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# Standard Test Methods for Deep Foundations Under Bi-Directional Static Axial Compressive Load[1]

This standard is issued under the fixed designation D8169/D8169M; 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 displacement of a single, deep foundation element when loaded in bi-directional static axial compression using an embedded bi-directional jack assembly. These methods apply to all deep foundations, referred to herein as "piles," which function in a manner similar to driven piles, cast in place piles, or barrettes, regardless of their method of installation. 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 bi-directional static axial compressive load. Plans, specifications, and/or provisions 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 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 provides the following test procedures:

| | | |
|---|---|---|
| Procedure A | Quick Test | 9.2.1 |
| Procedure B | Extended Test (optional) | 9.2.2 |

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 The engineer may use the results obtained from the test procedures in this standard 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 (specialty engineer, not to be confused with the foundation engineer as defined above) shall design and approve the load test configuration 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 as requirements of the standard. This standard also includes illustrations and appendixes intended only for explanatory or advisory use.

1.7 *Units*—The values stated in either SI units or inch-pound units (presented in brackets) 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. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

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.

1.9.1 The procedures 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 design.

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



[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.
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*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:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

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

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

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

D6026 Practice for Using Significant Digits in Geotechnical Data

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

D7949 Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations

2.2 *ASME Standards:*[3]

ASME B30.1 Jacks

ASME B40.100 Pressure Gauges and Gauge Attachments

## 3. Terminology

3.1 *Definitions:*

3.1.1 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 *axial compressive capacity, n*—the maximum axial compressive load that a deep foundation can transfer to the soil and rock around it at an acceptable axial movement.

3.2.2 *bi-directional jack, n*—a specialized hydraulic jack that has a repeatable, linear load-pressure calibration over its expansion range.

3.2.3 *bi-directional axial compressive load test, n*—an axial compressive load test performed on a deep foundation element by pressurizing an embedded jack assembly (see definition below), so that the foundation section above the jack assembly moves upwards and the foundation section below the jack assembly moves downwards, each section providing reaction from which to load the other.

3.2.4 *cast in-place pile, n*—a deep foundation element 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.

3.2.5 *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 (also referred to herein as a "pile"), such as a steel pipe pile or concrete drilled shaft.

3.2.6 *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 pushing.

3.2.7 *jack assembly, n*—one or more bi-directional jacks arranged together with any plates to act in parallel symmetrically around a central axis, which will be embedded within a deep foundation element to apply a bi-directional compressive load aligned with the central axis of the deep foundation element.

3.2.8 *steel reinforcement, n*—for the purpose of this Standard, this may consist of any steel assemblage or steel member such as a rebar cage, channel frame, box beam, wide-flange beam, etc., used to reinforce the concrete column, or in a non-production pile, to fix the jack(s) and instrumentation in place.



3.2.9 *telltale rod, n*—an unstrained metal rod extended through the test pile from a specific point within the pile to be used as a reference from which to measure the change in the length of the loaded pile section, or the absolute movement at that specific point.

3.2.10 *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 The bi-directional axial compressive load test provides separate, direct measurements of the pile side shear mobilized above an embedded jack assembly and the pile end bearing plus any side shear mobilized below the jack assembly. The maximum mobilized pile resistance equals two times the maximum load applied by the jack assembly. Test results may also provide information used to assess the distribution of side shear resistance along the pile, the amount of end bearing mobilized at the pile bottom, and the long-term load-displacement behavior.

4.2 The specified maximum test load should be consistent with the engineer's desired test outcome. For permanent (working) piles, the engineer may require that the magnitude of applied test load be limited in order to measure the pile movement at a predetermined proof load as part of a quality control or quality assurance program. Tests that attempt to fully

[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, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

mobilize the axial compressive resistance of the test pile may allow the engineer to improve the efficiency of the pile design by reducing the piling length, quantity, or size.

4.3 The engineer and other interested parties may analyze the results of a bi-directional axial compressive load test to estimate the load versus movement behavior and the pile capacity that would be measured during axial static compressive or tensile loading applied at the pile top (see Notes 1-3). Factors that may affect the pile response to axial static loading during a static test include, but are not limited to the:

*(1)* pile installation equipment and procedures,
*(2)* elapsed time since initial installation,
*(3)* pile material properties and dimensions,
*(4)* type, density, strength, stratification, and groundwater conditions both adjacent to and beneath the pile,
*(5)* test procedure,
*(6)* prior load cycles.

