AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Piles Under Lateral Loads[1]

This standard is issued under the fixed designation D 3966; 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 This test method covers procedures for testing vertical and batter piles either individually or in groups to determine the load-defection relationship when subjected to lateral loading. It is applicable to all deep foundation units regardless of their size or method of installation. This test method is divided into the following sections:

1.2 This test method only describes procedures for testing single piles or pile groups. It does not cover the interpretation or analysis of the test results or the application of the test results to foundation design or the use of empirical or analytic procedures for determining the magnitude and variation of the coefficient of horizontal subgrade reaction, bending stresses, and bending movements over the length of the pile. The term "failure" as used in this test method indicates a rapid progressive lateral movement of the pile or pile group under a constant or decreasing load.

1.3 Apparatus and procedures designated "optional" are to be required only when included in the project specifications and, if not specified, may be used only with the approval of the engineer responsible for the foundation design. The word "shall" indicates a mandatory provision and "should" indicates a recommended or advisory provision. Imperative sentences indicate mandatory provisions. Notes and illustrations included herein are explanatory or advisory.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety precautions, see Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*

A 36/A 36M Specification for Structural Steel[2]

A 240 Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels[2]

A 441/A 441M Specification for High-Strength Low-Alloy Structural Manganese Vanadium Steel[2]

A 572/A 572M Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality[2]

D 1143 Test Method for Piles Under Static Axial Compressive Load[3]

D 3689 Test Method for Individual Piles Under Static Axial Tensile Load[3]

2.2 *ANSI Standards:[4]*

B30.1 Safety Code for Jacks

B46.1 Surface Texture

3. Significance and Use

3.1 The actual lateral load capacity of the pile-soil system can best be determined by lateral testing. Such testing measures the response of the pile-soil system to lateral loads and may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

3.2 Under the iterative elastic method of analysis that considers the nonlinear response of the soil,[5] lateral testing combined with proper instrumentation can be used to determine soil properties necessary for the structural design of the pile to resist the lateral load to be applied.

3.3 Lateral testing as covered herein, when combined with

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] Available from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

[5] Reece, L. C., "Design and Evaluation of Load Tests on Deep Foundations," *Behavior of Deep Foundations, ASTM STP 670*, Am. Soc. Testing Mats., 1979.

an acceptance criterion, is suitable for control of pile foundation design and installation under building codes, standards, and other regulatory statutes.

4. Apparatus for Applying Loads

4.1 *General*:

4.1.1 The apparatus for applying lateral loads to the test pile(s) shall be as described in 4.3 or 4.4, unless otherwise specified, and shall be constructed so that the resultant loads are applied horizontally and in line with the central vertical axis of the pile or pile group so as to minimize eccentric loading and avoid a vertical load component.

NOTE 1—For lateral tests on batter pile frames or pile groups involving batter piles, consideration should be given to applying the lateral test loads at the actual or theoretical point of intersection of the longitudinal axis of the piles in the frame or group.

4.1.2 The test area within a radius of 20 ft (6 m) from the test pile or group shall be excavated or filled to the final grade elevation before testing the pile or pile group. If necessary, the pile(s) shall be cut off or extended so that the pile butt(s) is sufficiently above adjacent ground surface to permit construction of the load application apparatus, placement of the necessary testing and instrumentation equipment, and observation of the instrumentation. Before applying the test load, any annular space around the upper portion of the test pile(s) should be filled with sand or other suitable material and the same material and backfilling methods should be used for all production piles. Lateral test loads shall be applied at approximately pile cut-off elevation.

4.1.3 For tests on pile groups, except batter pile frames, the group of piles shall be capped with a reinforced concrete cap designed and constructed in accordance with accepted engineering practice to distribute the test loads uniformly to the piles in the group or shall be interconnected with steel members designed and constructed so that the piles act together. The connection between piles and pile caps and the depth of embedment of the pile butts into the pile cap shall simulate in-service conditions. Pile caps shall be cast above grade unless otherwise specified and may be formed on the ground surface unless 4.1.3.1 is specified.

4.1.3.1 *Elimination of Friction Beneath Pile Cap* (Optional)—For tests on pile groups, the bottom of the pile cap shall be clear of the ground surface.

NOTE 2—It is recommended that the bottom of the pile cap be clear of the ground surface when the friction between the soil and the pile cap may contribute significantly to the lateral resistance of the pile group.

4.1.3.2 *Passive Soil Pressures Against Pile Cap* (Optional)—For tests on pile groups, the pile cap shall be constructed below ground surface and backfilled with compacted fill on the side opposite the point of load application or the pile cap shall be constructed above ground surface against an embankment sufficient to permit the passive soil pressures to act during the test. If specified, compacted fill shall be placed against the sides of the pile cap to the extent practicable.

4.1.4 A steel test plate(s) of sufficient stiffness to prevent it from bending under the involved loads, but not less than 2 in. (50 mm) thick, shall be set vertically against the side of the pile, pile cap, or steel frame at the point(s) of load application and perpendicular to the line(s) of load application. The test plate shall be of sufficient size to accommodate the hydraulic cylinders but shall have a horizontal side dimension not less than one half the diameter or side dimension of the test pile(s) nor greater than the diameter or side dimension of the test pile(s). For tests on single piles other than square piles, the head of the pile shall be capped so as to provide a plane vertical bearing surface for the test plate, or the test plate shall be set in high-strength grout or adequately welded to the side of the pile using suitable filler material to provide full bearing against the projected area of the pile. If the test plate(s) is supported independently of the test pile or group during assembly of the testing apparatus, such temporary supports shall be removed when test loads are applied.

4.1.5 *Bearing Plates*, shall be of steel and of sufficient size to accommodate spherical bearings, load cells, hydraulic jacks, and struts, and to transmit the applied lateral loads without detrimental high unit pressures. Bearing plates shall be of adequate thickness to prevent bending under the applied load but shall not be less than 2 in. (50 mm) thick.

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

4.2 *Testing Equipment*:

4.2.1 Unless the test load is applied by pulling in accordance with 4.5, lateral loads shall be applied using one or more hydraulic cylinders equipped with spherical bearings. If two or more hydraulic cylinders are to be used to apply the test load, they shall be of the same piston diameter, connected to a common manifold and pressure gage, and operated by a single hydraulic pump.

4.2.2 Hydraulic jacks including their operation shall conform to the applicable provisions of ANSI B30.1.

4.2.3 Unless a calibrated load cell(s) or equivalent device(s) is used, the complete jacking system including the hydraulic cylinder(s), valves, hydraulic pump, and pressure gage shall be calibrated as a unit to an accuracy of not less than 5 % of the applied load.

4.2.4 When an accuracy greater than that obtainable with the jacking system is required, a properly constructed load cell(s) or equivalent device(s) shall be used in series with the hydraulic cylinder(s). Load cells or equivalent devices shall be calibrated to an accuracy of not less than 2 % of the applied load and shall be equipped with spherical bearings.

4.2.5 If the lateral load is applied by pulling 4.5.4) the equipment used to produce the pulling force shall be capable of applying steady constant forces over the required load testing range. The dynamometer(s) or other in-line load indicating device(s) shall be calibrated to an accuracy of not less than 10 % of the applied load.

4.2.6 Calibration of testing equipment shall be done before each test or series of tests in a test program. Hydraulic cylinders shall be calibrated by loading the test equipment with the hydraulic cylinders over their complete range of piston travel for increasing and decreasing applied loads. Double-acting hydraulic cylinders shall be calibrated in both the push and pull modes. Calibration reports shall be furnished for all testing equipment for which calibration is required and shall show the temperature at which the calibration was done.

