Designation: D 5780 – 95 (Reapproved 2002)

Standard Test Method for
Individual Piles in Permafrost Under Static Axial Compressive Load[1]

INTRODUCTION

This test method has been prepared to cover methods of axial load testing of piles in permafrost. The provisions permit the introduction of more detailed requirements and procedures when required to satisfy the objectives of the test program. The procedures herein produce a relationship between applied load and pile settlement for conditions of ground temperature at the time of test. The results may be interpreted to establish long-term load capacity of piles in permafrost.

1. Scope

1.1 This test method covers procedures for testing individual vertical piles to determine response of the pile to static compressive load applied axially to the pile. This test method is applicable to all deep foundation units in permafrost that function in a manner similar to piles regardless of their method of installation. This test method is divided into the following sections:

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NOTE 1—Apparatus and procedures designated "optional" are to be required only when included in the project specifications or 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, illustrations, and appendixes included herein are explanatory or advisory.

NOTE 2—This test method does not include the interpretation of test results or the application of test results to foundation design. See Appendix X1 for comments regarding some of the factors influencing the interpretation of test results. A qualified geotechnical engineer should interpret the test results for predicting pile performance and capacity.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.3 *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.* Specific precautionary statements are given in Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
2.2 *ANSI Standard:*
B 30.1 Safety Code for Jacks[3]

3. Terminology

3.1 *Definitions:*

3.1.1 The standard definitions of terms and symbols relating to soil and rock mechanics is Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adfreeze bond strength*—the strength of the bond developed between frozen soil and the surface of the pile.

3.2.2 *base load*—a load equivalent to the design load adjusted for test pile geometry and expected ground temperature.

3.2.3 *creep load*—that load applied to measure a rate of displacement.

3.2.4 *creep load increment*—an incremental load applied to a pile to determine the rate of displacement at 10 % of a failure load or at 100 % of a design load.

3.2.5 *design active layer*—the maximum depth of annual thaw anticipated surrounding the pile under design conditions.

3.2.6 *failure (in piles)*—pile displacement that is occurring at an increasing rate with time under the action of a constant load, incremental pile displacement that is increasing for uniform time increments, or a creep rate which exceeds 100 % of the design creep rate when loaded to 100 % of the design load.

3.2.7 *failure load*—that load applied to a pile to cause failure to occur.

3.2.8 *failure load increment*—the load increment applied to a pile that causes failure within a specified time period.

3.2.9 *freezeback*—for the purpose of this test method, freezeback shall be defined as the attainment of a subfreezing temperature at each ground temperature measuring point located below the design active layer, which have attained equilibrium with the surrounding soil.

3.2.10 *ice-poor*—frozen soil with a high solids concentration whose behavior is characterized mainly by soil particle contacts.

3.2.11 *ice-rich*—frozen soil with a moderate to low solids concentration whose behavior is characterized by ice particle contacts.

3.2.12 *pile, driven*—a pile driven into the ground with an impact or vibratory pile hammer.

3.2.13 *pile, grouted*—a pile placed in an oversized, pre-drilled hole and backfilled with a sand, cement grout.

3.2.14 *pile, slurried*—a pile placed in an oversized, pre-drilled hole and backfilled with a soil/water slurry.

3.2.15 *subfreezing temperature*—any temperature below the actual freezing temperature of the soil water combination being used.

3.2.16 *time to failure*—the total time from the start of the current test load increment to the point at which failure begins to occur.

4. Significance and Use

4.1 This test method will provide a relationship between time to failure, creep rate, and displacement to failure for specific failure loads at specific test temperatures as well as a relationship between creep rate and applied load at specific test temperatures for loads less than failure loads.

4.2 Pile design for specific soil temperatures may be controlled by either limiting long-term stress to below long-term strength or by limiting allowable settlement over the design life of the structure. It is the purpose of this test method to provide the basic information from which the limiting strength or long-term settlement may be evaluated by geotechnical engineers.

4.3 Data derived from pile tests at specific ground temperatures that differ from the design temperatures must be corrected to the design temperature by the use of data from additional pile tests, laboratory soil strength tests, or published correlations, if applicable, to provide a suitable means of correction.

4.4 For driven piles or grouted piles, failure will occur at the pile/soil interface. For slurried piles, failure can occur at either the pile/slurry interface or the slurry/soil interface, depending on the strength and deformation properties of the slurry material and the adfreeze bond strength. Location of the failure surface must be taken into account in the design of the test program and in the interpretation of the test results. Dynamic loads must be evaluated separately.

5. Installation of Test Pile(s)

5.1 Install the test pile according to the procedures and specifications used for the installation of the production piles.

NOTE 3—Because the pile behavior will be influenced by the soil type, temperature, ice content, and pore water salinity, the engineer must ensure that adequate information is available for soil/ice conditions at the construction site to determine their effect on the pile performance (that is, test pile should be installed in the same condition as the production piles—preferably at the same site).

5.2 The design and installation of the test pile shall address the effects of end bearing, as opposed to the shear resistance on the shaft of the pile. Address end bearing by measuring its effect, eliminating its effect, or accounting for its effect analytically. Measure end bearing by attaching a load cell to the tip of the pile prior to installation or by attaching a series of strain gages along the length of the pile prior to installation. Eliminate end bearing by attaching a compressible layer to the tip of the pile prior to installation or by providing a void beneath the tip of the pile.

5.3 Install thermistors or other temperature-measuring devices adjacent to the test pile to determine the ground temperature profile adjacent to the pile. Measure ground temperature in frozen ground at a minimum of three locations along the length of pile; for piles longer than 10 ft (3 m), it is recommended that ground temperatures be measured at 5-ft (1.5-m) depth intervals. Install the temperature-measuring devices in contact with the exterior pile surface; for slurried piles, installation may be as shown in Fig. 1; for driven piles, installation may be as shown in Fig. 2.

5.4 Measure ground temperatures periodically using the installed temperature-measuring devices to determine when freezeback occurs.

5.5 Where freezeback of soils adjacent to the pile is aided by the circulation of cold air or liquid coolant, discontinue such cooling when the measured ground temperatures become equal to the desired ground temperature for the pile test; significant overcooling shall not be permitted to occur. When freezeback of soils adjacent to the test piles is aided by a designed cooling system, such designed cooling system shall also be applied in a similar manner to all reaction piles to ensure freezeback of the reaction piles.

5.6 Isolate the surface of the test pile from the surrounding soil or ice over the depth of the design active layer. This may be accomplished by using a sleeve or casing. For slurried piles, a greased wrapping or other technique that will essentially eliminate the transfer of shear forces between the pile and the surrounding soil/ice in the design active layer may be used.

5.7 Where feasible, excavate the immediate area of the test pile or fill to the proposed finished grade elevation. Cut off test piles or build up to the proper grade necessary to permit
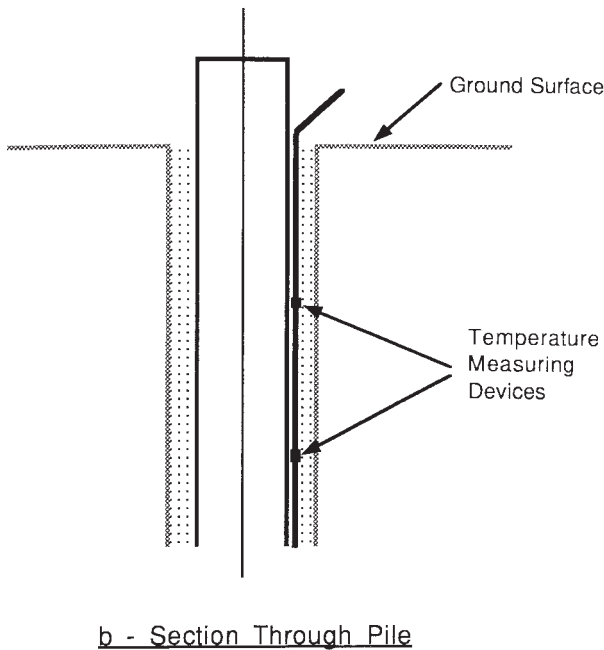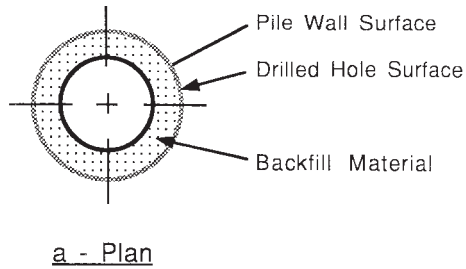
FIG. 1 Placement of Temperature Measuring Devices for Slurried Test Pile

FIG. 2 Potential Placement of Temperature Measuring Devices for Driven Structural-Shaped Test Pile

construction of the load-application apparatus, placement of the necessary testing and instrumentation equipment, and observation of the instrumentation. Where necessary, brace the unsupported length of the test pile(s) to prevent buckling without influencing the test results.

