Standard Test Method for Prebored Pressuremeter Testing in Soils[1]

This standard is issued under the fixed designation D 4719; 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 pressuremeter testing of soils. A pressuremeter test is an in situ stress-strain test performed on the wall of a borehole using a cylindrical probe that is expanded radially. To obtain viable test results, disturbance to the borehole wall must be minimized.

1.2 This test method includes the procedure for drilling the borehole, inserting the probe, and conducting pressuremeter tests in both granular and cohesive soils, but does not include high pressure testing in rock. Knowledge of the type of soil in which each pressuremeter test is to be made is necessary for assessment of (*1*) the method of boring or probe placement, or both, (*2*) the interpretation of the test data, and (*3*) the reasonableness of the test results.

1.3 This test method does not cover the self-boring pressuremeter, for which the hole is drilled by a mechanical or jetting tool inside the hollow core of the probe. This test method is limited to the pressuremeter which is inserted into predrilled boreholes or, under certain circumstances, is inserted by driving.

1.4 Two alternate testing procedures are provided as follows:

1.4.1 *Procedure A*—The Equal Pressure Increment Method.

1.4.2 *Procedure B*—The Equal Volume Increment Method.

NOTE 1—A standard for the self-boring pressuremeter is scheduled to be developed separately. Pressuremeter testing in rock may be standardized as an adjunct to this test method.

NOTE 2—Strain-controlled tests also can be performed, whereby the probe volume is increased at a constant rate and corresponding pressures are measured. This method shall be applied only if special requirements must be met and is not covered by this test method. Strain-controlled tests may yield different results than the procedure described in this test method.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *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.* See Note 6.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

3. Terminology

3.1 *Definitions*—For definitions of terms in this test method, refer to Terminology D 653.

3.1.1 *limit pressure, P_l [FL^{-2}], n*—the pressure at which the probe volume reaches twice the original soil cavity volume.

3.1.2 *pressuremeter modulus, E_p [FL^{-2}], n*—the modulus calculated from the slope of the pseudo-elastic portion of the corrected pressure-volume curve experiencing little to no creep.

3.1.3 *unload-reload modulus, E_R [FL^{-2}], n*—the modulus calculated from an unload-reload loop.

3.1.3.1 *Discussion*—The unload-reload modulus varies with stress, or strain level, or both, and thus, the modulus values should be reported with the pressure and volume at the start of the unloading, at the bottom of the loop and at the crossover point.

3.2 *Abbreviations:*

3.2.1 *PBP*—prebored pressuremeter test

4. Summary of Test Method

4.1 A pressuremeter cavity is prepared either by drilling a borehole, or by advancing some type of sampler. Under certain circumstances, the pressuremeter probe is driven into place, usually within a casing. The various tools and methods available to prepare the cavity produce different degrees of disturbance. The recommended methods to be used at a site depend on the soil and the conditions met. The proper choice of tools and methods is covered by this test method.

NOTE 3—It is recommended that several drilling techniques be available on the site to determine which method will provide the most suitable test hole.

4.2 The pressuremeter test basically consists of placing an inflatable cylindrical probe in a predrilled hole and expanding this probe while measuring the changes in volume and pressure in the probe. The probe is inflated under equal pressure increments (Procedure A) or equal volume increments (Procedure B) and the test is terminated when yielding in the soil

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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

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

becomes disproportionately large. A conventional limit pressure is estimated from the last few readings of the test and a pressuremeter modulus is calculated from pressure-volume changes read during the test. It is of basic importance that the probe be inserted in a borehole with a diameter close to that of the probe to ensure adequate volume change capability. If this requirement is not met, the test could terminate without reaching sufficient probe expansion in the soil to permit evaluation of the limit pressure. The instrument may be either of the type where the change in volume of the probe is directly measured by an incompressible liquid or the type where feelers are used to determine the change in diameter in the probe. The volume measuring system must be well protected and calibrated against any volume losses throughout the system while the feeler operated probe must be sensitive enough to measure relatively small displacements.

NOTE 4—This test method is based on the type of apparatus where volume changes are recorded during the test. For the system measuring probe diameters, alternate evaluation methods are given in the notes.

5. Significance and Use

5.1 This test method provides a stress-strain response of the soil in situ. A pressuremeter modulus and a limit pressure is obtained for use in geotechnical analysis and foundation design.

5.2 The results of this test method are dependent on the degree of disturbance during drilling of the borehole and insertion of the pressuremeter probe. Since disturbance cannot be completely eliminated, the interpretation of the test results should include consideration of conditions during drilling. This disturbance is particularly significant in very soft clays and very loose sands. Disturbance may not be eliminated completely but should be minimized for the prebored pressuremeter design rules to be applicable.