4.3 *Load Applied by Hydraulic Jack(s) Acting Against a Reaction System* (Fig. 1):

4.3.1 *General*—Apply the test loads to the pile or pile group using one or more hydraulic cylinders and a suitable reaction system according to 4.3.2, 4.3.3, 4.3.4, or 4.3.5. The reaction system may be any convenient distance from the test pile or pile group and shall provide a resistance greater than the anticipated maximum lateral test load. Set the hydraulic cylinder(s) (with load cell(s) if used) against the test plate(s) at the point(s) of load application in a horizontal position and on the line(s) of load application. Place a steel strut(s) or suitable blocking between the base(s) of the cylinder(s) and the reaction system with steel bearing plates in accordance with 4.1.5 between the strut(s) or blocking and the cylinder(s) and between the strut(s) and the reaction system. If a steel strut(s) is used, place it horizontally and on the line(s) of load application and brace the strut(s) to ensure it does not shift during load application. If two hydraulic cylinders are used, place both cylinders, load cells (if used), and struts or blocking at the same level and equidistant from a line parallel to the lines of load application and passing through the center of the test group. Support the jack(s), bearing plate(s), strut(s), and blocking on cribbing if necessary for stability.

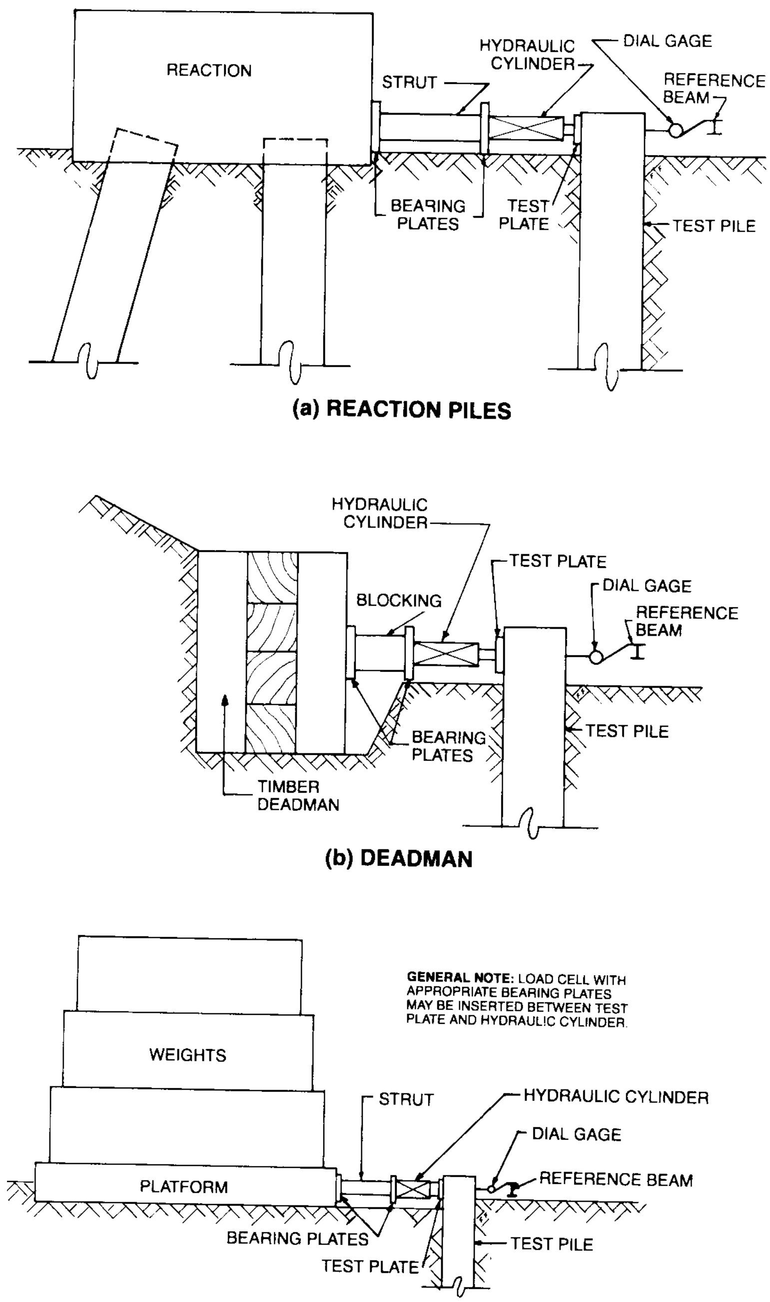


FIG. 1 Typical Set Ups for Applying Lateral Load with Conventional Hydraulic Jack

4.3.2 *Reaction Piles* (Fig. 1a)—Install two or more reaction piles vertically or on a batter (or a combination of vertical and batter) so as to provide the necessary reactive capacity for the maximum anticipated lateral test loads. Cap the reaction piles with reinforced concrete, steel, or timber, or brace between the piles, or fasten the pile butts together so as to develop the lateral resistance of the entire group.

NOTE 3—Unless two opposing batter reaction piles are installed, the batter piles should be battered in a direction away from the test pile or group (see Fig. 1a).

4.3.3 *Deadman* (Fig. 1b)—Where soil or site conditions are suitable, install a deadman consisting of cribbing, timber panels, sheeting, or similar construction bearing against an embankment or the sides of an excavation so as to provide the necessary reactive capacity to the maximum anticipated lateral test loads.

4.3.4 *Weighted Platforms* (Fig. 1c)—Construct a platform of any suitable material such as timber, concrete, or steel, and load the platform with sufficient weights to provide the necessary resistance to the maximum anticipated lateral test loads to be applied. Provide a suitable bearing surface on the edge of the platform against which the reactive lateral load will be applied.

4.3.5 *Other Reaction Systems* (Optional)—Use any other specified suitable reaction system such as an existing structure.

4.4 *Load Applied by Hydraulic Jack(s) Acting Between Two Test Piles or Test Pile Groups* (Fig. 2)—Test the lateral capacity of two single piles or two similar pile groups simultaneously by applying either a compressive or tensile force between the pile or pile groups with a hydraulic jack(s). Test piles or test groups may be any convenient distance apart. If necessary, insert a steel strut(s) between the hydraulic cylinder(s) and one of the test piles or groups. For the cylinder(s), load cell(s) (if used), strut(s), and bearing plate(s) (if used), comply with the requirements of 4.1.5, 4.1.6, and 4.3.1, except remove all temporary blocking and cribbing underneath plates, strut(s), and cylinder(s) (and load cell(s) if used), after the first load increment has been applied and do not brace the strut(s).

4.5 *Load Applied by Pulling* (Optional):

4.5.1 *General*—Apply the lateral load by pulling test pile or group using a suitable power source such as a hydraulic jack, turnbuckle or winch connected to the test pile or group with a suitable tension member such as a wire rope or a steel rod and connected to an adequate reaction system or anchorage. Securely fasten the tension member to the test pile or pile cap so that the line of load application passes through the vertical central axis of the test pile or group. If two tension members are used, fasten them to the test pile or pile cap at points equidistant from a line parallel to the lines of load application and passing through the vertical central axis of the test pile or group.

4.5.2 *Anchorage System*—Maintain a clear distance of not less than 20 ft (6 m) or 20 pile diameters between the test pile or group and the reaction or anchorage system complying with 4.3.2, 4.3.3, 4.3.4, 4.3.5, or as otherwise specified. Furnish an anchorage system sufficient to resist without significant movement the reaction to the maximum lateral load to be applied to the test pile or group.

4.5.3 *Pulling Load Applied By Hydraulic Jack Acting Against a Reaction System* (Fig. 3)—Apply the lateral tensile load to the test pile or pile group using any suitable hydraulic cylinder such as conventional type, push-pull type, or center-hole type. Center the conventional hydraulic cylinder (and load cell if used) on the line of load application with its base bearing against a suitable reaction system and its piston acting against a suitable yoke attached by means of two parallel tension members to the test pile or pile group (see Fig. 3a). Where required to adequately transmit the jacking load, install steel bearing plates in accordance with 4.1.5. If a double-acting type cylinder is used (Fig. 3b), place the cylinder on the line of load application connecting the cylinder's casing to the anchorage system and its piston to a suitable strut or steel rod adequately secured to the test pile or pile group. The steel strut or rod may be supported at intermediate points provided such supports do not restrain the strut or rod from moving in the direction of load application. If a center-hole cylinder is used (Fig. 3c), center the cylinder (and load cell if used) along the line of load application with its base bearing against a suitable reaction and with its piston acting against a suitable clamp or nut attached to a steel rod or cable fastened securely to the test pile or group. Provide a hole through the reaction system for the tension member. If necessary to transmit the jacking forces, insert a steel bearing plate in accordance with 4.1.5 between the reaction and the jack base.