NOTE 1—To estimate the load displacement curve for the pile as if it were loaded in compression at the top (as in Test Methods D1143/D1143M), the engineer may use strain and movement compatibility to sum the pile capacity mobilized above and below the embedded jack assembly for a given pile-top movement. This "top-load" curve will be limited by the lesser of the displacement measured above or below the embedded jack assembly. To obtain adequate minimum displacement during the test, the engineer may wish to specify a maximum test load greater than the desired equivalent "top load".

NOTE 2—A bi-directional load test applies the test load within the pile, resulting in internal pile stresses and pile displacements that differ from those developed during a load test applied at the pile top. Bi-directional testing will generally not test the structural suitability of a pile to support a load as typically placed at the pile top. Structural defects near the pile top may go undetected unless separate integrity tests are performed prior to or after bi-directional testing (see Note 8). The analysis of bi-directional load test results to estimate the pile-top movement that would be measured by applying a compressive load at the top of the pile should consider strain compatibility and load-displacement behavior. ASTM D1143/D1143M provides a standard test method for the direct measurement of pile top movement during an axial static compressive load applied at the pile top.

NOTE 3—The analysis of bi-directional load test results to estimate pile displacements that would be measured by applying a tensile (uplift) load at the top of the pile should consider strain and movement compatibility. Users of this standard are cautioned to interpret conservatively the tensile capacity estimated from the analysis of a compressive load. ASTM D3689/D3689M provides a standard test method for the direct measurement of axial static tensile capacity.

4.4 For the purpose of fully mobilizing the axial compressive capacity, the engineer will usually locate the jack assembly at a location within pile where the capacity above the assembly equals the capacity below it. A poorly chosen assembly location may result in excessive movement above or below the jack assembly, limiting the applied load and reducing the usefulness of the test result. Determination of the assembly's location requires suitable site characterization, consideration of construction methods, and the proper application of engineering principles and judgement (see Note 4). More complex test configurations, using multiple levels of jack assemblies, may provide a higher probability that the full resistance of the pile along its entire length may be determined. Details regarding such complex arrangements are beyond the scope of this standard.

NOTE 4—The bi-directional load test may not fully mobilize the axial compressive pile resistance in all sections of the pile. Practical, economical, or code considerations may also result in bi-directional load tests that are not intended to fully mobilize the axial resistance in some or all sections of the pile. In these cases, interpretation of the bi-directional test may under-predict the total axial compressive capacity of the pile.

NOTE 5—The quality of the results produced by this test method are dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/ inspection/etc. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

## 5. Test Foundation Preparation

5.1 Fig. 1 shows a typical schematic of an embedded jack assembly placed within a test pile in preparation for a bi-directional axial compressive load test. The resultant line of force of the jack assembly shall coincide with the central axis of the foundation element. During initial jack pressurization, a fracture plane will form through the concrete surrounding the jack assembly, and the pile reinforcement and instrumentation shall not restrain the subsequent expansion of the assembly after the fracture occurs. As indicated below, different types of deep foundations require different methods of jack installation. Other methods and procedures are possible. The depth to the embedded jack and the test instrumentation installed within the pile shall be measured to the nearest 25 mm [1 in.] or less with respect to a common fixed point near the pile top that will remain accessible after completion of the pile installation.

NOTE 6—The engineer should assure that the capacity of the jack assembly can mobilize the desired pile capacity found above and below the jack. Tests performed for design optimization should fully mobilize the axial compressive capacity when possible.

5.2 For cast-in-place piles constructed by excavating an open hole in the ground, such as drilled shafts or bored piles, position the jack assembly at the desired location within the pile prior to placing the pile concrete. Use a steel reinforcement cage, or a similar support frame, with centralizer devices to maintain the location and orientation of the assembly during concrete placement. Obtain sound concrete around the assembly by using a fluid concrete mixture, placing concrete at a slow and steady rate, and providing adequate clearance around the jack assembly to avoid restricting concrete flow and trapping any sediments, drill fluid, or laitance. If the allowable jack expansion is inadequate to compress sediments and mobilize the planned end bearing Sediments and cuttings should be removed from the pile bottom before concreting. This unremoved material may reduce the maximum possible test load since some or all the end bearing may not be mobilized. The jack assembly should be placed a minimum distance of one-half pile diameter above the pile bottom, as needed to place sound concrete or grout below it. A jack assembly placed along the pile length shall provide access to place concrete beneath the assembly. The engineer shall determine or at a minimum document what if any effect construction procedures may have on the bi-directional test results or the design assumptions.