6. Apparatus

6.1 *Hydraulic or Electric Probe*—The apparatus shall consist of a probe to be lowered in the borehole and a measuring or readout device to be located on the ground adjacent to the boring. The probe may be either the hydraulic type or the electric type. The hydraulic probe may be of a single cell or triple cell design. In the latter case, the role of which is to provide effective end restraint and ensure radial expansion of the central cell (Fig. 1a[3]). The combined height of the measuring and guard cells, if any, shall be at least six diameters. The design of the probe shall be such that the drilling liquid may flow freely past the probe without disturbing the sides of the borehole during insertion or removal. For both systems, the nominal hole diameter shall not be more than 1.2 times the nominal probe diameter. Typical probe dimensions and corresponding borehole diameters are indicated in Table 1.

6.1.1 *Probe Walls*—The flexible walls of the probe may consist of a single rubber membrane (single cell design) or of an inner rubber membrane fitted with an outer flexible sheath or cover (triple cell design) which will take up the shape of the borehole as pressure is applied. In a coarse-grained material like gravel, a steel sheath made of thin overlapping metal strips is often used. The accuracy of the test will be impaired when the probe cannot take up the shape of the borehole accurately.

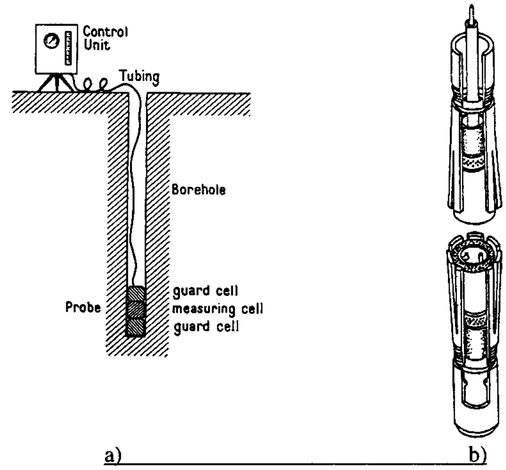


FIG. 1 a) Basic Principles of the Triple Cell Design Pressuremeter (Baguelin, Jézéquel and Shields, 1978,[3] b) Slotted Tube with Probe

TABLE 1 Typical Probe and Borehole Dimensions

Hole Diameter Designation	Probe Diameter, mm	Borehole Diameter	
		Nominal, mm	Max., mm
Ax	44	45	53
Bx	58	60	70
Nx	74	76	89

NOTE 5—Various membrane and sheath, or cover, materials may be used to better accommodate soil types; identify the membrane and sheath, or cover, used in the report.

6.1.2 *Measuring Devices*—Changes in volume of the measuring portion of the probe are measured in the hydraulic apparatus, and alternatively, the probe diameter can be measured by the use of feelers in the electric apparatus. Provisions to measure the diameter in directions at a 120° angle shall be provided with the electric apparatus. The measuring cell shall be prevented from expanding in the vertical direction by guard cells or other effective restraints in the hydraulic apparatus. The accuracy of the readout device shall be such that a change of 0.1 % in the probe diameter is measurable.

6.2 *Lines*—Lines connecting the probe with the readout device consist of plastic tubing in the hydraulic apparatus. To reduce measuring errors, a coaxial tubing is used, whereby the inner tubing is prevented from expanding by a gas pressure at its perimeter. By applying the correct gas pressure, expansion of the inner tubing is reduced to a minimum. Single tubing can also be used. In both cases, requirement for volume losses given in 7.3 should apply. Electric lines need special protection against groundwater.

6.3 *Readout Device*—The readout device includes a mechanism to apply pressure (Procedure A) or volume (Procedure B) in equal increments to the probe and readout of volume change

[3] Baguelin, F., Jézéquel, J.F., and Shields, D.H., "The Pressuremeter and Foundation Engineering," Trans Tech Publications, Series on Rock and Soil Mechanics, Vol 2, No. 4, 1978, p 617.

(Procedure A) or pressure change (Procedure B). The equipment using the hydraulic system and guard cells shall also include a regulator whereby the pressure in the gas circuit is kept below the fluid pressure in the measuring cell. The magnitude of pressure difference between gas and fluid must be adjustable to compensate for hydrostatic pressures developing in the probe. In the electrical system the volume readings are substituted by an electrical readout on the diameter of the probe.

6.4 *Slotted Tube*—A steel tube, (Fig. 1b) that has a series of longitudinal slots (usually six) cut through it to allow for lateral expansion, sometimes is used as a protective housing when the probe is driven, vibrodriven, or pushed into deposits that cannot be prevented from caving by drilling mud alone. The PBP test is performed within the slotted tube.

7. Calibration

7.1 The instrument shall be calibrated before each use to compensate for pressure losses (P_c) and volume losses (V_c).

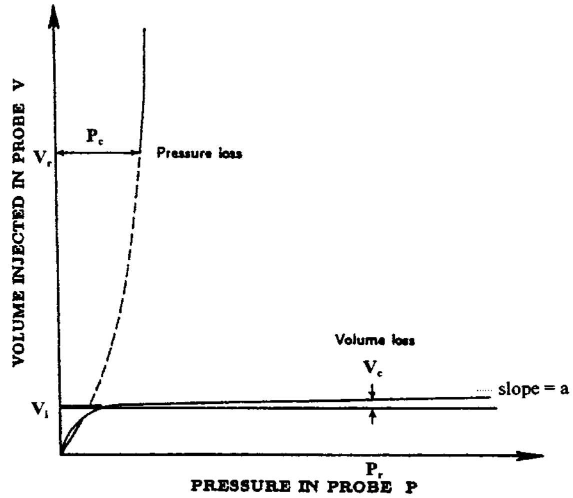
7.2 *Pressure Losses*—Pressure losses (P_c) occur due to the rigidity of the probe walls. The pressure readings obtained during the test on the readout device include the pressure required to expand the probe walls; this membrane resistance must be deducted to obtain the actual pressure applied to the soil. Calibrations for membrane resistance shall be performed by inflating the probe, completely exposed to the atmosphere, with the probe placed at the level of the pressure gage.