4.5.4 *Pulling Load Applied By Other Power Source Acting Against An Anchorage System* (Fig. 4)—Apply the lateral tensile load with a winch or other suitable device. Insert a dynamometer or other load indicating device in the pulling line between the power source and the test pile or group (see Fig. 4a). If a multiple part line is used, insert the dynamometer or equivalent device in the line connecting the pulling blocks with either the test pile (or group) or the anchorage system. (See Fig. 4b).

4.6 *Fixed-Head Test* (Optional):

4.6.1 *Individual Pile* (Fig. 5)—Install the test pile so that it

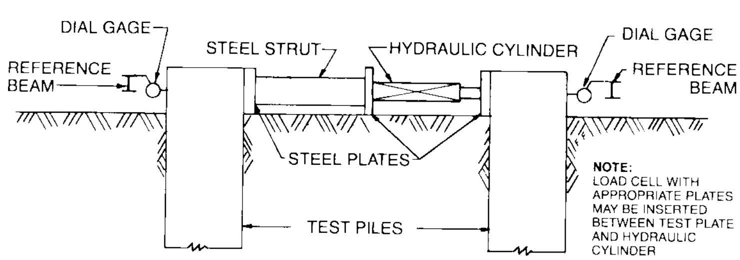


FIG. 2 Typical Arrangement for Testing Two Piles Simultaneously

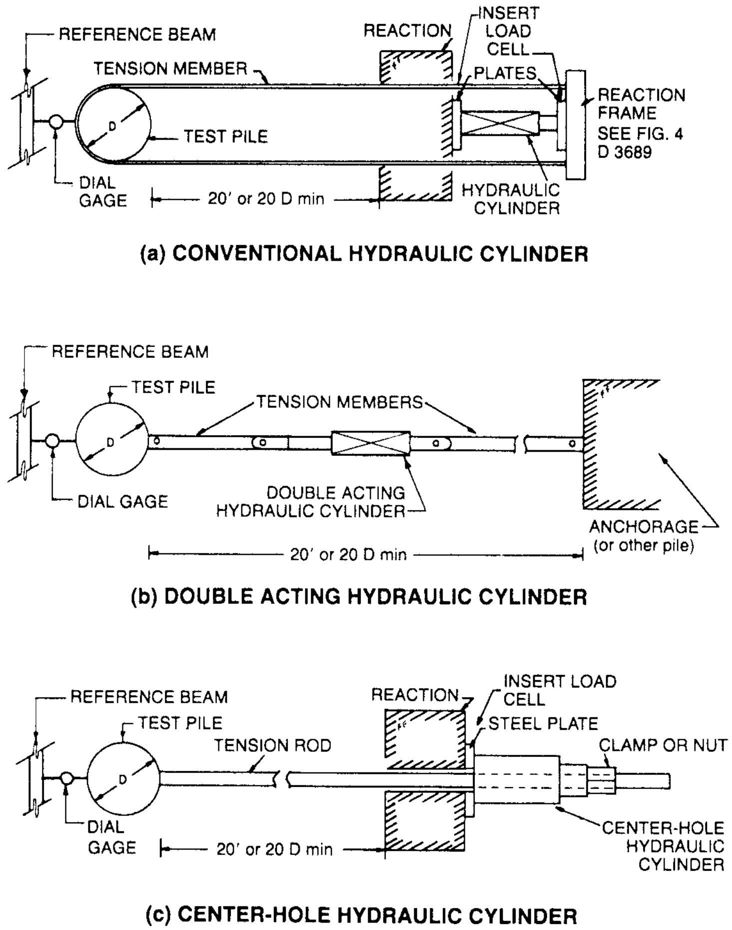


FIG. 3 Typical Arrangements for Applying Pulling Loads with Hydraulic Jack (Top Views)

extends a sufficient distance above the adjacent ground surface to accommodate the steel frames but not less than 6½ ft (2 m). Firmly attach by clamping, welding, or some other means, a right angle (approximately 30–60–90) frame to each side of that portion of the pile extending above ground surface. Design and construct the frame so as to prevent the top of the pile from rotating under the maximum lateral load to be applied. Support the ends of the frames on steel rollers acting between steel bearing plates with the bottom bearing plate supported on a pile(s) or cribbing with sufficient bearing capacity to prevent

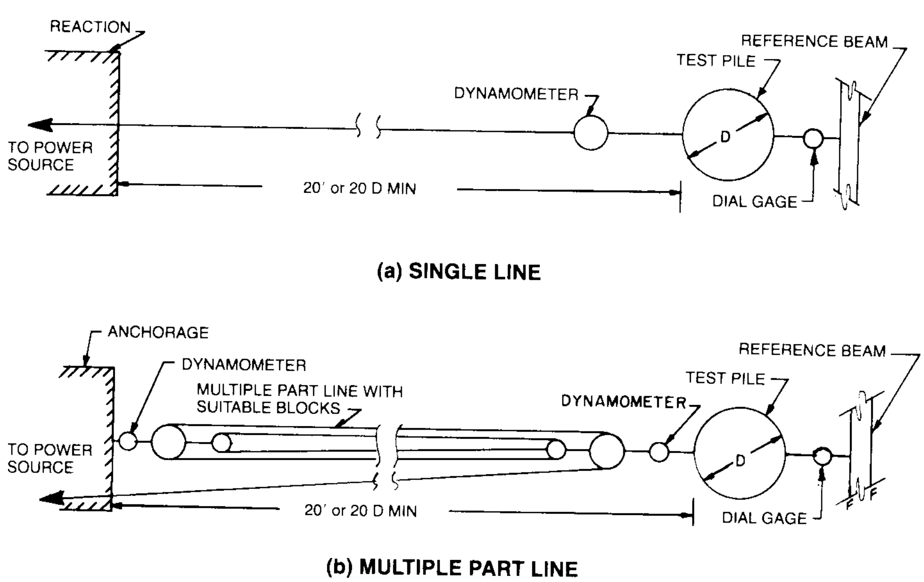


FIG. 4 Typical Arrangements for Applying Lateral Loads with Power Source such as Winch (Top Views)

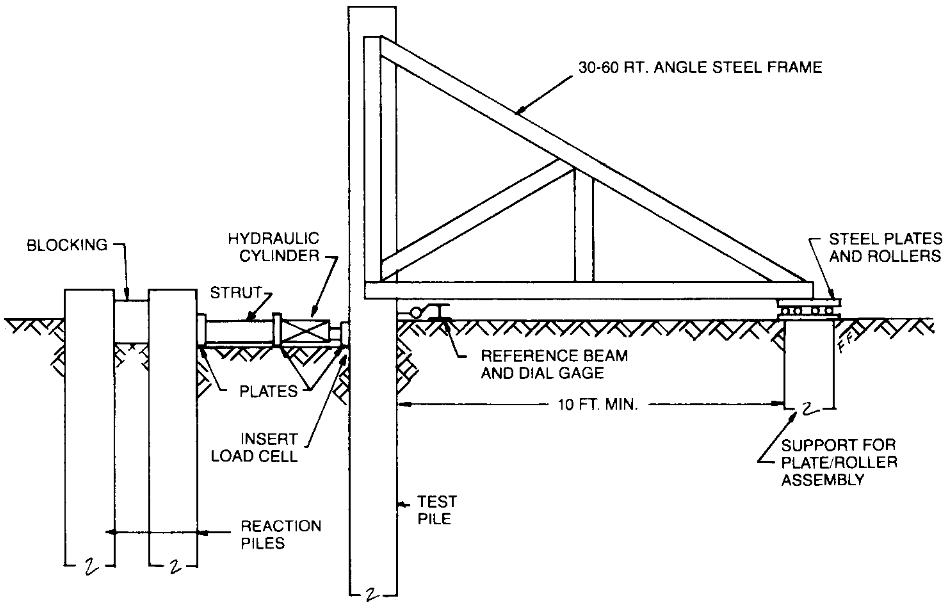


FIG. 5 Example of Fixed-Head Test Set Up for Lateral Test on Individual Pile

any significant vertical deflections of the ends of the frame. Maintain a clear distance of not less than 10 ft (3 m) between the test pile and support for the ends of the frames. The steel bearing plate shall be of sufficient size to accommodate the ends of the frames and the steel rollers including the maximum anticipated lateral travel. Steel rollers shall be solid and shall be of sufficient number and diameter (but not less than 2 in. (50 mm) in diameter) so as to permit free horizontal movement of the frames under the anticipated downward pressures resulting from the maximum lateral test load to be applied.

