, retesting a particular pile commonly results in different data from the initial testing due to plastic movement of the ground in which the pile is embedded.

12.1.1 The Subcommittee D18.11 is seeking any data from the users of these test methods that might be used to make a limited statement on precision.

12.2 *Bias*—There is no accepted reference value for these test methods, therefore, bias cannot be determined.

## 13. Keywords

13.1 axial load test ; deep foundation capacity; field testing; jack; load cell; loading procedure; reference beam; static load test

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