NOTE 7—When testing a cast-in-place pile, the size, shape, material composition and properties of the pile can influence the pile capacity and the interpretation of strain measurements described in Section 7.

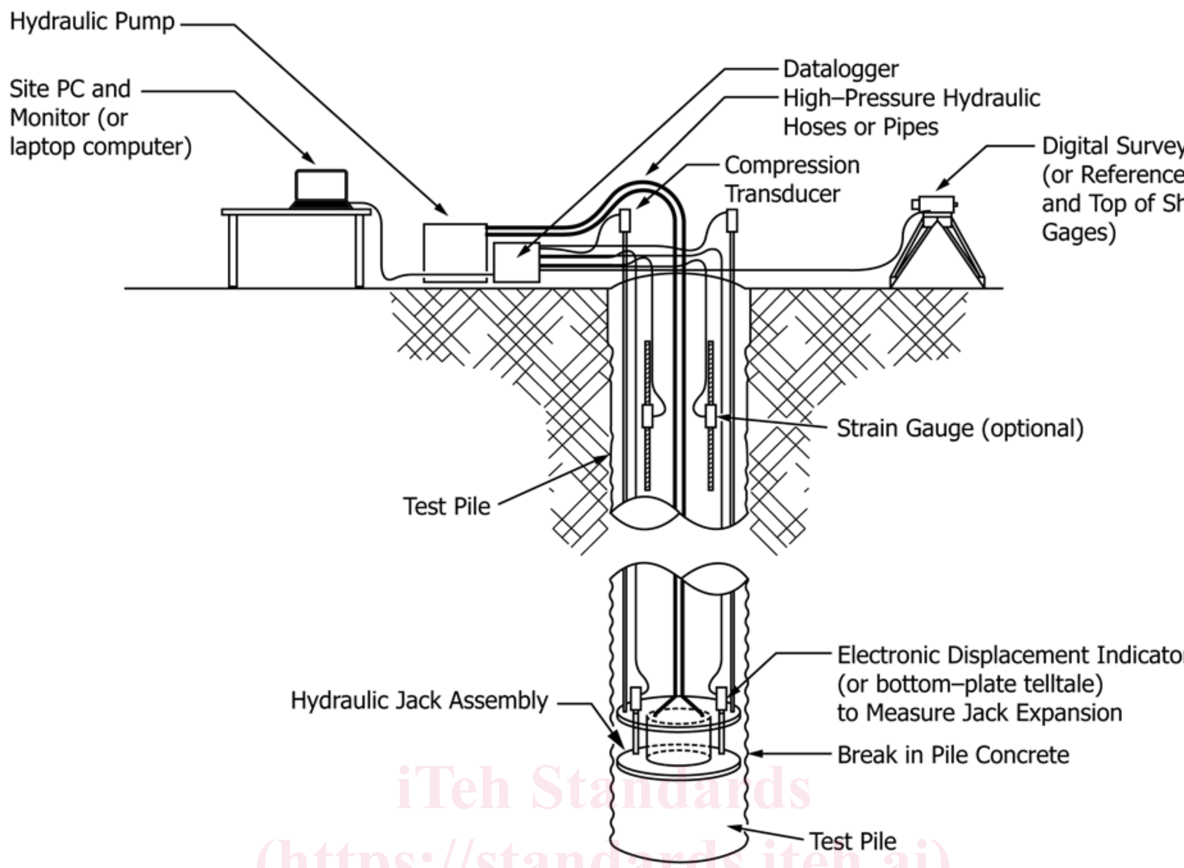


**FIG. 1 Schematic of Bi-Directional Load Test Instrumentation**



Therefore, direct or indirect measurements of the pile size, shape, material composition and properties versus depth are recommended.