NOTE 4—For practical purposes for a 10-ft (3-m) spacing between the test pile and frame support, it can be assumed that the vertical reaction at the ends of the frames is equal to the lateral load being applied to the test pile at the ground surface.

4.6.2 *Pile Group* (Fig. 6)—Install the test piles with pile tops a sufficient distance above the point of load application to provide fixity when the test group is capped. Cap the test group with an adequately designed and constructed reinforced concrete or steel grillage cap with sufficient embedment of the piles in the cap to provide fixity and with the side of the cap opposite the point of load application extended a sufficient distance to provide for the support pile(s). To prevent rotation of the pile cap under lateral load, support the end of the cap opposite that of the point of load application on one or more bearing piles with steel plates and rollers in accordance with 4.6.1 between the bottom of the cap and the top of the bearing pile(s).

4.7 *Combined Lateral and Axial Loading* (Optional):

4.7.1 *General*—Test the pile or pile group under a combination of lateral loading and axial compressive or tensile loading as specified. Apply the lateral load using method 4.3 or 4.4. Employ suitable methods and construction to ensure that the pile or pile group is not significantly restrained from lateral movement by the axial load.

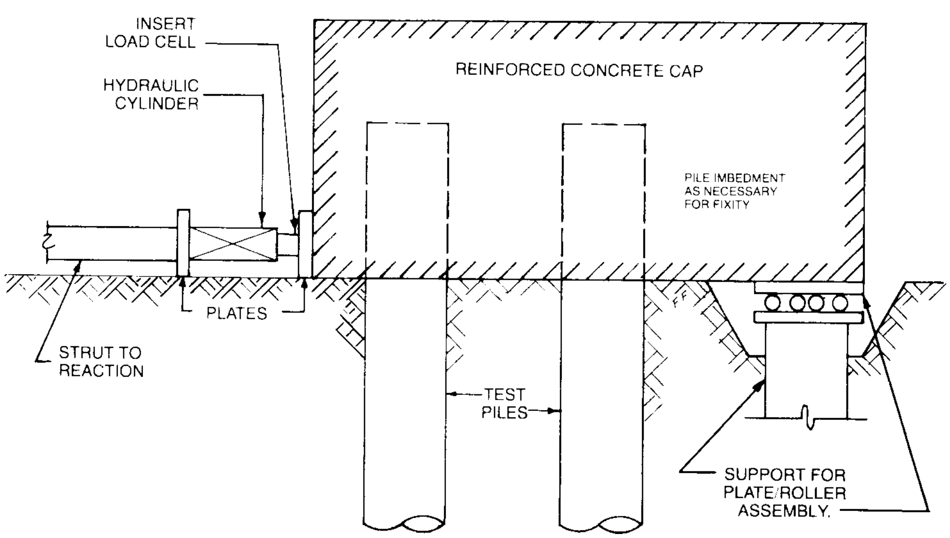
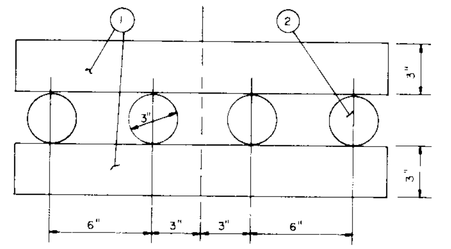


FIG. 6 Example of Fixed-Head Test Set Up for Lateral Test on Pile Group

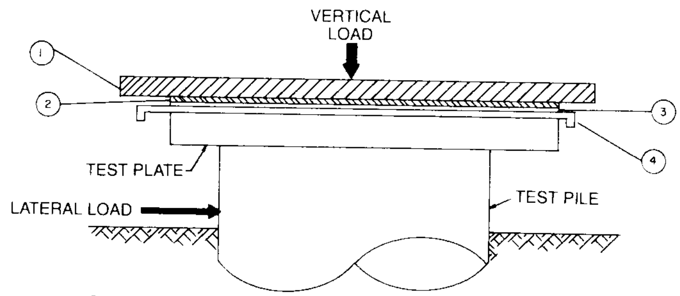
4.7.2 *Compressive Load* (Fig. 7)—Apply the specified axial compressive load in accordance with 3.3 or 3.4 of Test Method D 1143. Place an antifriction device in accordance with 4.7.2.1, 4.7.2.2, or as otherwise specified between the compressive loading jack and the test plate on top of the test pile or pile group.

4.7.2.1 *Plate and Roller Assembly* (Fig. 8a)—The plate and roller assembly shall be designed to support the maximum applied compressive load without crushing or flattening of rollers and without indention or distortion of plates, and to provide minimal restraint to the lateral movement of the test pile or group as the lateral test loads are applied. Fig. 8a illustrates a typical assembly having a compressive load limit of 100 tons (890 kN). The two plates shall be of Specification A 441/A 441M steel or equal with a minimum yield strength of 42 000 psi (290 MPa) and shall have a minimum thickness of 3 in. (75 mm). The plates shall have sufficient lateral dimensions to accommodate the length of rollers required for the compressive loads and for the anticipated travel of the rollers as the test pile or group moves laterally under load. The contacting surfaces of the steel plates shall have a minimum surface roughness of 63 as defined and measured by ANSI B46.1. The rollers shall be of sufficient number and length to accommodate the compressive loads and shall be of Specification A 572/A 572M steel Grade 45 or equal (minimum yield strength 45 000 psi (310 MPa) with a minimum diameter of 3 ± 0.001 in. (75 ± 0.03 mm). The rollers shall have a minimum surface roughness of 63 as defined and measured by ANSI B46.1. The plates shall be set level and the rollers shall be placed perpendicular to the direction of lateral load application with adequate spacing to prevent binding as lateral movement occurs.

4.7.2.2 *Antifriction Plate Assembly* (Fig. 8b)—The antifriction plate assembly shall be designed and constructed as illustrated in Fig. 8b and shall consist of the following elements: (*1*) a minimum 1-in. (25-mm) thick steel plate, (*2*) a minimum 10-gage (3.4-mm) steel plate tack welded to the 1-in. thick plate, (*3*) a minimum 3⁄32-in. (2.4-mm) sheet of virgin tetrafluoroethylene polymer with reinforcing aggregates prebonded to the 10-gage plate by a heat-cured epoxy, and (*4*) a minimum ¼-in (6.4-mm) thick plate of Specification A 240 Type 304 stainless steel having a minimum surface roughness of 4 as defined and measured by ANSI B46.1. The area of contact between the tetrafluoroethylene polymer and the stainless steel plate shall be sufficient to maintain a unit pressure of less than 2000 psi (14 MPa) under the compressive loads to be applied. The area of the stainless steel plate shall be sufficient to maintain full surface contact with the tetrafluoroethylene polymer as the test pile or group deflects laterally. The stainless steel plate shall be formed with lips on opposite sides to engage



(a) PLATE AND ROLLER ASSEMBLY



(b) ANTI FRICTION PLATE ASSEMBLY

FIG. 8 Typical Antifriction Devices for Combined Load Test

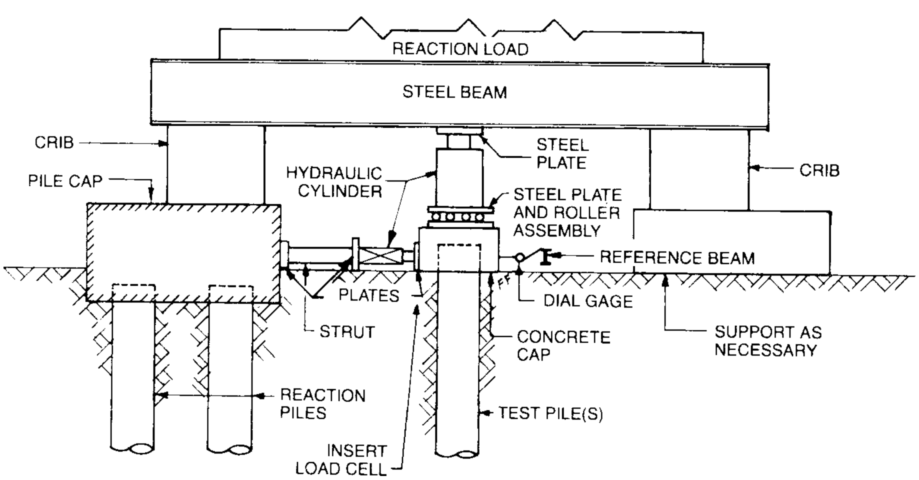


FIG. 7 Typical Example of Set Up For Combined Lateral and Axial Compressive Load

the edges of the test plate under the lateral load. During the lateral test, the lips shall be oriented in the direction of the applied lateral load. The use of a plate assembly having an equivalent sliding friction shall be permitted. The use of two steel plates with a layer of grease in between shall not be permitted.