NOTE 6—**Warning:** The performance of the pressuremeter test, and particularly the calibration procedures, may present a safety hazard to the operator and persons assisting in the test. The blowout of the probe if on the ground or at shallow depth in the hole may cause injuries from flying debris. Wearing protective devices over the eyes and face or other measures such as putting the probe in a protective cylinder during calibration are recommended.

7.2.1 Apply pressures in 10-kPa increments for Procedure A and hold for 1 min. Make volume readings after 1-min elapsed time. When Procedure B is used, increase the volume of the probe in increments equal to 5% of the nominal volume of the measuring portion of the uninflated probe (V_0). Apply the volume increase in about 10 s and hold constant for 1 min. Continue steps in both procedures until the maximum probe volume is reached. Plot results using a pressure versus volume plot. The obtained curve is the pressure calibration curve. The pressure correction (P_c)is the pressure loss obtained from the calibration for the volume reading (V_r) (Fig. 2).

7.2.2 The pressure correction (P_c) must be deducted from the pressure readings obtained during the test. The maximum value of P_c should be less than 50 % of the limit pressure as defined in 10.6.

7.3 *Volume Losses*—Volume losses (V_c) occur due to expansion of tubing and compressibility of any part of the testing equipment, including the probe and the liquid. Calibration is made by pressurizing the equipment with the probe in heavy duty steel casing or pipe. A suggested procedure is to increase the pressure in steps of 100 kPa or 500 kPa depending if the probe is designed for a maximum expansion pressure of 2.5 MPa or 5.0 MPa, respectively. Each pressure increment should be reached within 20 s and once in contact with the steel tube, held constant for 1 minute. The resulting graph of injected volume (V_r) at the end of each pressure increment (P_r) is the volume calibration curve. The zero volume calibration is obtained by first fitting a straight line extension of the curve to zero pressure, as shown in Fig. 2. The resulting intercept V_i can be used to estimate the deflated volume of the probe measuring cell (V_o) as follows:



NOTE 1—The schematic graphs are not to scale; each calibration requires different volumes and pressures.

FIG. 2 Calibration for Volume and Pressure Losses

$$V_o = (\pi/4)\, L D_i^2 - V_i \quad (1)$$

where:

D_i = inside diameter of the heavy duty steel casing or pipe, and

L = length of the measuring cell.

The volume loss (V_c) of the instrument for a particular pressure is obtained by using the factor a corresponding to the slope of the volume versus pressure calibration plot (Fig. 2) as follows:

$$V_c = V_r - aP_r \quad (2)$$

This volume loss correction (V_c) must be deducted from the measured volumes during the test. This correction is relatively small in soils and can be neglected if the correction is less than 0.1 % of the nominal volume of the measuring portion of the uninflated probe (V_0) per 100 kPa (1 tsf) of pressure. In very hard soils or rock, the correction is significant and must be applied. In no case should this correction exceed 0.5 % of the nominal volume of the measuring portion of the deflated probe (V_0) per 100 kPa (1 tsf) of pressure.

7.4 Corrections for temperature changes and head losses due to circulating liquid are usually small and may be disregarded in routine tests for soils. For tests at depths greater than 50 m (150 ft), special procedures are required to account for head losses.

7.5 The amount of hydrostatic pressure (P_δ) exerted on the probe by the column of liquid in the testing equipment must be determined as follows:

$$P_\delta = H \times \delta_t \quad (3)$$

where:

H = depth of probe below the control unit, m, and
δ_t = unit weight of test liquid in instrument, KN/m^3.

The test depth (H) is the distance from the center of the pressure gage to the center of the probe (Fig. 3). The obtained pressure is exerted on the probe but is not registered by the pressure gages. This pressure must accordingly be added to the pressure readings obtained on the readout device.

7.6 For triple cell pressuremeters, the pressure of the guard cells (P_G) must be set below the actual pressure generated in the probe to provide effective end restraint. This is obtained by subtracting this pressure from the test pressures as follows:

$$P_G = P_R + P_\delta - P_d \tag{4}$$

where:
P_G = guard cells pressure, kPa,
P_R = pressure reading on control unit, kPa,
P_δ = hydrostatic pressure between control unit and probe, kPa (see 7.5), and
P_d = pressure difference between guard cells and measuring cell, kPa (usually twice the limit pressure of the membrane).