5.3 For cast-in-place piles constructed by placing grout or concrete during withdrawal of an auger, the jack assembly shall be attached to a steel reinforcement, or a similar support frame, and then placed into the fluid grout or concrete to the desired location. Use centralizing devices to avoid damaging the jack or altering the size and shape of the pile. Provide a minimum clearance between the jack and the sidewalls of the excavation of the lesser of 75 mm [3 in.] or 8 times the diameter of largest coarse aggregate unless otherwise specified by the engineer.

NOTE 8—Deep foundations sometimes include hidden defects that may go unnoticed prior to static testing. Low strain integrity tests (D5882), ultrasonic crosshole integrity tests (D6760), thermal integrity (D7949) or similar integrity tests may provide useful pre-test information about the test pile. However, the embedded jack assembly typically, but may not always, appear as an anomaly itself. The engineer should use caution when using such tests and the results to conclude that an anomaly exists near the assembly as opposed to being the anomaly. In most cases the initial part of the load test itself is the best indicator of whether such an anomaly is significant or likely to affect the test.

5.4 For driven, pushed, or screwed piles, the jack assembly is usually installed during the manufacture of the pile. The pile is then installed as per normal procedures. Alternatively, if these piles have a full-length central void (for example, pipe, cylinder, etc.), any material inside the pile may be excavated after installation and the jack assembly may be installed as described in 5.2.

5.5 Use a jack assembly containing a single jack when possible. Multi-jack assemblies shall be designed to load the pile symmetrically about its axis, typically using jacks of the same make, model, and capacity with each jack having independent pressure supply hoses or pipes.

5.6 Unless approved otherwise by a qualified test engineer, install a minimum of two hydraulic hoses or pipes (input and return) extending from the pile top to the jack assembly. To confirm the hydraulic flow to each jack and to isolate potential pressure leaks during the test, two hoses or pipes extending from the pile top are recommended for each individual jack. Jacks directly connected together within an assembly in series shall be tested together to verify flow continuity and check for pressure leaks. Alternatively, jacks may be connected in parallel using a manifold. Flow and pressure to each jack can be directly verified. To limit potential leaks, the hoses or pipes should not include unnecessary fittings or connections within the pile. Each hose or pipe shall be clearly marked at each jack, at both sides of any connections, and at the pile top to identify the jack connected to it.

5.7 Install a minimum of two pipes or tubes to vent the location at which the jack assembly will cause the pile to break during the test.

5.8 Permanent (working) piles may use the vent pipes or tubes for post-test grouting of the fracture plane created in the pile by the expanded jack assembly. The hydraulic hoses or pipes installed for each jack may be used to grout the expanded jack(s) with a fluid, high-strength, non-shrink grout as approved by a qualified engineer.

5.9 Excavate or add fill to the ground surface around the test pile to the final design elevation as directed by a qualified engineer.

5.10 Cut off or build up the test pile or test pile steel as necessary to permit the placement, use, and operation of the testing equipment and instrumentation. Remove any damaged or unsound material from the pile top as required to place the test instrumentation.

5.11 When temporarily dewatering a test site, maintain the groundwater level as near to a fixed elevation as possible for the duration of the test as directed by the engineer.

## 6. Safety Requirements

6.1 All operations in connection with pile load testing shall be carried out in such a manner so as 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: (Also see 1.11.)

6.1.1 Provide a stable and level work area around the test pile. 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.

6.1.2 Provide temporary devices as needed to keep the embedded jack assembly safely closed during handling and placement in the test pile. When placing the jack assembly as part of the steel reinforcement, provide adequate connections between the steel reinforcement and the jack assembly to maintain the stability and integrity of the overall steel reinforcement during its handling and placement. Use multiple lifting connections as required to prevent permanent distortion of the steel reinforcement and provide safe handling.

6.1.3 Loads shall not be hoisted, swung, or suspended over test personnel and shall be controlled by tag lines.

6.1.4 Permit only authorized personnel within the immediate test area and only as necessary to monitor test equipment. As best as is possible, locate the pumping apparatus and the hoses connecting it to the jack assembly a safe distance away from test personnel, load cell readouts, data loggers, and test monitoring equipment.

## 7. Apparatus and Preparation for Applying and Measuring Loads

7.1 *General:*

7.1.1 A qualified structural engineer shall design and approve the loading apparatus or reaction of any kind if any part thereof extends to the ground surface or is likely to have any effect on surface structures or cause bulk ground action.