NOTE 5—Combined lateral and axial compressive loading is recommended to simulate in-service conditions. Precautions should be taken to avoid a vertical component resulting from the applied lateral load or a lateral component from the applied axial load.

NOTE 6—An apparatus for applying an axial tensile load to the test pile in combination with a lateral test load is difficult to construct without restraining the test pile from moving laterally under the lateral test loads. If it is required that a pile be tested under combined axial tensile and lateral loading, the use of a suitable crane equipped with a line load indicator is suggested for applying the uplift or tensile loads. Some type of universal acting device should be used in the tension member connecting the test pile with the crane hook. That in combination with the crane falls, should minimize restraint against lateral movement of the test pile under lateral loads.

5. Apparatus for Measuring Movements

5.1 *General*:

5.1.1 Set all reference beams and wires level and support them independently with supports firmly embedded in the ground and at a clear distance of not less than 7 ft (2 m) from the test pile(s) or group. Reference beams shall be of sufficient axial and lateral rigidity to provide stable reference points for pile deflection measurements. If a steel reference beam is used, one end of the beam shall be free to move horizontally as the length of beam changes with temperature variations.

5.1.2 Dial gage stems shall have at least a 3-in. (75-mm) travel and sufficient gage blocks shall be provided to allow for the maximum anticipated travel. Gages shall have a precision of at least 0.01 in. (0.25 mm). Provide smooth bearing surfaces perpendicular to the direction of the gage stem travel for all gage stems. Scales used to measure movements shall read to 1⁄64 in. or 0.01 in. (0.25 mm). Target rods shall read to 0.001 ft (0.3 mm).

5.1.3 Clearly mark all dial gages, scales, and reference points with a reference number or letter to assist in recording data accurately. Protect the instrumentation measuring system and reference system from adverse temperature variations and from accidental disturbance. Mount all gages, scales, or reference points so as to prevent movement relative to their support system during the test.

5.2 *Pile Butt Movements*—The apparatus for measuring lateral movement and recovery of the test pile or group along the line of load application shall consist of a primary and secondary system in accordance with the following methods:

NOTE 7—Two separate measuring systems are required for determining lateral movements of the test pile or group in order to have a check on the observed data, to provide for accidental disturbance of the measuring system, and to permit continuity of data in case it becomes necessary to reset the gages or scales.

5.2.1 *Dial Gage*—Orient the reference beam perpendicular to the line of load application. If the reference beam is located on the side of the test pile or group opposite the point of load application, allow sufficient clearance between the test pile or pile cap and the reference beam for the anticipated lateral movement of the pile or pile group. Mount the gage(s) on the reference beam with stem(s) bearing against the side of the pile or pile cap or mount the gage(s) on lugs attached to the test pile or pile cap with stems bearing against the reference beam. Mount the gages so their stems are horizontal and for single piles, along the line of load application. For tests on pile groups, mount the dial gages equidistant from the central line of load application.

5.2.2 *Wire, Mirror, and Scale* (Fig. 9)—Mount a mirror and scale on the top center of the test pile or pile cap or on a bracket mounted along the line of load application on the side of the test pile or cap with the scale along the line of load application. Stretch a piano wire or equivalent type perpendicular to the line of load application and passing over the face of the scale. Locate the wire not more than 1 in. (25 mm) from the face of the scale and at the supports install a suitable device to maintain tension in the wire throughout the test so that when plucked or tapped, the wire will return to its original position. If the scale and wire is placed on the side of the pile or cap opposite the point of load application, allow sufficient clearance between the pile or cap and the wire to provide for anticipated lateral movements of the pile or group.

5.2.3 *Transit and Scale*—Mount a scale horizontally on the side or top of the test pile or pile cap parallel to the line of load application and readable from the side. Establish outside of the immediate test area a permanent transit station and a permanent backsight or foresight reference point on a line perpendicular to the line of load application and passing through the target scale. With an engineer's transit, take readings on the target scale of lateral movements of the test pile or group referenced to the fixed backsight or foresight.

5.2.4 *Other Types of Measuring Apparatus*—Any other type of measuring device such as electrical or optical gages that yield accuracy equivalent to 0.01 in. (0.25 mm) may be used.

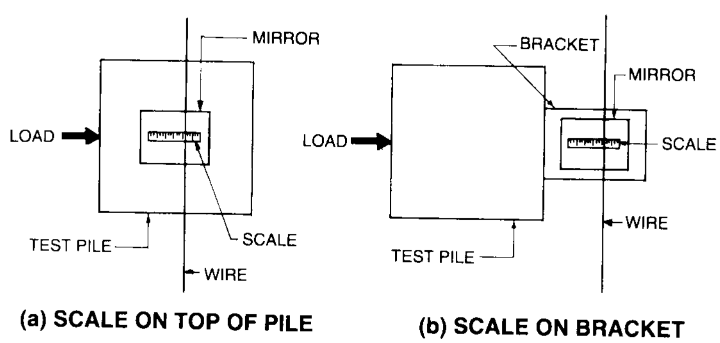
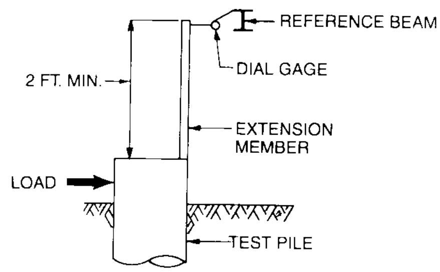


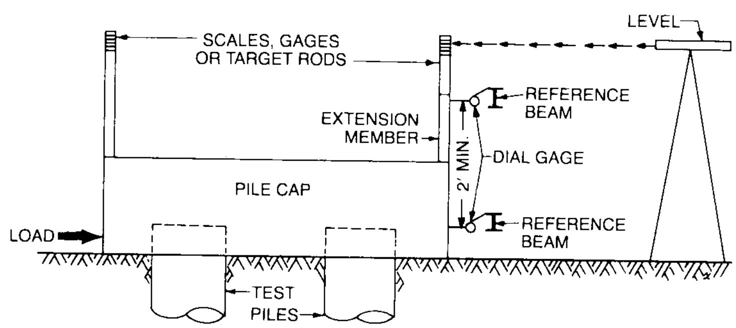
FIG. 9 Typical Wire-Scale Arrangements to Measure Lateral Deflections (Top Views)

5.3 *Rotational Movement* (Optional) (Fig. 10)—For a test on a single pile(s) measure the rotation of the head of the test pile(s). Firmly attach to or embed in the test pile(s) a steel extension member in axial alignment with the test pile(s) and extending a minimum of 2 ft (0.6 m). Mount a dial gage on a reference beam with the gage stem horizontal and on the line of load application and bearing against the side of the extension member near its top (Fig. 10a). For tests on pile groups, measure the rotation of the pile cap by either (*1*) readings on reference points on top of the pile cap on the line of load application and on opposite ends of the cap using either dial gages mounted on an independent reference system or with a surveyors level reading a target rod on the reference points or vertical scales mounted on the pile cap at the reference point and referenced to a fixed bench mark; or (*2*) a dial gage mounted on a reference beam a minimum of 2 ft (0.6 m) vertically above the dial gage used to measure pile butt movements 5.2.1 with its stem horizontal and on the line of load application and bearing against the side of the pile cap or a suitable extension thereto (Fig. 10b). For fixed-head tests on individual piles, use the apparatus for measuring rotation of free-head tests except that the upper dial gage stem may bear against the pile or measure the vertical movements at the ends of the steel frames using either a dial gage or a surveyor's level with a target rod or scale (Fig. 10c).