5.8 If the top of the pile has been damaged during installation, remove the damaged portion prior to the test.

NOTE 4—Consideration should be given to placing insulation on the ground surface around the test pile in order to reduce the variation in ground temperatures with time during the testing period. Where used, ground surface insulation should be placed all around the test pile to a distance of 5 ft (1.5 m), two times the depth of thawed soil or one third of the installed pile length, whichever is greater. The effect of insulation at the surface should be taken into account in the design of production piles, which could be done analytically.

5.9 Allow the lateral normal stresses between the pile surface and the surrounding soil that develop during pile installation or freezeback, or both, to dissipate to a nominal level prior to pile testing. For purposes of this test method, the delay time corresponding to the approximate test condition from Table 1 shall be permitted to occur prior to commencing load application to allow for the dissipation of normal stresses on the pile shaft as discussed above.
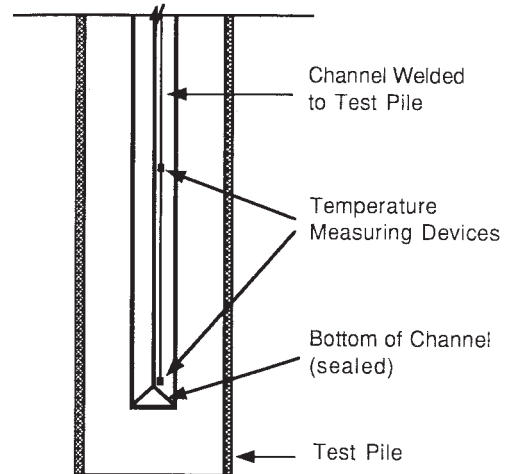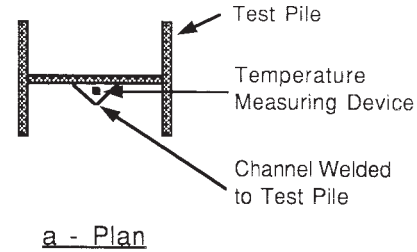
TABLE 1 Minimum Delay Times (Days After Freezeback)

Permafrost Condition	Ground Temperature, – °F (°C)	Delay Times, Days	
		Driven Piles	Slurried Piles
Ice-poor	above 28 (–2)	10	14
	23 to 28 (–2 to – 5)	5	7
	below 23 (–5)	2	3
Ice-rich	above 28 (–2)	14	20
	23 to 28 (–2 to – 5)	7	10
	below 23 (–5)	5	7

NOTE 5—The engineer may direct that delay times other than those shown in Table 1 be implemented, based on other completed pile test results, laboratory test results, or analytical results. Such other time interval shall allow for the dissipation of normal stresses developed due to pile installation or freezeback, or both, to a level of 1 % or less of their maximum value.

6. Apparatus for Applying Loads

6.1 *General*:

6.1.1 The apparatus for applying compressive loads to the test pile shall be as described in 6.3, 6.4, or 6.5, or as otherwise specified and shall be constructed so that the loads are applied to the central longitudinal axis of the pile to minimize eccentric loading. Subsections 6.3-6.5 are suitable for applying axial loads to individual vertical piles.

NOTE 6—Consideration should be given to providing sufficient clear space between the pile cap and the ground surface to eliminate any support of the cap by the soil. A properly constructed steel grillage may serve as an adequate pile cap for testing purposes.

6.1.2 For testing an individual pile, center a steel-bearing plate(s) on the pile and set perpendicular to the longitudinal axis of the pile. It shall be of sufficient thickness to prevent it from bending under the loads involved (but not less than 2 in. (50 mm) thick). The size of the test plate shall be not less than the size of the pile top nor less than the area covered by the base(s) of the hydraulic jack(s).

6.1.3 For tests on precast or cast-in-place concrete piles, set the test plate, when used, in high-strength quick-setting grout. For tests on individual steel H-piles or pipe piles, weld the test plate to the pile. For tests on individual timber piles, the test plate may be set directly on the top of the pile that shall be sawed off to provide full bearing of the test plate, or alternatively, the test plate may be set in high-strength quick-setting grout.

6.1.4 In 6.3 and 6.4, center the hydraulic jack(s) on the test plate(s) with a steel-bearing plate of adequate thickness between the top(s) of the jack ram(s) and the bottom(s) of the test beam(s). If a load cell(s) or equivalent device(s) is to be used, center it on the bearing plate above the ram(s) with another steel bearing plate of sufficient thickness between the load cell(s) or equivalent device(s) and the bottom(s) of the test beam(s). Bearing plates shall be of sufficient size to accommodate the jack ram(s) and the load cell(s) or equivalent device(s) and properly bear against the bottom(s) of the test beam(s).

6.1.5 In 6.5, a test plate may be used in accordance with the appropriate provisions of 6.1 or, alternatively, the test beam(s) may be set directly on the pile cap or the loading material applied directly on the cap. Test beam(s) set directly on the cap shall obtain full bearing using high-strength quick-setting grout, if necessary.

6.2 *Testing Equipment*:

6.2.1 Hydraulic jacks including their operation shall conform to ANSI B30.1.

6.2.2 Unless a calibrated load cell(s) is used, calibrate the complete jacking system including the hydraulic jack(s), hy-

draulic pump, and pressure gage as a unit before each test or series of tests in a test program to provide an accuracy of less than 1 % of the applied load. Calibrate the hydraulic jack(s) over its complete range of ram travel for increasing and decreasing applied loads at a temperature within the air temperature range expected to occur during the load test. If two or more jacks are to be used to apply the test load, they shall be of the same ram diameter, connected to a common manifold and pressure gage, and operated by a single hydraulic pump.

NOTE 7—Where tests will be carried out in subfreezing fluctuating air temperatures, it is recommended that thermal insulation be applied to the hydraulic jack, the hydraulic lines, and other components of the loading system.

6.2.3 When an accuracy greater than that obtainable with the jacking system is required, use a properly constructed load cell(s) or equivalent device(s) in series with the hydraulic jack(s). Calibrate load cell(s) or equivalent device(s) prior to the test to provide an accuracy of less than 1 % of the applied load and equipped with a spherical bearing(s).

6.2.4 The hydraulic jack pump shall be equipped with an automatic regulator or accumulator to maintain the load within 1 % of the specified load as pile settlement occurs.

6.2.5 Furnish calibration reports for all testing equipment for which calibration is required, and show the temperature at which the calibration was done.

NOTE 8—Considerations should be given to employing a dual load-measuring system (jack pressure and load cell) to provide a check and as a backup in case one system malfunctions. Hydraulic jack rams should have sufficient travel to allow for anticipated pile settlements, deflections of the test beam, and elongation of connections to anchoring devices.

6.2.6 The use of a single high-capacity jack is preferred to the use of multiple jack(s). If a multiple jacking system is used, each jack should be fitted with a pressure gage (in addition to the master gage) in order to detect malfunctions.