7.2 *Bi-directional Jacks, Pressure Gauges, and Pressure Sensors:*

7.2.1 For the bi-directional load test, the maximum load applied by the embedded jack assembly will be half of the specified maximum test load. The rated nominal capacity of the jack assembly shall exceed the maximum anticipated jack load by at least 10 %. The ram of each bi-directional jack shall have a minimum travel of 150 mm [6 in.] unless otherwise approved by the engineer. Each bi-directional jack shall have a pressure versus force calibration demonstrating a maximum linearity error less than or equal to 2 % of the maximum anticipated jack load to at least 100 mm [4 in.] of expansion. At a minimum, each jack shall include a calibration performed at ram extensions of approximately 25 mm [1 in.] and 100 mm [4 in.] or greater. The design of the embedded jack shall maintain its pressure versus force calibration and load linearity up to a tilt of 1 degree from its axis, which shall on request from the engineer be demonstrated during calibration. For safety reasons, the jack assembly should be pressurized using hydraulic fluid, for example, oil, water, or both.

7.2.2 Assemble the bi-directional jack assembly with steel bearing plates, stiffeners, or equivalent as needed to distribute the jack load evenly over the pile cross-section. Properly distributed load shall yield a uniform cross-sectional distribution of the axial load at no more than two pile diameters above and below the assembly. Consult a qualified structural engineer as needed. Measure and record the distance from the pile top reference to the top and bottom of the jack assembly to the nearest 25 mm [1 in.] or less.

7.2.3 Weld or lock the jack assembly so that it remains closed during handling and installation in the pile. The welds or locks shall be designed so that they may be disengaged completely (no resistance to expansion) prior to testing or to provide no resistance after 1 mm [0.04 in.] or less of assembly expansion. When placed as an integral part of the steel reinforcement in a cast in-place pile, the jack assembly and its connection to the steel reinforcement shall be designed to safely withstand handling and placement stresses. A jack assembly cast into a driven pile shall include anchorage that will safely withstand handling and driving stresses.

7.2.4 Bi-directional jacks that will open within soil, especially when installed in a driven pile, may include a plate around the pile perimeter that covers the opening between the load plates to minimize disturbance of the surrounding soil during installation and testing.

7.2.5 The pump(s) and any hoses, pipes, fittings, pressure gauges and pressure sensors used to pressurize the jack assembly shall be rated to a minimum safe pressure corresponding to the nominal capacity of the jack assembly.

7.2.6 Unless otherwise approved by the engineer, measure the pressure in the jack assembly using pressure gauges or sensors with a range greater than or equal to the rated pressure of the jack assembly and provide at least two measurements of the pressure in the jack assembly during testing, including the pressure applied on the input hydraulic line(s) and the pressure in the return line(s). Pressure gauges and pressure sensors shall have minimum graduations less than or equal to 1 % of the maximum anticipated pressure and shall conform to ASME B40.100 or similar international standards. When used for control of the test, pressure sensor output in units of pressure or calibrated load shall be displayed in real-time during the test.

7.2.7 If specified by the engineer, and when the specified maximum test load exceeds 4500 kN [1000 kips], install instrumentation within the pile that can be used to indicate the load applied by the embedded jack assembly. This instrumentation may consist of strain gauges as described in 8.6, or less commonly, embedded, sacrificial load cells. If used, each load cell shall have a calibration to at least its maximum anticipated measured load, performed within the twelve months prior to the load test. Each calibration shall show a maximum linearity error less than or equal to 2 % of the load cell's maximum anticipated measured load.

7.2.8 Each embedded jack, pressure gauge, pressure sensor, and load cell shall be plainly marked by a unique serial number and shall have a calibration versus a traceable standard performed no more than twelve months prior to the test that satisfies the above specifications to at least the maximum anticipated jack load. The engineer should specify more recent calibration when recommended by the manufacturer, or in the event of rough handling or harsh storage conditions. Furnish the calibration reports prior to performing a load test. Calibration reports shall include the ambient temperature.

7.2.9 Strain gauges are recommended at stratigraphic elevations to assess the load in the pile, to calculate the load transfer along the pile length. See 8.6 for more detail.

NOTE 9—Bi-directional tests of working piles may seek only to evaluate the pile displacement at a pre planned proof load. The engineer should assess the economic benefit of using strain gauges for working piles.