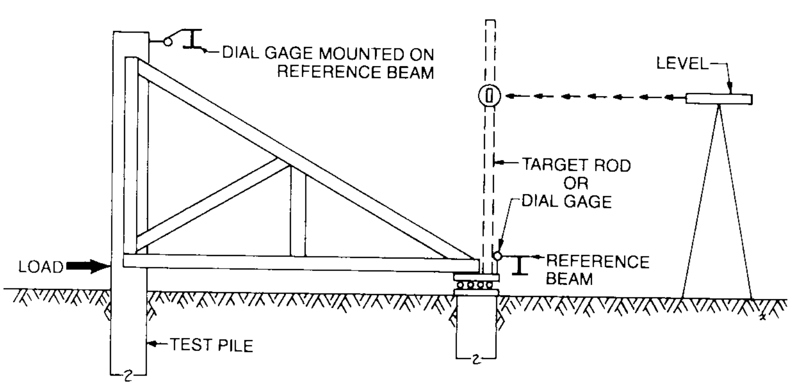
5.4 *Vertical Movement* (Optional)—Measure the vertical movements of the test pile(s) or pile group in accordance with 4.2 of Test Method D 1143 except that only one measuring system shall be required. For a test on an individual pile(s), a single reference point on the pile(s) is sufficient and for a test on a pile group, take readings on two reference points on opposite sides of the pile cap and in line with the applied load.



(a) SINGLE PILE



(b) PILE GROUP



(c) FIXED-HEAD

FIG. 10 Typical Arrangements for Measuring Pile Head Rotation

5.5 *Side Movement* (Optional)—Measure the movement of the test pile(s) or pile group in a direction perpendicular to the line of load application using either a dial gage mounted on a reference beam with the gage stem bearing against the side of the pile or pile cap or a scale mounted horizontally on the pile or pile cap perpendicular to the line of load application and read with an engineer's transit set up at a fixed position with the line of sight referenced to a fixed foresight or backsight.

NOTE 8—The measurement of vertical and side movements of the test pile under lateral loading may reveal eccentric loading or an abnormal behavior of the test pile. Such measurements are recommended if the precise response of the test pile to the lateral test load is required.

5.6 *Movement of Testing Apparatus* (Optional):

5.6.1 *Lateral Longitudinal Movements*—Measure the movements along the line of load application of the reference beam(s) and reaction system as well as the crushing of reaction system members using either an engineer's transit reading target scales attached to the reference beam(s) and the reaction system at strategic locations along the line of load application or by using dial gages suitably mounted and referenced. For transit readings, establish permanent transit stations and fixed backsights or foresights outside of the immediate test area.

5.6.2 *Vertical Movement*—Measure vertical movements of the reference beam(s) and reaction system using a surveyors level reading a target rod or scale located at strategic reference points along the line of load application. Reference level readings to a fixed bench mark located outside of the test area.

NOTE 9—To improve the reliability of measurements of test pile movements under load, it is recommended that the lateral and vertical movements of reference beams and the reaction system be measured in accordance with 5.6.

5.7 *Axial Deflections* (Optional)—Install in or on the test pile(s) to the depth(s) specified, tubing or ducts suitable to accommodate the types of inclinometer specified to be used.

NOTE 10—Except for very short stiff piles, inclinometer measurements are generally not warranted for the full length of the pile. Generally such measurements can be limited to the upper ⅓ to ½ of the pile length. The entire instrumentation system including materials, installation, equipment, and use should be set forth in the project specifications to the extent that this work is the responsibility of the contractor conducting the load tests.

6. Loading Procedures

6.1 *Standard Loading Procedures*—Unless failure occurs first, apply and remove a total test load equal to 200 % of the proposed lateral design load of the pile or pile group as follows:

Standard Loading Schedule

Percentage of Design Load	Load Duration, min
0	...
25	10
50	10
75	15
100	20
125	20
150	20
170	20
180	20
190	20
200	60
150	10
100	10
50	10
0	...

NOTE 11—Consideration should be given to limiting the lateral test load to that which would produce a maximum specified lateral movement, established for safety and load stability reasons.

6.2 *Loading in Excess of Standard Test Load* (Optional)—After applying and removing the standard test load in accordance with 6.1 (and 6.3 for standard loading if applicable), apply and remove the additional specified test loads in accordance with the following table:

Excess Loading Schedule
(following 6.1 loading)

Percentage of Design Load	Load Duration, min
0	10
50	10
100	10
150	10
200	10
210	15
220	15
230	15
240	15
250	15
etc. to maximum load specified in 10 % increments	etc. at 15 min intervals
max	30
75 max	10
50 max	10
25 max	10
0	...

6.3 *Cyclic Loading* (Optional)—Apply and remove the test load in accordance with the following table:

Cyclic Loading Schedules
Standard Loading

Percentage of Design Load	Load Duration, min	Percentage of Design Load	Load Duration, min
0	–	75	10
25	10	0	10
50	10	50	10
25	10	100	10
0	10	150	10
50	10	170	20
75	15	180	20
100	20	190	20
50	10	200	60
0	10	150	10
50	10	100	10
100	10	50	10
125	20	0	...
150	20		

Cyclic Loading Schedules
Excess Loading[A]

Percentage of Design Load	Load Duration, min	Percentage of Design Load	Load Duration, min
Follow standard		100	10
cylic loading		0	10
schedule to 200 %		50	10
200	60	100	10
100	10	150	10
0	10	200	10
50	10	250	10
100	10	260	15
150	10	270	15
200	10	280	15
210	15	290	15
220	15	300	30
230	15	225	10
240	15	150	10
250	15	75	10

200	10	0	...

[A] Schedule for 300 % maximum load. For loading in excess of 300 %, hold 300 % load for 15 min, follow loading and holding time pattern for additional loading and hold maximum load for 30 min.

6.4 *Surge Loading* (Optional):

6.4.1 *General*—Surge loading involves the application of any specified number of multiple loading cycles at any specified load level. Surge loading may be applied in conjunction with standard loading or after the completion of standard loading. Apply surge loads at a uniform rate by continuous activation of the hydraulic jack (or other power source) and remove the surge load at a uniform rate by continuous release of the power source.

6.4.2 *Surge Loading with Standard Loading*—Apply and remove the test load in accordance with the following table:

Surge Loading Schedule[A] with Standard Loading

Percentage of Design Load	Load Duration, min
0	...
25	10
50	10
75	15
100	20
50	10
0	10
100	...
0	...
100	...
0	...
50	10
75	10
100	10
125	20
150	20
75	10
0	10
150	...
0	...
150	...
0	...
50	10
100	10
150	10
170	20
180	20
190	20
200	60
100	10
0	10
200	...
0	...
200	...
150	10
100	10
50	10
0	...

[A] Schedule shown for two surges at three load levels. If additional surges are specified or at other load levels follow the same loading and holding pattern.

6.4.3 *Surge Loading After Standard Load*—After applying and removing loads in accordance with 6.1, reapply the load to each specified load level and for the specified number of loading cycles, allowing sufficient time at each zero and peak load level for taking and recording the required load-movement data.

6.5 *Reverse Loading* (Optional)—Reverse loading involves the application of lateral test loads in either the push mode followed by the pull mode or vice versa. Test the pile or pile group in accordance with the loading schedule in 6.1, 6.2, 6.3, or 6.4 as specified first in one direction and then in the opposite direction.

6.6 *Reciprocal Loading* (Optional)—Apply and remove each specified lateral load level first in one direction and then in the opposite direction for the number of specified cycles. Hold each peak and zero load until load-deflection readings can be taken.