7.6.1 A tabulation of gas and liquid pressures for a pressure difference of P_d = 100 kPa for various test depths is shown by Table 2.

8. Drilling

8.1 Whenever possible, place the pressuremeter probe by lowering it into a prebored hole. Two conditions are necessary to obtain a satisfactory test cavity: the diameter of the hole should meet the specified tolerances, and the equipment and method used to prepare the test cavity should cause the least possible disturbance to the soil and the wall of the hole. When testing soils, the pressuremeter tests must be performed immediately after the hole is formed.

8.2 The preparation of a satisfactory borehole is the most important step in obtaining an acceptable pressuremeter test. An indication of the quality of the test hole is given by the magnitude of scatter of the test points and by the shape of the pressuremeter curve obtained. Fig. 4 shows the typical shape of a pressuremeter curve obtained from a prebored test cavity. Fig. 5 shows a pressuremeter curve obtained when the borehole is too small or when the test is performed in a swelling soil. Fig. 6 shows a curve obtained when the borehole is too large.

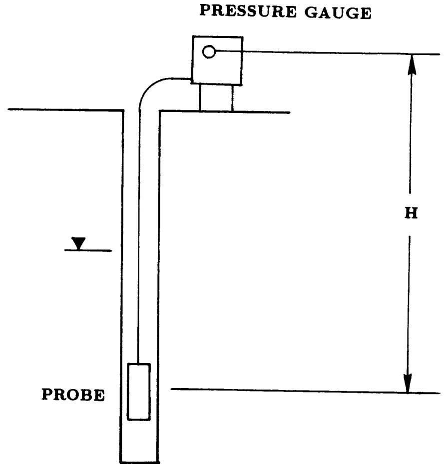


FIG. 3 Depth *H* for Determination of Hydrostatic Pressure in Probe

TABLE 2 Pressure Compensation for Guard Cells Based on Test Depth

Test Depth (H) m	Test Depth (H) ft	Liquid Pressure from Head of Test Liquid on Probe P, kPa	Gas Pressure Reduction on Readout Gages[A] P_d, 100 (kPa)
0	0	0	−100
5	17	50	−50
10	33	100	0
15	50	150	+ 50
20	67	200	+ 100

[A]To maintain guard cell pressure 100 kPa below the measuring cell pressure, deduct (−) or add (+), these pressures to the guard cell circuit.

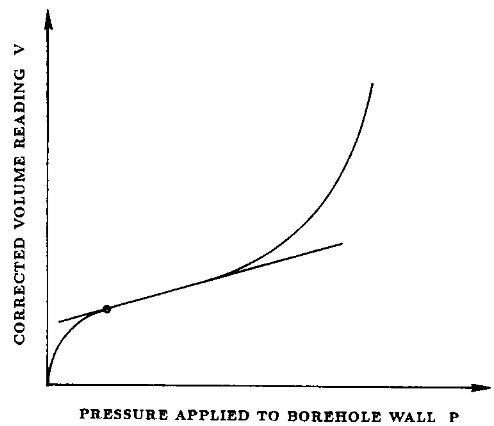


FIG. 4 Ideal Shape of the Pressuremeter Corrected Curve

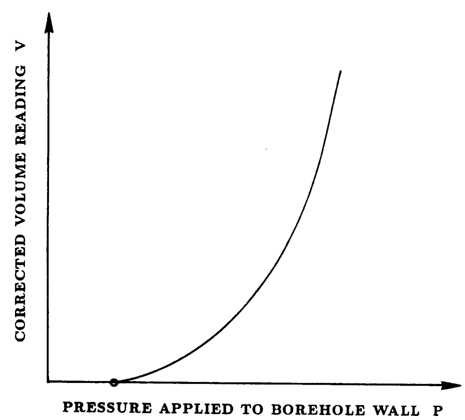


FIG. 5 Pressuremeter Corrected Curve When the Borehole is too Small

NOTE 7—The shape of the pressuremeter test curve is not sufficient to ensure that the test is reliable. The hole diameter requirements developed in 8.3.1 should also be met.

8.3 *Requirements of Test Cavity with Respect to Probe Diameter*:

8.3.1 *Hole Diameter*—Dimensions used in this test method are as follows:

8.3.1.1 *Diameter of the Pressuremeter Probe, D*—The typical diameter *D* of the pressuremeter probe varies from approximately 32 to 74 mm (1.25 to 3 in.).