6.3 *Load Applied to Pile by Hydraulic Jack(s) Acting Against Anchored Reaction Frame (see Fig. 3)*:

6.3.1 Install a sufficient number of anchor piles or suitable anchoring device(s) to provide adequate reactive capacity. Provide a clear distance from the test pile of at least five times
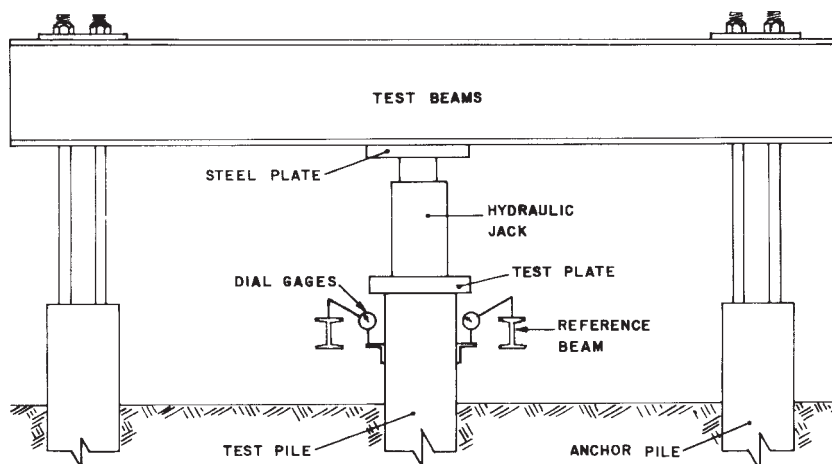

FIG. 3 Schematic Setup for Applying Loads to Pile Using Hydraulic Jack Acting Against Anchored Reaction Frame

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the maximum diameter of the largest anchor or test pile(s) or 6 ft (2 m), whichever is greater.

6.3.2 Center a test beam(s) of sufficient size and strength over the test pile to avoid excessive deflection under load. Provide sufficient clearance between the bottom flange(s) of the test beam(s) and the top of the test pile for the necessary bearing plates, hydraulic jack(s) or load cell(s), or both, if used. For large test loads requiring several anchors, a steel framework may be required to transfer the applied loads from the test beam(s) to the anchors.

6.3.3 Attach the test beam(s) (or reaction framework if used) to the anchoring devices with connections designed to adequately transfer the applied loads to the anchors so as to prevent slippage, rupture, or excessive elongation of the connections under the maximum required test load.

6.3.4 Apply the test load to the test pile with the hydraulic jack(s) reacting against the test beam(s) in accordance with the loading procedure in 8.1 or as otherwise specified.

6.4 *Load Applied to Pile by Hydraulic Jack(s) Acting Against a Weighted Box or Platform (see Fig. 4)*:

6.4.1 Center the test pile under a test beam(s) of sufficient size and strength to avoid excessive deflection under load allowing sufficient clearance between the top of the test pile or pile cap and the bottom(s) of the beam(s) after deflection under load to accommodate the necessary bearing plates, hydraulic jack(s), (and load cell(s) if used). Support the ends of the test beam(s) on temporary cribbing or other devices.

6.4.2 Center a box or platform over the test beam(s) with the edges of the box or platform parallel to the test beam(s) supported by cribbing or piles placed as far from the test pile as practicable but in no case less than a clear distance of 6 ft (2.0 m). If cribbing is used, the bearing area of the cribbing at ground surface shall be sufficient to prevent adverse settlement of the weighted box or platform. Insulation may be placed beneath the cribbing to mitigate the effects of thaw settlement.

6.4.3 Load the box or platform with any suitable material such as soil, rock, concrete, steel, or water-filled tanks with a total weight (including that of the test beam(s) and the box or platform) at least 10 % greater than the anticipated maximum test load.

6.4.4 Apply the test loads to the pile with the hydraulic jack(s) reacting against the test beam(s) in accordance with 8.1 or as otherwise specified.

6.5 *Load Applied Directly to the Pile With Known Weights (see Fig. 5)*:

6.5.1 Center on the test plate or pile cap a test beam(s) of known weight and of sufficient size and strength to avoid excessive deflection under load with the ends supported on temporary cribbing if necessary to stabilize the beam(s). Alternatively, the known test weights or loading material may be applied directly on the pile or pile cap.

6.5.2 Center and balance a platform of known weight on the test beam(s) or directly on the pile cap with overhanging edges of the platform parallel to the test beam(s) supported by cribbing or by piles capped with timber beams, so that a clear distance of not less than 6 ft (2.0 m) is maintained between the supports and the test pile or pile group.

6.5.3 Place sufficient pairs of timber wedges between the top of the cribbing or timber cap beams and the bottom edges of the platform so that the platform can be stabilized during loading or unloading.

6.5.4 When the platform is ready to load, remove any temporary supports at the ends of the test beam(s) and tighten the wedges along the bottom edges of the platform so that the platform is stable. Load the platform in accordance with the standard loading procedures in 8.1 or as otherwise specified using material such as steel or concrete so that the weight of incremental loads can be determined within 1 %.

NOTE 9—With the loading apparatus described in 6.5, provisions can be made for taking target rod level readings directly on the center of the pile or pile cap or center of the test plate to measure pile top movements as specified in 7.2.3. For tests on concrete piles, a hole is required in the center of the test plate through which would extend a steel pin embedded in the top of the pile or pile cap. For tests on steel or timber piles, readings
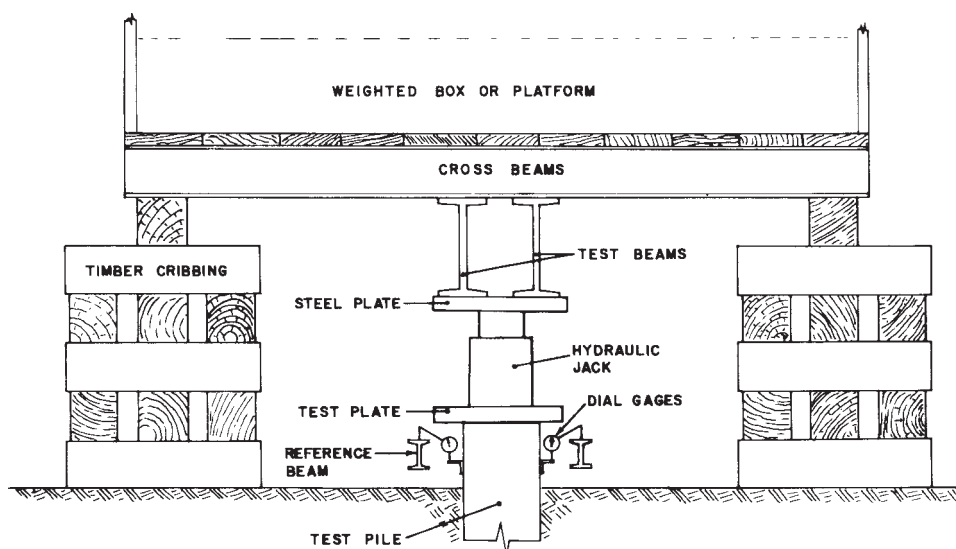

FIG. 4 Schematic Setup for Applying Loads to Pile Using Hydraulic Jack Acting Against Weighted Box or Platform
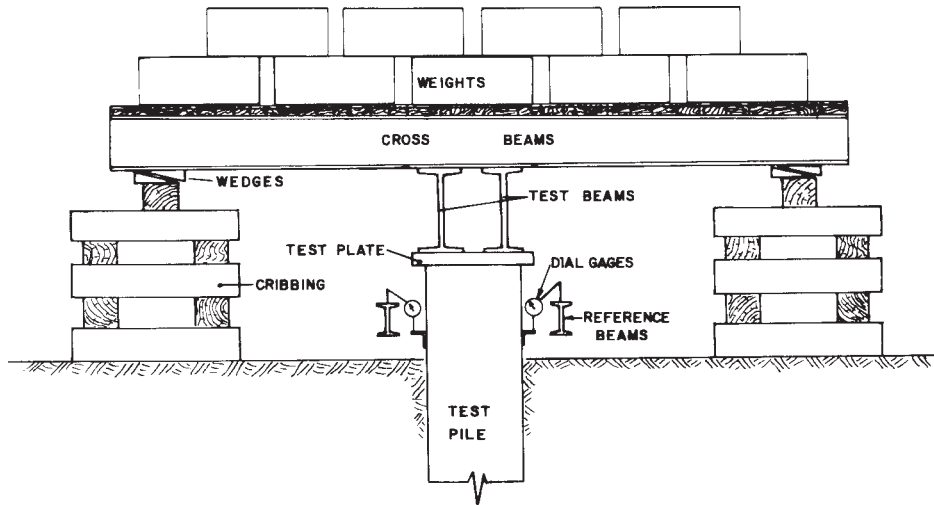
FIG. 5 Schematic Setup for Applying Loads Directly to Pile Using Weighted Platform

would be taken on the test plate. To accommodate the target rod, a double test beam must be used with sufficient space between the beams and a hole must be left through the platform. To permit sighting on the target rod, it may be necessary to leave a space between the test weights in line with the line of sight.