NOTE 12—Suitable apparatus is required to permit reversing the loads. Double-acting hydraulic cylinders are available in various sizes that can be activated by hand-operated, electric-powered, or air-hydraulic-powered pumps. Fig. 11illustrates various possible setups for applying reverse and reciprocal loading. Reciprocal loads can be applied with a suitable powered crank and connecting rod system combined with a device to measure the applied loads.

6.7 *Loading to Specified Total Lateral Movement* (Optional)—Apply the lateral test loads in accordance with 6.1, 6.2, 6.3, or 6.4 as specified until the gross lateral movement of the test pile or group is as specified and then remove the test load in four equal decrements allowing 10 min between decrements.

6.8 *Combined Loading*—When the pile or pile group is tested under combined loading, in accordance with 4.7, apply the specified axial load before applying the lateral loads and hold the axial load constant during the application of the lateral loads in accordance with 6.1, 6.2, 6.3, or 6.4, as specified.

7. Procedures for Measuring Movements

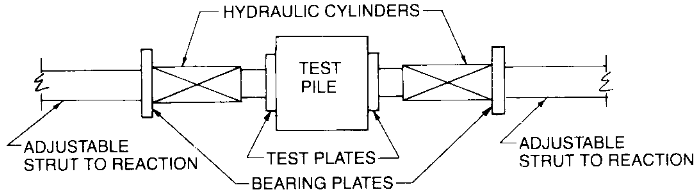
7.1 *General*—Take required readings at each properly identified gage, scale, or reference point as nearly simultaneously as practicable. Clearly indicate and explain any adjustments made during the tests to the instrumentation or to the data recorded in the field. Also clearly explain any discontinuities in the data. If method 5.2.2 is used, take readings by lining up the wire with its image in the mirror.

7.2 *Standard Measuring Procedures*—Take and record readings of time, load, and movement immediately before and after the application of each load increment and the removal of each load decrement. Take and record additional readings at 5-min intervals between load increments and load decrements. While the total test load is applied, take and record readings at not less than 15-min intervals. Take and record readings 15 min and 30 min after the total load has been removed. If pile failure occurs, take the reading immediately before removing the first load decrement.

7.3 *Measurements for Surge Loading*—For initial application of test loads, for holding periods, for initial removal of the load and after removal of all loads, take and record the readings of time, load, and movement in accordance with 7.2. For the surge loading, take and record readings at the start and end of each load application.

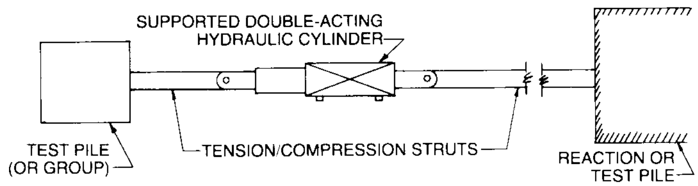
7.4 *Measurements for Combined Loading*—If load tests are conducted in accordance with 4.7, take and record readings of vertical and side movements of the test pile(s) or group in accordance with 5.4 and 5.5 before and after the axial load is applied and removed.

7.5 *Measurements for Rotational Movements*—If observation of rotational movements of the test pile is specified (5.3), take and record the readings of rotational movement immediately before and after the application of each load increment



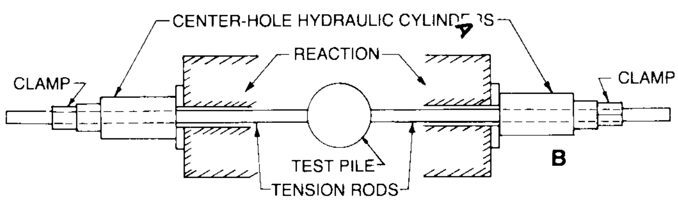
NOTES: 1. USE SINGLE-ACTING SOLID-PLUNGER HYDRAULIC CYLINDER (PUSH TYPE).
2. RELEASE CONNECTION BETWEEN TEST PILE AND REACTION ON SIDE OPPOSITE THAT OF LOAD APPLICATION (E.G. REMOVE JACK, BLOCKING, STRUT, ETC. OR RELEASE ADJUSTABLE STRUT).
3. PREVENT RESTRAINTS AGAINST LATERAL MOVEMENT OF TEST PILE UNDER LOAD.
4. NOT SUITABLE FOR RECIPROCAL LOADING.
5. LOAD CELLS WITH APPROPRIATE PLATES COULD BE INSERTED BETWEEN HYDRAULIC CYLINDERS AND TEST PLATES.

(a) WITH STANDARD HYDRAULIC CYLINDER



NOTES: 1. USE DOUBLE-ACTING HYDRAULIC CYLINDER IN COMBINATION WITH 4-WAY DIRECTIONAL VALVE.
2. START TEST WITH PLUNGER EXTENDED TO ONE-HALF ITS STROKE.
3. LATERAL MOVEMENT OF TEST PILE(S) EITHER SIDE OF CENTER IS LIMITED TO 1/2 THE PLUNGER STROKE.
4. STROKES RANGE FROM 8 TO 14 INCHES.
5. SUITABLE FOR RECIPROCAL LOADING.

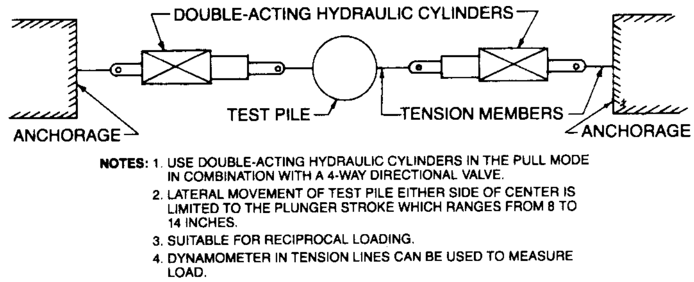
(b) WITH DOUBLE-ACTING HYDRAULIC CYLINDER



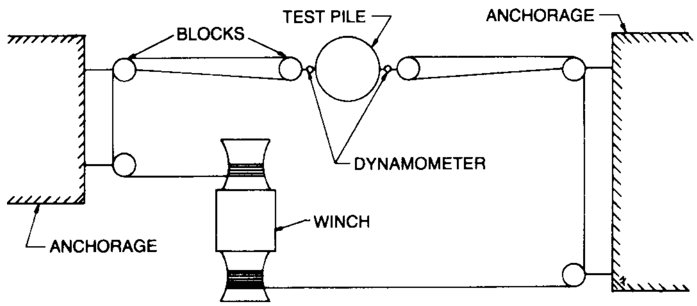
NOTES: 1. USE SINGLE-ACTING HOLLOW-PLUNGER HYDRAULIC CYLINDERS IN COMBINATION WITH 4-WAY DIRECTIONAL VALVE.
2. LATERAL MOVEMENT OF TEST PILE EITHER SIDE OF CENTER IS LIMITED TO 1/2 PLUNGER STROKE OR FROM 1 TO 1-1/2 INCHES UNLESS SYSTEM OPERATED AS FOLLOWS:
A. RELEASE CLAMP A — ACTIVATE CYLINDER B
B. RELEASE LOAD FROM CYLINDER B
C. RELEASE CLAMP B — ACTIVATE CYLINDER A
D. RELEASE LOAD FROM CYLINDER A
3. SUITABLE FOR LIMITED RECIPROCAL LOADING.
4. LOAD CELLS WITH APPROPRIATE PLATES COULD BE INSERTED BETWEEN REACTIONS AND HYDRAULIC CYLINDERS.