7.2.10 The hydraulic pump used to pressurize each jack or the jack assembly shall be monitored and controlled by qualified personnel at all times, either in person or by remote access. Automated and remotely controlled loading systems shall include a clearly marked mechanical override to safely reduce hydraulic pressure in an emergency.



## 8. Apparatus and Preparation for Measuring Movement and Strain

8.1 *General:*





8.1.1 At a minimum, measure the pile top movement as described in 8.2 and the movement of the top and bottom of the jack assembly as described in 8.3. The engineer may also require optional direct measurements of the pile bottom movement, the pile compression above or below the jack assembly, or the strain in the pile to help interpret and verify the pile behavior. When the jack assembly is located more than 1 m [3 ft] above the bottom of the pile, measure the movement of the pile bottom as described in 8.4.

8.1.2 When positioning the test instrumentation and references, the load test provider shall consider the anticipated test pile movement to minimize repositioning requirements and the risk of damage during the test.

8.1.3 Report upward pile movement as positive and downward movement as negative. Report pile compression as positive and expansion as negative. Report jack assembly expansion as positive and closure as negative.

8.1.4 Reference beams and wirelines, if used, shall have 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 but not less than 2.5 m [8 ft]. Depending on the size and height of the pile top, orient a single reference beam across the pile top or two parallel reference beams, one on each side of the test pile. Reference beams shall have adequate strength, stiffness, and cross bracing to provide stable support for the test instrumentation and to minimize vibrations that may affect the measurement of the pile movement. One end of each beam shall be free to move along its axis as the beam length changes with temperature variations. Supports for reference beams and wirelines shall be isolated from moving water and wave action.

8.1.5 Provide a tarp or shelter to prevent direct sunlight and precipitation from affecting the measuring and reference systems.

8.1.6 Dial and electronic displacement indicators shall conform to ASME B89.1.10.M Dial Indicators (For Linear Measurements) or similar international Standards. Electronic indicator movement shall be displayed in real-time during the test. Dial indicators and electronic displacement indicators shall be in good working condition and shall have a full range calibration within twelve months prior to each test. Furnish calibration reports prior to performing a test, including the ambient air temperature during calibration. 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 (if applicable, not applicable for in-line set-ups). Displacement indicators used for measuring pile movements shall have a minimum travel of 100 mm [4 in.] and minimum graduations of 0.1 mm [0.01 in.] or less, with similar accuracy or better, and shall be read to the nearest graduation or less. Provide greater travel, stem extensions, or calibrated blocks if larger displacements are anticipated (adjust gradations and accuracy proportionally as needed ). Displacement indicators used for measuring pile compression (see 8.5) shall have a travel of at least 25 mm [1 in.] and minimum graduations of 0.01 mm [0.0005 in.] or less, with similar accuracy or better, and shall be read to the nearest graduation or less.

8.1.7 Optical, laser, or digital survey levels may be used for secondary pile top axial movement measurements (see 8.2) and to verify reference movements. Survey levels shall be in good working condition and shall have a calibration within twelve months prior to each test. Furnish calibration reports prior to performing a test, including the ambient air temperature during calibration. These levels shall have an accuracy of 3 mm at 30 m [0.13 in. at 100 ft] or better and shall be self leveling (automatic). Scales, targets, detectors, or staffs used with these levels for shall have a length no less than 150 mm [6 in.] and minimum graduations of 0.5 mm [0.02 in.] or less, with similar accuracy or better, and shall be read to the nearest 0.25 mm [0.01 in.] or less. Survey rods shall have minimum graduations of 1 mm [0.01 ft] or less, with similar accuracy or better, and shall be read to the nearest 0.25 mm [0.001 ft].

8.1.8 Digital survey levels may be used for primary movement measurements (see 8.2) provided they have an accuracy of 0.25 mm at 30 m [0.01 in at 100 ft] or better and are self leveling (automatic). Digital survey levels shall be in good working condition and shall have a calibration within twelve months prior to each test. Furnish calibration reports prior to performing a test, including the ambient air temperature during calibration. Targets used with these levels shall have a length no less than 150 mm [6 in.] and provide for a reading precision of 0.25 mm [0.01 in.] or less, with similar accuracy or better. The movement from digital survey levels shall be displayed in