6.6 *Other Types of Loading Apparatus (Optional)*—Any other type of loading apparatus satisfying the basic requirements of 6.3 or 6.4 may be used.

7. Apparatus for Measuring Movement

7.1 *General*:

7.1.1 All reference beams and wires shall be independently supported with supports firmly embedded in the ground at a clear distance of not less than 8 ft (2.5 m) from the test pile and as far as practical from the anchor piles or cribbing. Reference beams shall be sufficiently stiff to support the instrumentation such that excessive variations (± 0.0004 in. (± 0.01 mm)) in readings do not occur. If steel reference beams are used, one end of each beam shall be free to move horizontally as the beam length changes with temperature variations. Reference beams and the exposed length of the test pile shall be shielded from direct sunlight and exposure to the wind. Movement of the reference beams due to ambient temperature variations can be minimized through the addition of thermal insulation to the reference beams.

7.1.2 Reference and reaction beams shall each include one thermistor or other temperature-measuring device attached to each beam at or near the dial gage location or near the point of load application. The thermistor or other temperature-measuring device shall be located and attached in a manner which will allow the measurement of the temperature of the reference and reaction beams.

7.1.3 Dial gages shall have at least a 1-in. (25-mm) travel; longer gage stems or sufficient gage blocks shall be provided to allow for greater travel if anticipated. Gages shall have a precision of at least 0.0001 in. (0.0025 mm). Smooth bearing surfaces (such as glass) shall be provided for the gage stems perpendicular to the direction of gage-stem travel.

7.1.4 All dial gages, scales, and reference points shall be clearly marked with a reference number or letter to assist in

recording data accurately. Provisions shall be made to protect the measuring system, reference system, and instrumentation from adverse temperature variation and from disturbance. All gages, scales, or reference points attached to the test pile or pile cap shall be mounted so as to prevent movement relative to the test pile cap or pile cap during the test.

7.1.5 Prior to commencement of the loading procedures detailed in 8.1, the movements of each reference beam with varying air temperature shall be measured during a 24-h calibration period. During this 24-h period, dial gage measurements and reference and reaction beam temperature measurements shall be taken concurrently at 30-min intervals and the test pile shall be subjected to a nominal load to seat the loading system on the top of the test pile. This nominal load shall be maintained at a constant value during the calibration load period. The data obtained during the calibration load period shall be used to develop a deflection correction curve for the measured reference beam temperature.

7.2 *Pile Top Axial Movements (see Fig. 6)*—The apparatus for measuring axial movement of the top of the test pile shall consist of a primary and secondary system in accordance with the following methods. The primary system shall consist of dial gages or other system with a precision of at least 0.0001 in. (0.0025 mm). The secondary system shall have a precision of at least 0.01 in. (0.25 mm).

NOTE 10—Two separate measuring systems are required in order to provide 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.

7.2.1 *Dial Gages (Primary)*—Two parallel reference beams, one on each side of the test pile or pile cap, shall be oriented in a direction that permits placing their supports as far as practicable from anchor piles or cribbing. A minimum of two dial gages shall be mounted on the reference beams approximately equidistant from the center of and on opposite sides of the test pile or pile cap with stems parallel to the longitudinal axis of the pile and bearing on lugs firmly attached to the sides of the pile or pile cap below the test plate. Alternatively, the two dial gages shall be mounted on opposite sides of the test
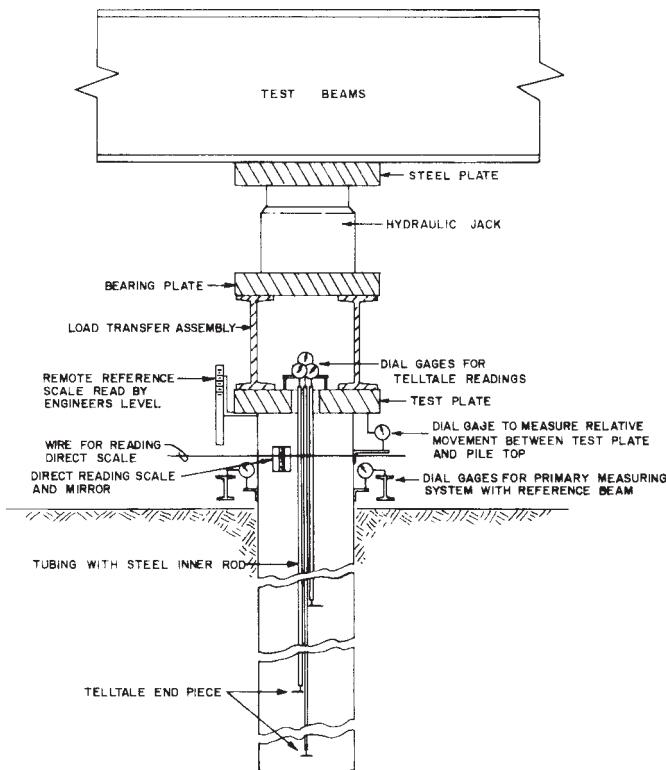
FIG. 6 Possible Arrangement of Instrumentation for Measuring Vertical Movements of Pile

pile cap below the test plate with stems parallel to the longitudinal axis of the pile(s) and bearing on lugs firmly attached to the reference beams. However, gages may be mounted to bear on the top of the pile cap or on the test plate provided that two additional gages shall be mounted on opposite sides of the test plate to measure relative movements between the test plate and the pile or pile cap (see Fig. 6).

NOTE 11—The use of four dial gages mounted 90° apart is recommended to compensate for lateral movement or rotation of the pile top due to accidental eccentric loading.

7.2.2 *Wire, Mirror, and Scale (Secondary)*—Two parallel wires, one on each side of the test pile or pile cap, shall be oriented in a direction that permits placing the wire supports as far as practicable from anchor piles or cribbing. Each wire shall pass across and be clear of the face of a scale that is mounted parallel to the axis of the test pile and that is attached to a mirror fixed to the test pile or pile cap so that consistent readings of axial movement can be made directly from the scale by lining up the wire and its image in the mirror. The wire shall not be more than 1 in. (25 mm) from the face of the scale. A suitable method shall be used to maintain tension in the wires throughout the test so that when plucked or tapped, the wire will return to its original position. Piano wire or equivalent type shall be used.

7.2.3 *Surveyor's Level or Laser Beam (Secondary)*— Readings using a surveyor's level or laser beam shall be taken on a target rod or a scale and shall be referenced to a permanent bench mark located outside of the immediate test area or,

alternatively, the surveyor's level shall be mounted on an object of fixed elevation (for example, another pile) outside of the immediate test area. Measuring points or scales used in taking settlement readings shall be mounted on the sides of the test pile or pile cap and located on opposite sides except that measuring points may be on top of the pile or readings may be taken on a single fixed point in the center of the test pile top, test plate or pile cap, or on scales mounted on the test plate provided that relative movements between the test plate and the top of the pile are measured in accordance with 7.2.1 (see Fig. 7).

7.2.4 *Other Types of Measuring Apparatus (Optional)*— Any other type of measuring device such as electric or optical gages of proven reliability and that yield an accuracy of 0.0001 in. (0.0025 mm) may be used as a primary system.

7.3 *Lateral Movements (Optional)*—The lateral movements of the top of the test pile or pile group shall be measured to an accuracy of 0.1 in. (2.5 mm) using either of the following methods: (*a*) two dial gages mounted on the reference beam 90° apart with their stems perpendicular to the longitudinal axis of the test pile(s) and bearing against the sides of the test pile or pile cap, or (*b*) an engineer's transit reading from fixed positions scales mounted horizontally on the sides of the test pile or pile cap 90° apart with readings references to fixed foresights or backsights.