8.3.1.2 *Diameter of Test Cavity, D_H*—The diameter of the

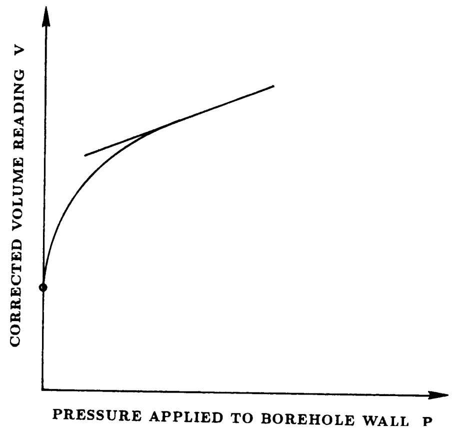


FIG. 6 Pressuremeter Corrected Curve When the Borehole is too Large

test cavity D_H should satisfy the following condition derived from experience:

$$1.03D < D_H < 1.2D \quad (5)$$

8.3.2 *Cutting Tool Diameter*:

8.3.2.1 When determining the diameter of the necessary cutting tool for a bored hole, three factors must be considered: (*a*) the required diameter of the cavity, (*b*) the overcutting of the cavity resulting from the wobble of the cutting tool or the wall erosion by the mud circulation in medium to large-grained soils, or both, and (*c*) the inward yielding that occurs between the removal of the cutting tool and the probe placement. Inward yielding can be reduced by the use of drilling mud.

8.3.2.2 When selecting equipment for the site, several bits of various sizes should be available so as to adjust the size of the bit depending on whether overcutting or inward yielding prevails.

8.3.2.3 When selecting the tool consider also that the wall of the test cavity should be as smooth as possible and the diameter D_H should be as constant as possible over the length of the hole.

NOTE 8—If D_H varies significantly over the length of the probe, because of ravelling for example, or if the borehole is noncylindrical, the quality of the test will be impaired.

8.4 *Methods and Tools Used to Prepare the Test Cavity*:

8.4.1 Any method and tool that can satisfy the general requirements of 8.1 through 8.3 may be used.

8.4.2 The following methods are used to prepare the test cavity for the pressuremeter probe:

8.4.2.1 *Rotary Drilling*—The drill bits used are usually drag bits in clays and roller bits in sands and gravels. Advance the rotating drill bit into the soil while satisfying the following conditions: low vertical pressure on the drilling tool (200 kPa (30 psi)), slow rotation (less than 60 rotations per minute) and a regulated low drilling fluid flow (to less than 15 L/min (4 gal/min)). Inject the drilling fluid by axial bottom discharge to cause the least damage to the borehole wall. The fluid must have a viscosity high enough to remove the cuttings at low pumping rates.

8.4.2.2 *Tube Sampling*—Thin wall samplers similar to those described in Practice D 1587 are used. The sampling tube must be long enough to ensure that the length of cavity to be tested is obtained with a single push. If the tube plugs or if full recovery is not obtained, then another method of preparing the test cavity should be considered. Withdraw the tube slowly to limit inward yielding of the cavity wall due to suction. If thick wall samplers are used, an inward bevel cutting edge must be provided to minimize pre-testing stressing of the borehole wall.

8.4.2.3 *Continuous Flight Augering*—Use a single 1.52-m (5-ft) length of auger at the bottom of a drill string to advance the borehole to the testing level. The cutting head must be slightly greater in diameter than the auger flight to prevent smearing the borehole wall. Rotate the auger during withdrawal. The same rotation and penetration pressure parameters as in 8.4.2.1 apply to continuous flight augering.

8.4.2.4 *Hand Augering*—Use an Iwan-Type auger with or without a hand pump for bottom discharge injection of mud.

NOTE 9—The use of hand auger is difficult below a depth of 6 m (20 ft), and should accordingly be considered only for testing at shallow depths.

8.4.2.5 *Driving or Vibrodriving a Sampler*—Drive a split barrel sampler into the soil. Driving or vibrodriving a flush sampling tube may also be used. The requirements of 8.4.2.2 apply.

8.4.2.6 *Core Drilling*—This method is described in Practice D 2113.

8.4.2.7 *Rotary Percussion*—Use a pneumatic or hydraulic drifter working with a bottom discharge bit. The removal of cuttings can be done by compressed air in dry formations, or by mud in wet soils.

8.4.2.8 *Pilot Hole Drilling and Subsequent Tube Sampling*—Drill a pilot hole smaller in diameter than the pressuremeter probe. Trim the hole to the proper diameter by a pushed or driven sampler. The requirements of 8.4.2.2 apply.

8.4.2.9 *Pilot Hole Drilling and Simultaneous Shaving*—Drill a pilot hole smaller in diameter than the pressuremeter probe. Immediately behind the drill bit, (Fig. 7) on the string of the drilling rods is a thin hollow cylinder that trims the cavity. Advance the drill bit and cylinder with high viscosity drilling fluid.

8.4.2.10 *Driving, Vibrodriving, or Pushing a Slotted Tube*—A slotted tube (see 6.4 and Fig. 1b) generally is used as a protective housing for the probe in formations that cannot be prevented from caving by drilling mud alone or when testing is

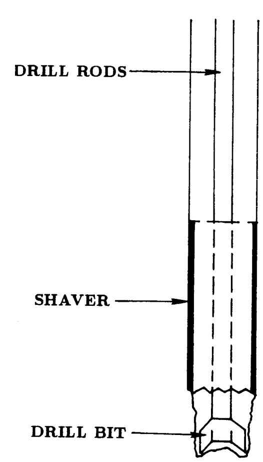


FIG. 7 Preparing the Test Cavity by the Pilot Hole Drilling and Simultaneous Shaving Technique

done in larger particle size soils. Place the probe in the slotted tube and drive, vibrodrive, or push the whole assembly into the soil to the testing depth. The test is performed within the slotted tube. This method is a full displacement method and should only be used when non-displacement methods cannot be employed. Calibrate the probe within the slotted tube prior to testing.