(c) WITH TWO CENTER-HOLE HYDRAULIC CYLINDERS

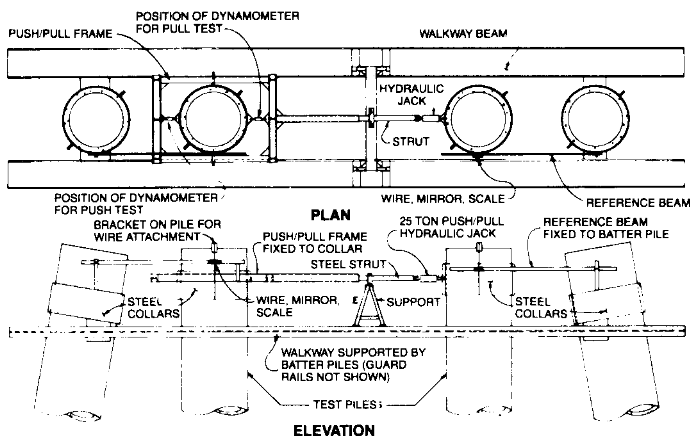
FIG. 11 Typical Reverse Lateral Loading Set Ups



(d) WITH TWO PULL-TYPE HYDRAULIC CYLINDERS



(e) WITH TWO-DRUM WINCH



(f) WITH SPECIAL PUSH-PULL FRAME

(COURTESY RAYMOND INTERNATIONAL, INC.)

FIG. 11 *(continued)*

and the removal of each load decrement. Take and record final recovery readings 30 min after the total test load has been removed.

7.6 *Measurements for Fixed-Head Tests, for Vertical and Side Movements, and for Movements of Testing Apparatus*—If the requirements of 4.6, 5.4, 5.5, or 5.6 are specified, take and record the readings before any test load is applied, at the proposed design load, at the maximum applied load and after all loads have been removed. Intermediate readings may be required if such measurements during testing appear unusual.

8. Safety Precautions

8.1 All operations in connection with pile load testing should be carried out in such a manner so as to minimize, avoid, or eliminate the exposure of people to hazards. Following are examples of safety rules to be followed in addition to general safety requirements applicable to construction operations.

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

8.1.2 All timbers and blocking and cribbing material shall be of quality material and be in good serviceable condition with flat surfaces and without rounded edges.

8.1.3 Hydraulic cylinders shall be equipped with spherical bearing plates, shall be in complete and firm contact with the bearing surfaces, and shall be aligned so as to avoid eccentric loading.

8.1.4 All struts used to transfer test loads to the reaction system or to another test pile or group shall be of steel, and shall be of sufficient size, strength, and stiffness to resist without excessive bending or deflection, a compression load 25 % greater than the maximum test load to be applied.

8.1.5 All tension rods used for pull tests shall be of sufficient size and strength to resist without excessive elongation a tension load 25% greater than the maximum test load to be applied and shall be adequately connected to the test pile or group, to the hydraulic cylinder, and to the anchorage system.

8.1.6 All lines, rope, and cable used for pull tests shall be in good serviceable condition, free of abrasive wear, broken strands, kinks, and knots, and shall be of sufficient strength to resist a load 50 % greater than the maximum test load to be applied and shall be adequately connected to the test pile or group, to the power source, and to the reaction system.

8.1.7 All reaction systems shall be designed and constructed to have a reactive capacity sufficient to resist a load 25 % greater than the maximum test load to be applied.

8.1.8 All struts, blocking, bearing plates, and testing equipment shall be accurately aligned to minimize eccentric loading, and where necessary shall be restrained from shifting as test loads are applied so as not to affect the test results.

8.1.9 Attachments to the test pile(s), pile cap, or reaction system shall be designed and installed to transmit the required loads with an adequate factor of safety.

8.1.10 Loads shall not be hoisted, swung, or suspended over anyone and shall be controlled by tag lines.

8.1.11 All personnel shall stand clear of the jacking or pulling systems whenever test loads are being applied.

8.1.12 Only authorized personnel shall be permitted within the immediate test area.

9. Report

9.1 The report of the load test shall include the following information when applicable:

9.1.1 *General*:

9.1.1.1 Project identification,

9.1.1.2 Project location,

9.1.1.3 Test site location,

9.1.1.4 Owner,

9.1.1.5 Structural (foundation) engineer,

9.1.1.6 Geotechnical engineer,

9.1.1.7 Pile contractor,

9.1.1.8 Test boring contractor,

9.1.1.9 Designation and location of nearest test boring with reference to test pile or group,

9.1.1.10 Log of nearest test boring,

9.1.1.11 Horizontal control datum, and

9.1.1.12 Vertical control (elevation) datum.

9.1.2 *Pile Installation Equipment*:

9.1.2.1 Make, model, type, and size of hammer,

9.1.2.2 Rated energy of hammer, and

9.1.2.3 Size of predrilling or jetting equipment.

9.1.3 *Test and Reaction Piles*:

9.1.3.1 Identification of test and reaction piles,

9.1.3.2 Location of test piles and anchorage or reaction system,

9.1.3.3 Design load of pile or pile group,

9.1.3.4 Type of pile(s)—test and reaction,

9.1.3.5 Test pile material including basic specifications,

9.1.3.6 Tip and butt dimensions of pile(s),

9.1.3.7 General quality of timber test piles including occurrence of knots, splits, checks, and shakes, and straightness of piles,

9.1.3.8 Preservative treatment and conditioning process used for timber test piles including inspection certificates,

9.1.3.9 Wall thickness of pipe test pile,

9.1.3.10 Weight per foot of H-test pile,

9.1.3.11 Description of banding—timber piles,

9.1.3.12 Date precast test piles made,

9.1.3.13 Concrete cylinder strengths when pile tested (approximate),

9.1.3.14 Description of internal reinforcement used in test pile (size, length, number, longitudinal bars, arrangement, spiral or tie steel),

9.1.3.15 Condition of precast piles including spalled areas, cracks, head surface, and straightness of piles,

9.1.3.16 Effective prestress,

9.1.3.17 Number of piles in test or reaction group,

9.1.3.18 Which piles vertical or batter,

9.1.3.19 Degree of batter,

9.1.3.20 Embedded length—test and reaction piles,

9.1.3.21 Final elevation of test pile butt(s) and the ground surface at test pile, referenced to fixed datum, and

9.1.3.22 The depth of excavation and the distance from test pile(s) to adjacent excavation banks.

9.1.4 *Pile Installation-Test and Reaction*:

9.1.4.1 Date driven (installed),

9.1.4.2 Date concreted (cast-in-place),

9.1.4.3 Description of concrete (grout) mix including slump (cast-in-place),

9.1.4.4 Volume of concrete or grout placed in pile,

9.1.4.5 Description of pre-excavation or jetting (depth, size, pressure, duration),

9.1.4.6 Description of special installation procedures used,

9.1.4.7 Type and location of pile splices,

9.1.4.8 Driving logs (blows per foot),

9.1.4.9 Final penetration resistance (blows per inch),

9.1.4.10 Cause and duration of interruptions in pile installation, and

9.1.4.11 Notations of any unusual occurrences during installation.

9.1.5 *Pile Testing*:

9.1.5.1 Date tested,

9.1.5.2 Type of lateral test,

9.1.5.3 Brief description of load application apparatus, including jack capacity,

9.1.5.4 Description of instrumentation used to measure pile movement including location of gages or other reference points (see Note 13),

9.1.5.5 Description of special instrumentation such as inclinometers,

9.1.5.6 Point of load application with reference to top of pile or pile cap, and to ground surface.

9.1.5.7 Special testing procedures used,

9.1.5.8 Axial load—type, amount, how applied, 9.1.5.9 Identification and location sketch of all gages, scales, and reference points (see Note 13),

9.1.5.10 Tabulation of all time, load, and movement readings,

9.1.5.11 Tabulation of inclinometer readings, declination versus depth,

9.1.5.12 Description and explanation of adjustments made to instrumentation, or field, data, or both,

9.1.5.13 Notation of any unusual occurrences during testing,

9.1.5.14 Test jack and other required calibration reports, and

9.1.5.15 Temperature and weather conditions during tests.

NOTE 13—In addition to the above required information to be reported, the results of any in-place and laboratory soil tests should be made available for the proper evaluation of test results.

NOTE 14—Suitable photographs can be very helpful in showing the instrumentation set-up, location of gages, scales, and reference points.

10. Precision and Bias

10.1 *Precision*—It is not practicable to specify the precision of the procedure in this test method for measuring pile movement versus applied load because each 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.

10.2 *Bias*—There is no true value for the data resulting from this test method for measuring pile movement versus applied load since each pile is unique due to the variable nature of the ground in which it is embedded. Therefore, no statement on bias is being made.