7.4 *Incremental Strain Measurements (Optional)*:

7.4.1 The test pile(s) shall be instrumented as specified to determine distribution of load transfer from the pile to the soil. If displacement rods or telltales (see Fig. 6, Fig. 7, Fig. 8, and Fig. 9) are used, they shall be installed in or on the test pile terminating at the pile tip and at other points along that pile as required and shall be sheathed or encased to ensure free movement of the rods during the test. The influence of the sheathing on the elastic properties of the pile section shall be considered. If electric resistance strain gages are used, the gage type and installation shall be as specified and shall include temperature-compensating gages.

NOTE 12—Where feasible, measurement programs involving strain gages should include calibration of the fully instrumented pile and a notation of complete strain history starting before the pile is installed.

7.4.2 Pile top axial movements shall be measured with dial gages (see 7.2.1). The movements of the top of each displacement rod relative to the top of the test pile shall be measured with a dial gage reading to 0.0001 in. (0.0025 mm). Dial gages shall be referenced to points on the test pile below the test plate except that they may be referenced to the top of the test plate if the plate is welded to the pile or if relative movements between the top of the test pile and the test plate are measured in accordance with 7.2.1 (see Fig. 6).

8. Safety Requirements

8.1 Carry out all operations in connection with pile load testing in such a manner so as to eliminate the exposure of people to hazard. The following safety rules are in addition to general safety requirements applicable to construction operations:
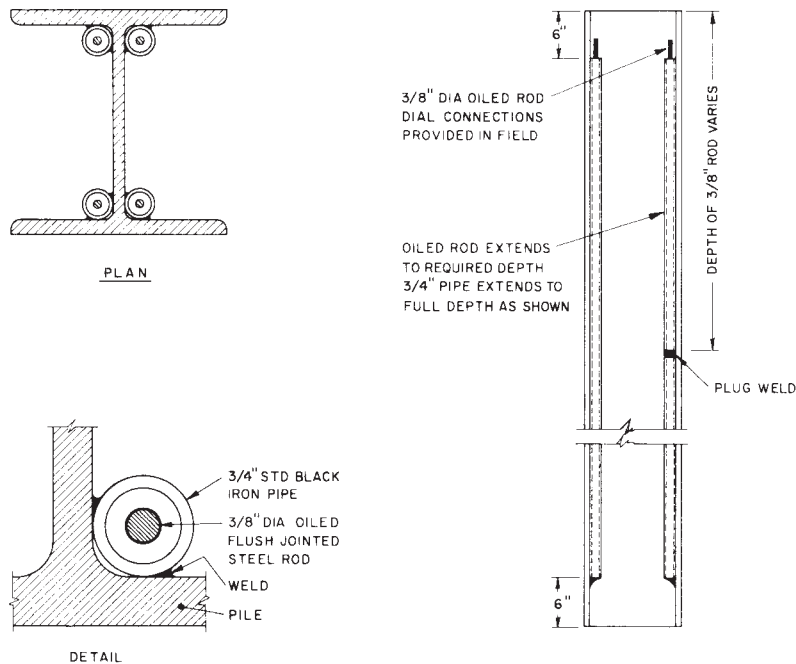
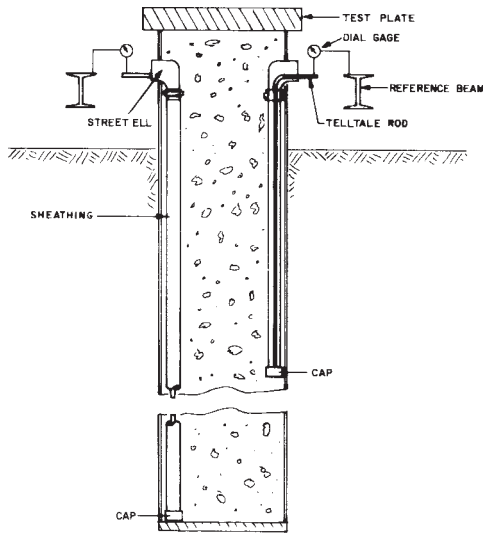FIG. 7 Possible Installation of Telltales for Steel H-Piles

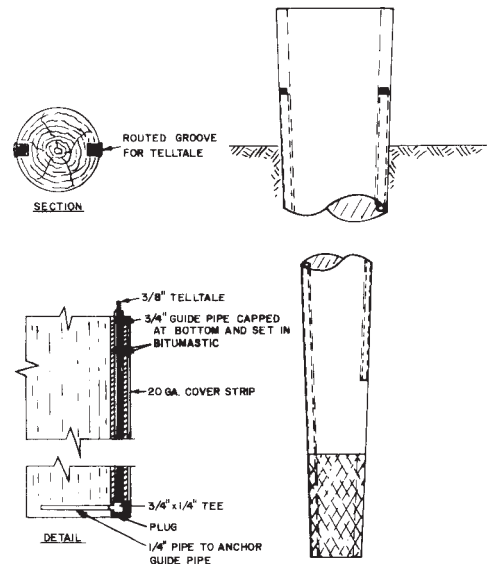FIG. 8 Possible Installation of Telltales for Pipe Piles

FIG. 9 Possible Installation of Telltales for Timber Piles

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

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

8.1.3 Equip hydraulic jacks with spherical bearing plates or in complete and firm contact with the bearing surfaces and aligned so as to avoid eccentric loading.

8.1.4 Do not hoist, swing, or suspend loadings over anyone and control them by tag lines.

8.1.5 Design the attachments of the test beam(s) or reaction frame to the anchor piles or other anchoring devices and install to transmit the required loads with an adequate factor of safety.

8.1.6 Stable and balance all reaction loads. When using the loading method in 6.5, safety wedges shall be in place at all times to prevent the platform from tipping. During testing, monitor movements of the reaction load or system to detect impending unstable conditions.

8.1.7 Adequately support all test beams, reaction frames, platforms, and boxes at all times.

8.1.8 Permit only authorized personnel within the immediate test area.

9. Loading Procedures

9.1 The requirements in this section apply to the test procedures given in Section 10.

9.1.1 Apply the test load in a continuous uniform manner until the test load is attained. The load should be applied quickly (5 to 10 s). Impact loadings shall not be permitted.

9.1.2 For test increments designated as creep load increments, maintain the required load on the test pile until a uniform rate of movement of the test pile is achieved as measured for four consecutive measurement intervals of not less than 15 min or for a minimum period of three days, whichever is greater. If failure occurs prior to attaining the criteria, the load test may be terminated. If a uniform rate of movement of the test pile is not attained in seven days, the engineer may elect to terminate that test increment (see 9.1.4). The engineer shall either apply a larger creep load and begin a new creep load increment or use the rate of pile movement at the end of the test increment for analytical purposes.

9.1.3 Maintain failure load increments on the test pile until failure occurs (see 3.2.8). If failure of the test pile is not attained in seven days, the engineer may elect to terminate that test increment (see 9.1.4). The engineer shall apply a larger failure load and begin a new failure load increment.

9.1.4 After either pile failure occurs or the requirements of 9.1.2 are achieved, remove the applied load and take rebound measurements as required in 11.2. The test pile shall remain unloaded for at least 24 h before a subsequent load increment, if required, is applied.

9.1.5 Take readings of the ground temperature-measuring devices prior to the start of each load increment, after the completion of each load increment, and at least once a day during each load increment.

10. Procedures

10.1 This section describes three alternative test procedures: standard; alternative; and confirmation test procedures, along with their areas of applicability. For each procedure the following requirements shall apply:

10.1.1 The engineer shall calculate a base load value prior to the load test. The base load shall be equivalent to the design pile load adjusted for the test pile geometry and for the expected ground temperature at the time of the load test. Base the design pile load on the pile design criteria or, where pile design criteria are not available, base it on structural performance requirements.

10.1.2 Prior to the load test, the engineer shall establish a tentative relationship between pile load and time to failure. This tentative relationship may be established as described in X1.2. Base the relationship on published soil strength data or laboratory test strength data for soil types and conditions similar to those in the test area.