8.5 *Selecting Methods for Hole Preparation*:

8.5.1 Make the proper choice from the previously mentioned or other acceptable methods. This choice depends on the type of soil to be tested. The major influencing factors are:

8.5.1.1 Particle size distribution.

8.5.1.2 Plasticity.

8.5.1.3 Strength.

8.5.1.4 Degree of saturation.

8.5.2 Table 3 gives guidelines for selecting methods for borehole preparation in typical soils classified according to the factors mentioned in 8.5.1.1-8.5.1.4. Table 3 does not cover all possible methods of borehole preparation or probe placement, or both, and is included as a guide for selecting drilling methods.

9. Procedure

9.1 Perform the drilling of the borehole in accordance with Section 8.

9.2 Advance the hole to the test level and clean any debris or cuttings.

9.3 Before the probe is positioned in the hole for testing, make an accurate determination of the 0 volume reading (V_0). The volume V_0 is the volume of the measuring portion of the uninflated probe at atmospheric pressure. Accomplish this by deairing all circuits and adjusting all gages of the instrument to 0 while the probe is at atmospheric pressure. Close the volume circuit, preventing any further change in the volume of the measuring circuit. Lower the probe to test depth in this condition. Determine the test depth as the depth of the midpoint of the probe.

9.4 When using Procedure A, place the probe in test position and apply the pressure on the control unit in about equal increments, until the expansion of the probe during one load increment exceeds about ¼ of V_0 as defined in 9.3 (typically 200 cm^3 for a 800-cm^3 probe). Generally, 25, 50, 100, or 200-kPa pressures are selected for testing soils. Too small steps will result in an excessively long test, too large steps may yield results with inadequate accuracy. The pressure steps should be determined in such a way that about 7 to 10 load increments are obtained.

9.5 When using Procedure B, increase the volume of the probe in volume increments of 0.05 to 0.1 times the volume V_0 (as defined in 9.3) until the limit of the equipment is reached.

9.6 For both procedures, take readings after 30 s and 1 min after the pressure or volume increments have been applied. Volume readings are recorded to an accuracy of 0.2% of V_0 (as defined in 9.3) and pressure readings to an accuracy of 5% of the limit pressure.

9.7 Once the test has reached the maximum test step as determined in 9.4 and 9.5, terminate the test by deflating the probe to its original volume and removing the probe from the hole.

9.8 One or several load-unload cycles may also be performed in this test within the elastic expansion range (see Fig. 8). These cycles, if a probe with guard cells is used, requires the accurate control of gas pressure in the guard cells to obtain a representative reading on decreased volumes. The performance of unload-reload cycle(s) is encouraged but not required. Prebored pressuremeter design rules were established historically based on testing without unload-reload loops.

9.9 *Spacing and Testing Sequence*:

9.9.1 Minimum spacing between consecutive tests (center to center of probe) should not be less than 1½ times the length of the inflatable part of the probe. Common spacings vary from 1 to 3 m (3 to 10 ft).

9.9.2 In soft, loose, and sensitive soils, the hole should be predrilled ahead of the testing depth only far enough so that the cuttings settling at the bottom of the hole will not interfere with the test.

9.9.3 In stiff soils and weathered rocks where degradation

TABLE 3 Guidelines for Selection of Borehole Preparation Methods and Tools[A]

Soil	Type	Rotary Drilling With Bottom Discharge of Prepared Mud	Pushed Thin Wall Sampler	Pilot Hole Drilling and Subsequent Sampler Pushing	Pilot Hole Drilling and Simultaneous Shaving	Continuous Flight Auger	Hand Auger in the Dry	Hand Auger With Bottom Discharge of Prepared Mud	Driven or Vibro-driven Sampler	Core Barrel Drilling	Rotary Percussion	Driven Vibro-driven or Pushed Slotted Tube
Clayey soils	Soft	2[B]	2[B]	2	2	NR	NR	1	NR	NR	NR	NR
	Firm to stiff	1[B]	1	2	2	1[B]	1	1	NR	NR	NR	NR
	Stiff to hard	1	2	1	1	1[B]	NA	NA	NA	1[B]	2[B]	NR
Silty soils	Above GWL[C]	1[B]	2[B]	2	2[B]	1	1	2	2	NR	NR	NR
	Under GWL[C]	1[B]	NR	NR	2[B]	NR	NR	1	NR	NR	NR	NR
Sandy soils	Loose and above GWL[C]	1[B]	NR	NR	2	2	2	1	2	NA	NR	NR
	Loose and below GWL[C]	1[B]	NR	NR	2	NR	NR	1	NR	NA	NR	NR
	Medium to dense	1[B]	NR	NR	2	1	1	1	2	NR	2[B]	NR
Sandy gravel or gravely sands below GWL	Loose	2	NA	NA	NA	NA	NA	NA	NR	NA	2	2
	Dense	NR	NA	NA	NA	NR	NA	NA	NR	NA	2	1[D]
Weathered rock	...	1	NA	2[B]	NA	1	NA	NA	1	2	2	NR

[A] 1 is first choice; 2 is second choice; NR is not recommended; and NA is nonapplicable.
[B] Method applicable only under certain conditions (see text for details).
[C] GWL is ground water level.
[D] Pilot hole drilling required beforehand.