10.2 *Standard Test Procedure*:

10.2.1 This standard test procedure shall be the basic test procedure used to test piles in permafrost under this test method. Use it in locations where no other pile load test data for similar conditions in the same area are available or where pile design criteria have not yet been developed.

10.2.2 The standard test procedure requires the testing of two piles with two test load increments on each test pile. Load each test pile with one creep load increment and one failure load increment using the procedures of 9.1.

10.2.3 The first test pile shall be loaded as follows:

10.2.3.1 Apply a creep load equal to 10 % of the failure load, and

10.2.3.2 Apply a failure load predicted to achieve pile failure in 6 to 12 h.

10.2.4 Load the second test pile as follows:

10.2.4.1 Apply a creep load increment equal to 100 % of the base load. This creep load may be adjusted based on the test results of the first pile test, and

10.2.4.2 Apply a failure load predicted to achieve pile failure in three to five days.

10.2.5 If the results of either the two creep test load increments or the two failure load increments are inconsistent, the engineer shall require the testing of a third pile with both a creep load increment and a failure load increment. The engineer shall determine the magnitude of the loads to be applied to the third test pile based on the results of the previous tests.

10.3 *Alternative Test Procedure*

10.3.1 This alternative test procedure is equivalent to the standard test procedure (see 10.2) and may be used instead of the standard test procedure.

10.3.2 The alternative test procedure requires the testing of three piles with one test load increment on each test pile. Load two piles with one failure load increment each and load one pile with one creep load increment using the procedures of 9.1.

10.3.3 Load the first test pile as follows: apply a failure load predicted to achieve pile failure in 3 to 6 h.

10.3.4 Load the second test pile as follows: apply a failure load predicted to achieve pile failure in three to five days.

10.3.5 Load the third test pile as follows: apply a creep load equal to 100 % of the base load (see 10.1.1).

10.3.6 If the results of the failure load tests in the first and second test piles are inconsistent or the results of the creep load test on the third pile are inconsistent with the expected results, the engineer shall require the testing of a fourth pile with either a failure load or a creep load increment, or both. The engineer shall determine the magnitude of the load(s) to be applied to the fourth test pile based on the results of the previous tests.

10.4 *Confirmation Test Procedure*:

10.4.1 This confirmation test procedure may be used in locations where pile design criteria have been developed or where other pile test data for similar conditions in the same area are available. Use the confirmation test procedure specifically to confirm existing pile design criteria.

10.4.2 The confirmation test procedure requires the testing of one pile. Load the test pile with one creep load increment and one failure load increment using the procedures of 9.1.

10.4.3 Load the test pile as follows:

10.4.3.1 Apply a creep load equal to 100 % of the base load (see 10.1.1), and

10.4.3.2 Apply a failure load predicted to achieve pile failure in 24 h.

10.4.4 Consider the confirmation test successful if both of the following are true:

10.4.4.1 The final rate of pile movement resulting from the creep load increment, when adjusted to the actual pile geometry and design ground temperature conditions, is equal to or less than the design pile creep rate; and

10.4.4.2 The time of failure resulting from the failure test increment is greater than or equal to 24 h.

10.4.5 If the requirements of 10.4.4 are not met, test a second pile as required in 10.2.4.

10.4.6 If, after testing a second pile as required above, the results of the two creep test increments or the two failure load increments are inconsistent, the engineer shall require the testing of a third pile with both a creep load increment and a failure load increment. The engineer shall determine the magnitude of the loads to be applied to the third test pile based on the results of the previous tests.

10.5 *Summary of Acceptable Test Procedures*—For convenience, the requirements for the acceptable test procedures in 10.2, 10.3, and 10.4 are summarized and presented in Table 2.

11. Procedures for Measuring Pile Movements

11.1 *General*—For axial movements, take readings on the test pile or pile cap; readings may be taken on the test plate, provided that the requirements of 7.2.1 are satisfied. For lateral movements, take readings at each properly identified gage, scale, or reference point as nearly simultaneously as practicable. Record the temperature of each reaction and reference beam at the time of all required readings. When using the loading method described in 6.5, take the no-load reading before the test beam(s) and platform are permitted to bear on the pile(s). Clearly indicate and explain any adjustments made to instrumentation or to data recorded in the field.

11.2 *Standard Measuring Procedures*—Take readings of time, load, movement, reference and reaction beam temperatures, and record them before and after the application of each load increment or the removal of each applied load. Sets of readings should all be taken and recorded in identical sequence. During loading, provided that the test pile has not failed, take additional readings and record them at intervals not exceeding 10 min during the first 30 min, not exceeding 20 min during the next 1½ h, not exceeding 1 h for the next 10 h, not exceeding 2 h for the next 12 h, and not exceeding 6 h thereafter. If pile failure occurs, take readings immediately before removing the applied load. During unloading, record readings at intervals as for loading. Take a final rebound reading 24 h after all load has been removed.

NOTE 13—If incremental strain measurements as in 7.4 are made using strain gages, gage readings should be taken and recorded before and after the pile is installed and immediately before the application of test loads and as required above, so that a complete strain history is obtained and residual stresses can be accounted for.

TABLE 2 Acceptable Pile Test Procedures

Procedure	Pile Number	Load Number	Load Type[A]	Load Level
Standard	1	1	C	10 % failure test load
		2	F	failure in 6 to 12 h
	2	1	C	100 % base test load
		2	F	failure in 3 to 5 days
Alternate	1	1	F	failure in 3 to 6 h
	2	1	F	failure in 3 to 5 days
	3	1	C	100 % base test load
Confirmation[B]	1	1	C	100 % base test load
		2	F	failure in 24 h

[A] C = Creep Load; F = Failure Load
[B] For use in areas where other pile load test data are available.

NOTE 14—Secondary system readings should be taken on the reference beams and on the reaction system to determine if any excessive movement occurs. Such readings should be recorded before any test load is applied, at the maximum test load, once daily during loading, and after all load has been removed. Intermediate readings may be required if results during testing appear to be unusual.

11.3 Record a deflection correction based on the measured temperature of the reference beam(s) on the pile data sheet. Adjust the measured pile deflection by the amount of the deflection correction to give an adjusted pile deflection value for each measurement interval.

11.4 Calculate a pile movement rate expressed in inches per day during the test period for each measurement interval. Calculate the pile movement rate as the difference in inches between the current and previous adjusted pile deflection value divided by the time in days between the current and previous measurement time. Plot the log of the pile displacement rate versus log of time and use it to determine when uniform pile movement has occurred (see 9.1.2) or when pile failure has occurred (see 9.1.3), or both.

NOTE 15—Where pile movement rates exhibit significant variability, assessment of decreasing, constant, or increasing pile movement rates may be made using accepted data smoothing techniques, such as curve fitting, moving average procedures, and the like.

12. Report

12.1 Report the following information of the load test when applicable:

12.1.1 *General*:

12.1.1.1 Project identification,

12.1.1.2 Project location,

12.1.1.3 Test site location,

12.1.1.4 Owner,

12.1.1.5 Structural engineer,

12.1.1.6 Geotechnical engineer,

12.1.1.7 Pile contractor,

12.1.1.8 Test boring contractor,

12.1.1.9 Designation and location of nearest test boring with reference to test pile,

12.1.1.10 Log of nearest test boring,

12.1.1.11 Horizontal control datum, and

12.1.1.12 Vertical control (elevation) datum.

12.1.2 *Pile Installation Equipment*:

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

12.1.2.2 Weight of hammer and ram,

12.1.2.3 Stroke or arm,

12.1.2.4 Rated energy of hammer,

12.1.2.5 Rated capacity of boiler or compressor,

12.1.2.6 Type and dimensions of capblock and pile cushion,

12.1.2.7 Weight and dimensions of drive cap and follower,

12.1.2.8 Size of predrilling or setting equipment,

12.1.2.9 Weight of clamp, follower, adapter, and oscillator for vibratory driver,

12.1.2.10 Type, size, length, and weight of mandrel,

12.1.2.11 Type, size, and length of auger, or other drilling equipment

12.1.2.12 Type and size of grout pump, and

12.1.2.13 Type, size, wall thickness, and length of drive casing.

12.1.3 *Test and Anchor Piles*:

12.1.3.1 Identification and location of test and anchor piles,

12.1.3.2 Design load of pile,

12.1.3.3 Type of pile(s)—test and anchor,

12.1.3.4 Test pile material including basic specifications,

12.1.3.5 Tip and top dimension of pile(s),

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

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

12.1.3.8 Wall thickness of pipe test pile,

12.1.3.9 Weight per foot of *H* test pile,

12.1.3.10 Description of test pile tip reinforcement or protection,

12.1.3.11 Description of banding-timber piles,

12.1.3.12 Description of special coatings used,

12.1.3.13 Test pile (mandrel) weight as driven,

12.1.3.14 Date precast test piles made,

12.1.3.15 Concrete cylinder strengths when test pile driven and when pile tested (approximate),

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

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

12.1.3.18 Effective prestress,

12.1.3.19 Length of test pile during driving,

12.1.3.20 Embedded length-of-test and anchor piles,

12.1.3.21 Load-bearing length of test pile,

12.1.3.22 Final elevation of test pile tops referenced to fixed datum,

12.1.3.23 Description of rings, flights, lugs, blades, or other appurtenances to the pile shaft in the load-bearing zone, and

12.1.3.24 Description of refrigeration system, if used (passive or active, internal or external to the pile, dimensions, thermal capacity, type of coolant, evaporation temperature, and other data as may be deemed pertinent by the engineer).

12.1.4 *Pile Installation—Test and Anchor*:

12.1.4.1 Date driven (installed),

12.1.4.2 Date concreted (cast-in-place),

12.1.4.3 Volume of concrete or grout placed in pile,

12.1.4.4 Grout pressure used,

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

12.1.4.6 Operating pressure for double-acting and differential type hammers,

12.1.4.7 Throttle-setting diesel hammer (at final driving),

12.1.4.8 Fuel-type diesel hammer,

12.1.4.9 Horsepower delivered and frequency of vibratory driver during final 10 ft (3 m) of pile penetration,

12.1.4.10 Description of measures taken to alleviate load bearing in the active layer,

12.1.4.11 Type and location of pile splices,

12.1.4.12 Driving logs (blows per foot),

12.1.4.13 Final penetration resistance (blows per inch),

12.1.4.14 Rate of pile penetration for last 10 ft (3 m), vibratory driving,

12.1.4.15 When capblock replaced (indicate on log),

12.1.4.16 When pile cushion replaced (indicate on log),

12.1.4.17 Cause and duration of interruptions in pile installation,

12.1.4.18 Notation of any unusual occurrences during installation,

12.1.4.19 Date of hole excavation for slurried piles,

12.1.4.20 Total depth of hole excavated for slurried piles,

12.1.4.21 Descriptive log of soil excavated for slurried piles noting soil thermal state and changes thereof, soil composition and changes thereof, and ice content and changes thereof,

12.1.4.22 Date of pile placement and slurry placement,

12.1.4.23 Description of equipment and procedure used in pile placement, and slurry placement,

12.1.4.24 Gradation and salinity of slurry material,

12.1.4.25 Moisture content (or slump) and temperature of slurry material immediately prior to placement, and

12.1.4.26 Placement temperature and temperature versus time data of grout, if grout backfill is used.

12.1.5 *Pile Testing*:

12.1.5.1 Date tested,

12.1.5.2 Type test,

12.1.5.3 Pile designation,

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

12.1.5.5 Description of instrumentation used to measure pile movement including location of gages or other reference points with respect to pile top (see Note 17),

12.1.5.6 Description of special instrumentation such as strain rods or gages including location of such with reference to pile top,

12.1.5.7 Special testing procedures used,

12.1.5.8 Ground temperature measurements from pile installation through pile testing,

12.1.5.9 Tabulation of all time, load, temperature, and movement readings,

12.1.5.10 Identification and location sketch of all gages, scales, and reference points (see Note 17),

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

12.1.5.12 Notation of any unusual occurrences during testing,

12.1.5.13 Test jack and other required calibration reports, and

12.1.5.14 Air temperature and weather conditions during tests.

NOTE 16—Suitable photographs can be very helpful in showing the instrumentation setup, location of gages, scales, and reference points.

NOTE 17—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 the test results.

13. Precision and Bias

13.1 *Statement of Precision*—Due to the nature of the soil or rock materials tested by this test method, it is either not feasible or too costly at this time to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.19

welcomes proposals that would allow for development of a valid precision statement.

13.2 *Statement of Bias*—There is no accepted reference value for this test method, therefore bias cannot be determined.

14. Keywords

14.1 axial load; compressive load; displacement rate; frozen; permafrost; piles; soil; static load

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF TEST RESULTS

X1.1 Because of the variation of the strength characteristics of frozen soil and ice with temperature, time, and load level, the results of pile load tests cannot be compared directly to long-term pile behavior criteria. The factors listed in X1.1.2 through X1.1.5 must be taken into account when evaluating pile load test data. The factors listed in X1.1.6 through X1.1.13 may also influence the behavior of the test pile in comparison to production piles.

X1.1.1 The ground temperature during the pile test period must be related to the design ground temperature conditions. A relationship between soil strength and temperature must be used. This relationship may be developed based on laboratory strength test results on similar soil types for various temperatures or upon published data or correlations, if available, for similar soil types and conditions.

X1.1.2 The salinity, if any, of the pore fluid in the soil/ice system being tested will have a major effect on the long-term behavior of the system under load. Where saline permafrost is encountered, it is recommended that laboratory tests on representative samples be conducted in order to establish relationships between strength and temperature, between strength and time to failure, and between load and creep rate.

X1.1.3 Failure loads will, for constant environmental conditions, vary with time of load application. Estimated failure loads may be calculated using published, or otherwise available, data and an analytical procedure such as given in X1.1.2.

X1.1.4 Evaluation of creep test results should be made using the adjusted pile movement for the latest, non-failure test time. Representative pile movement rates will not occur at early test times because of the redistribution of the test load along the pile length with time, and because of the effects of primary creep. Piles in some soil types and conditions may not exhibit constant pile movement rates at certain load levels. Granular soils and soils without any excess ice may not produce a constant pile movement rate at the lower test load levels.

X1.1.5 Potential residual loads generated during pile installation and freezeback that will dissipate over time could influence the interpreted test results.

X1.1.6 Stress history or the stored effects of prior loading increments could influence the interpreted test results. In particular, the time to failure in the failure load increments may be affected by effects of prior loading increments.

X1.1.7 Possible interaction of friction loads from test pile with upward friction transferred to the soil from anchor piles obtaining part or all of their support in soil at levels above the tip level of the test pile could influence the interpreted test results.

X1.1.8 Differences between conditions at time of testing and after final construction such as changes in grade will influence the behavior of the test pile in comparison to production piles.

X1.1.9 Possible differences in the performance of a pile in a group or a pile group from that of a single isolated pile may influence the behavior of the test pile in comparison to production piles.

X1.1.10 The affect on long-term pile performance of factors such as creep, environmental effects on pile material, negative friction loads not previously accounted for, and strength losses may influence the behavior of the test pile in comparison to production piles.

X1.1.11 The type of structure to be supported, including sensitivity of structure to settlements and relation between live and dead loads may influence the behavior of the test pile in comparison to production piles.

X1.1.12 Special testing procedures that may be required for the application of certain acceptance criteria or methods of interpretation may influence the behavior of the test pile in comparison to production piles.

X1.1.13 Unless all conditions for non-tested piles are basically identical to those for test pile including such things as subsurface conditions, pile type, length, size and stiffness, and pile installation methods and equipment, the behavior of the test pile may differ from the behavior of the production piles.

X1.2 Because of the nature of frozen materials, there is a relationship between applied load, soil temperature, and time to failure. In order to plan and evaluate pile load tests in permafrost, this relationship must be quantified for the given test site conditions. The selected test loads will determine the duration of the test program.