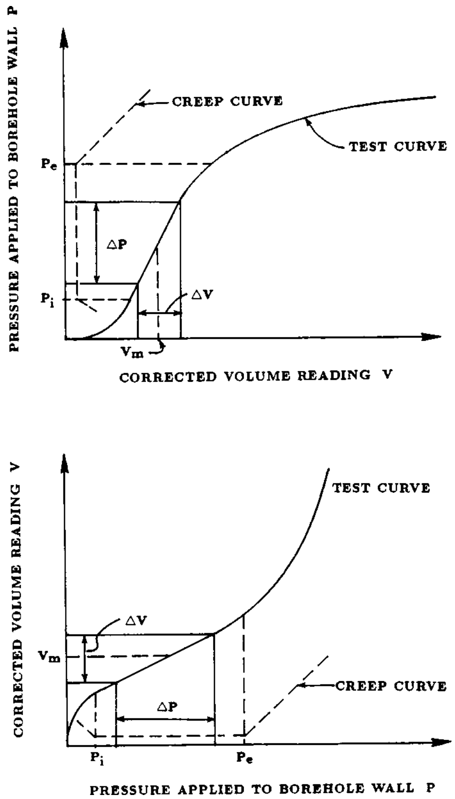


FIG. 8 Pressuremeter Test Curves for Procedure A

due to exposure is not significant, the hole can be predrilled to several test depths.

9.9.4 When the probe is driven into the soil, testing can take place continuously, while observing the minimum spacing requirements indicated in 9.9.1. No withdrawal is required between tests.

10. Calculations

10.1 The pressure transmitted to the soil by the probe from the pressure readings is calculated as follows:

$$P = P_R + P_\delta - P_c \quad (6)$$

where:

P = pressure exerted by the probe on the soil, kPa,
P_R = pressure reading on control unit, kPa,
P_δ = hydrostatic pressure between control unit and probe, kPa (see 7.5), and
P_c = pressure correction due to stiffness of instrument at corresponding volume, kPa, determined in accordance with 7.2.

10.2 Calculate the corrected volume reading of the probe from the volume readings as follows:

$$V = V_R - V_c \quad (7)$$

where:

V = corrected increase in volume of the measuring portion of the probe, cm^3,
V_R = volume reading on readout device, cm^3, and
V_c = volume correction determined in accordance with 7.3 and made at the test pressure readings corresponding to $P = P_R + P_\delta$, cm^3.

10.3 Plot the pressure-volume increase curve by entering the corrected volume and the corrected pressure on a coordinate system. Connect the points by a smooth curve. This curve is the corrected pressuremeter test curve and is used in the determination of the results (Fig. 8(a) and Fig. 8(b)). Other plots, such as pressure versus relative increase in radius, may also be used (Fig. 9).

NOTE 10—Historically, pressures were plotted on the horizontal axis and volume on the vertical axis. Considering the stress-strain nature of this test, it has become increasingly customary to reverse the coordinates. According to this test method, both presentations are acceptable.

10.4 For Procedure A, plot the volume increase readings (V_{60}) between the 30 s and 60 s reading on a separate graph. Generally, a part of the same graph is used, see Fig. 8. For Procedure B, plot the pressure decrease reading between the 30 s and 60 s reading on a separate graph. The test curve shows an almost straight line section within the range of either low volume increase readings (V_{60}) for Procedure A or low pressure decrease for Procedure B. In this range, a constant soil deformation modulus can be measured. Past the so-called creep pressure, plastic deformations become prevalent.

10.5 The pressuremeter modulus is determined as follows:

$$E_p = 2(1 + \gamma)(V_0 + V_m)\frac{\Delta P}{\Delta V} \quad (8)$$

where:

E_p = pressuremeter modulus, kPa, an arbitrary modulus of deformation as related to the pressure- meter based on data reduction included herein,
γ = Poisson ratio,

NOTE 11—For compatibility with tests performed with this instrument earlier, a value of 0.33 is recommended by this test method. Other values

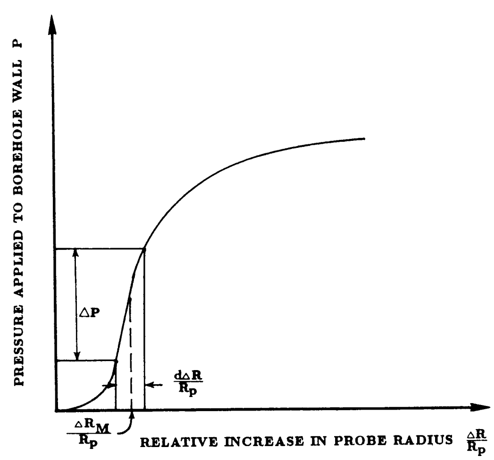


FIG. 9 Pressure Versus Relative Increase in Radius

may be used, but the value must be reported.