X1.2.1 Although the behavior of a loaded pile in frozen soil is complex, it has been shown (Vyalov, (**1**)[4]; Sayles, (**2**); Long, (**3**)) that experimental points lie in a straight line if the reciprocal of the shear stress $\left(\frac{1}{\tau}\right)$ is plotted vertically and the logarithm of the time during which shear displacement takes place (*ln T*) is plotted horizontally. From this it follows that the

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[4] The boldface numbers given in parentheses refer to a list of references at the end of the text.

loss of strength of frozen soil can generally be approximated by the following relationship:

$$\frac{\beta}{\tau} = ln\left(\frac{T}{B}\right) \qquad \text{(X1.1)}$$

where:
τ = shear stress,
T = time to failure, and
β, B = reference parameters that depend on soil characteristics and temperature.

X1.2.2 The parameters β and B in Eq X1.1 may be evaluated based on laboratory test results, on field test results or, if no data are available prior to the pile load tests, on published data for similar soil types at similar temperatures.

X1.2.3 The relationship between failure strength and time to failure should be established tentatively prior to the pile tests in order to select failure loads which will generally meet the failure times called for in 9.1.3, 9.1.4, and 9.1.5. Upon completion of each pile load test, projections can be made for additional pile load tests using X1.2.3.1 as a guide.

X1.2.3.1 After the completion of an initial test, the failure time of the next test can be approximated using values from the following equation as divisors of τ, to increase time to failure and as multipliers of τ to decrease time to failure:

10^{-3}	10^{-2}	10^{-1}	10^0	10^1	10^2	10^3	(time, hours)
2.38	1.74	1.42	1.26	1.18	1.14		(differences, fitted values from 22 pile tests)
10.85	0.90	0.16	0.08	0.04	0.03		(standard deviation from 22 pile tests)

Example—Assume an initial test failed in 6 min = 10^{-1} h.
For a second test to fail at approximately 1 h, $\tau_2 = \tau_1/1.42$
For a second test to fail at approximately 100 h, $\tau_2 = \tau_1/$
    $(1.42 \times 1.26 \times 1.18)$
For a second test to fail at approximately 1/100 h, $\tau_2 = \tau_1 \times 1.74$

X1.2.3.2 Once two or more pile load tests are completed the parameters in Eq X1.1 should be reevaluated using the pile load test results.

X1.2.3.3 A complete example of the determination of pile adfreeze strength, rate of pile displacement, and pile displacement to failure as a function of time and temperature for a particular pile configuration and soil for which no preexisting information is available, is provided.

X1.2.3.4 The example at Prudhoe Bay will require a 10-in. (254-mm) adfreeze pile to satisfy structural requirements. Tests will be required to determine allowable adfreeze stresses and displacement to failure for a design life of 100 years or 1×10^6 h.

X1.2.3.5 The example will be calculated for a base load of 173 250 lb (79 kg) on 10-in. (254-mm) diameter pile using a fine silty sand backfill between depths below ground surface of 25.6 and 30.4 ft (7.4 and 10.2 m) in permafrost soil. With a hole diameter of 18 in. (457 mm), the soil should fail in pile adfreeze rather than perimeter shear. From Santana **(4)** calculate the approximate variation of temperature with time (see Eq X1.3):

$$T = 1.42 \; sin\;[360/365(t_d + 105)] - 9.78 \qquad \text{(X1.2)}$$

where:
T = temperature, °C, and
t_d = number of days from first of year.

X1.2.3.6 From Eq X1.2 obtain approximate seasonal ground temperature data at a mean bearing depth of 28 ft (8.5

m) (see Eq X1.2). The average temperature is 14°F (−10°C) varying from 11.3°F (−11.5°C) in early June to 17.4°F (−8.1°C) in early December. Assuming the first test will be completed by mid-July, estimate a temperature of 12°F (−11.1°C). Using Sanger **(5)** and extending his data with a power curve (see Eq X1.4) for saturated fine sands, obtain an ultimate adfreeze bond stress in creep of

$$1/\tau = 0.0553T^{-0.7668} \qquad \text{(X1.3)}$$

approximately 114.6 psi at 12°F (−11.1°C). From Eq X1.2 approximate a failure stress in 10 h by multiplying 1.18 by 1.14 by 1.12 by 1.11 by 1.10 by 114.6 psi and obtain 211 psi. A base load of 173 250 lb (79 kg) in 10^6 h is needed. From Eq X1.3 at 17.4°F (−8.1°C), the maximum design temperature, obtain 90.0 psi. Divide 173 250 by 90 psi to get a required adfreeze area of 1925 in.² (1.24 m²). Apply a failure load of 1925 in.² by 211 psi for 406 000 lb (184 kg). The load failed in 2.67 h at 211 psi and 11.4°F (−11.4°C). The second test should fail in three to five days or 1 ½ orders of magnitude slower than the first test or the 10 h to failure tried on the first test. From Eq X1.2 divide 211 psi by [(1.26 + 1.18)/2] by 1.18 to get 147 psi for an estimate of failure in three to five days. Examine the cyclic change in temperature and estimate a soil temperature of 13°F by early August. From Eq X1.3 interpret 117 psi (0.81 MPa) at 11.4°F and 111 psi 122 kg at 13°F (−10.6°C); 111/117 by 147 = 140 1.24 m² psi estimated adfreeze stress. 140 psi (0.97 MPa) by 1925 in.² = 269 500 lb (122 kg) required. Failure occurred in 45 h at 13.2°F (−10.1°C) and 140-psi (0.97 MPa) adfreeze stress.

X1.2.3.7 Laboratory pile adfreeze tests were run at temperatures of 29°F (−1.7°C), 25°F (−3.9°C), 15°F (−9.4°C), and 10°F (−12.2°C) with varying load and time to failure. From these laboratory tests obtain the following:

$$1/\tau = 0.1518 * T^{-1.418} + 0.007978 * e^{-0.469*T} * ln\,t \qquad \text{(X1.4)}$$

where:
τ = unit adfreeze stress, psi,
T = temperature, (−)°C, and
t = time to failure, h.

X1.2.3.8 Correct the field test data to various temperatures by using the ratio of laboratory values for the different temperatures by the field value for each time to failure. Doing this for each of the tests to failure can derive log of time versus τ^{-1} curves for each temperature. Then take the "a" and "b" factors of each temperature curve versus the negative temperatures in° C to obtain a smoothing of the data with the following equation **(3)**:

$$1/\tau = 0.1367 * T^{-1.4177} + 0.01569 * T^{-1.4711} * ln\,t \qquad \text{(X1.5)}$$

If the first two tests give a feeling of insecurity, calculate from Eq X1.5 a τ for failure in ¹⁄₁₀ h for time period of mid-October of 16.4°F (−8.7°C). From Eq X1.5 at ¹⁄₁₀h obtain an estimated strength of 205 psi at 16.4°F. The load is 1925 by 205 = 395 000 lb (179 kg). Failure occurred at 5 min and 24 s, or 0.090 h at 16.6°F (−8.6°C) and 205 psi. This checks the previous two pile tests.

X1.2.3.9 The techniques used may also be used to evaluate displacement to failure and secondary rate of displacement as a basis of design **(6, 7, 8)**. At this point, the displacement to

failure, displacement versus time, and rate of displacement versus time for the laboratory and field tests are already established.

X1.2.3.10 From laboratory displacement rates derived for each temperature and time to failure at which failure occurred as well as those temperatures and time to failure at which solution is wanted, adjust the field pile displacement rates to the temperatures for which information is desired. For this case, elect to fit the laboratory rate of displacement against unit stress for each temperature and obtain the power curve fits for temperatures below 0°C as follows (3).

$$\rho' = 0.003527 * T^{-2.256} * \tau^{0.7119 * T^{-0.1443}} \qquad (X1.6)$$

where:

τ = unit stress, psi,
T = temperature, (–)°C, and
ρ' = rate of displacement, in./h.

Using this power formula, derive an estimated secondary rate of displacement for each temperature and time to failure for which there is an interest, as follows (3):

$$\rho' = 897.0 \cdot 10^{-9} * T^{-2.236} * \tau^{2.945 * T^{-0.0315}} \qquad (X1.7)$$

X1.2.3.11 Estimates of secondary displacement to failure can be obtained from the analysis by multiplying the rate of displacement by the time to failure. By adding the structural compression with the load of the piles an estimate of the total pile movement to failure is obtained.

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