V_0 = volume of the measuring portion of the uninflated probe at 0 volume reading at ground surface, cm^3,
V = corrected volume reading of the measuring portion of the probe,
ΔP = corrected pressure increase in the center part of the straight line portion of the pressure-volume curve (see Fig. 8).
ΔV = corrected volume increase in the center part of the straight line portion of the pressure-volume curve, corresponding to ΔP pressure increase (see Fig. 8), and
V_m = corrected volume reading in the center portion of the ΔV volume increase.
$V_0 + V$ = current volume of inflated probe.

NOTE 12—If a break in the straight line portion of the pressuremeter curve is observed, calculations shall include a pressuremeter modulus for each straight line section of the pressuremeter test curve.

NOTE 13—A pressuremeter modulus can also be calculated from an unload-reload cycle. This modulus should be identified as the unload-reload pressuremeter modulus (Fig. 10).

NOTE 14—For tests where the probe diameter (radius) is measured, the pressuremeter modulus can be determined by converting the measurements into volume changes of the probe, in which case the formula given in this test method will apply (10.5). The pressuremeter modulus may also be calculated from diameter measurements directly as follows:

$$E_p = (1 + \gamma)(R_p + \Delta R_m)\Delta P/d\Delta R \quad (9)$$

where:
R_p = radius of probe in uninflated condition, mm,
ΔR_m = increase in radius of probe up to the point corresponding to the pressure where E_p is measured, mm,
$d\Delta R$ = increase of probe radius corresponding to ΔP pressure increase, mm,
ΔR = increase in probe radius, mm, and
$R_p + \Delta R$ = current radius of inflated probe, mm.

10.6 The conventional limit pressure is determined as follows: the limit pressure (P_l) is defined as the pressure where the probe volume reaches twice the original soil cavity volume, defined as the volume $V_0 + V_i$, (Fig. 8) where V_i is the corrected volume reading at the pressure where the probe made contact with the borehole. The volume reading at twice the original soil cavity volume is ($V_0 + 2V_i$). The limit pressure is usually not obtained by direct measurements during the test due to limitation in the probe expansion or excessively high pressure. If the test was conducted to read sufficient plastic deformation, the limit pressure can be determined by a $1/V$ to P plot, as shown by Fig. 11.

10.6.1 Points from the plastic range of the test generally fall in an approximate straight line. The extension of this line to twice the original probe volume will give the limit pressure (P_l) on the plot.

NOTE 15—The theoretical limit pressure is defined as the pressure where infinite expansion of the probe occurs. For practical purposes the definition outlined in 10.6 is recommended. Several methods are used to estimate the limit pressure from points measured during the test. These methods may also be used but should be properly reported.

NOTE 16—When the requirement of 8.3.1 about hole diameter tolerances is not met, only part of the test curve may be suitable for interpretation. The limit pressure is less sensitive to borehole size.

11. Report

11.1 For each pressuremeter test the following observations shall be recorded:

11.1.1 Date.

11.1.2 Boring number.

11.1.3 Type of test (Procedure A or B).

11.1.4 Type of probe (single or triple cells, measuring system for pressure, and volume or displacement, etc.).

11.1.5 Outside diameter of expandable section of probe.

11.1.6 Length of expandable probe section.

11.1.7 Description of membrane and sheath on probe.

11.1.8 Depth to center point of expanding portion of probe.

11.1.9 Time elapsed between end of borehole preparation and start of test.

11.1.10 Pressure or volume steps.

11.1.11 Volume readings at 30 and 60-s elapsed time for each load increment for Procedure A, pressure readings at 30 and 60-s elapsed time for each volume increment for Procedure B.

11.1.12 Notes on any deviation from standard test procedure.

11.1.13 Volume versus pressure graph, pressuremeter modulus, limit pressure.

11.1.14 Description of calibrations and calibration curves.

11.2 In addition, the following observations shall be recorded for the boring:

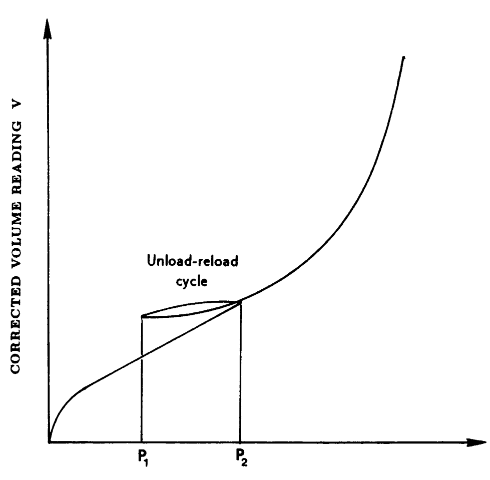


FIG. 10 Cyclic Pressuremeter Test Curve

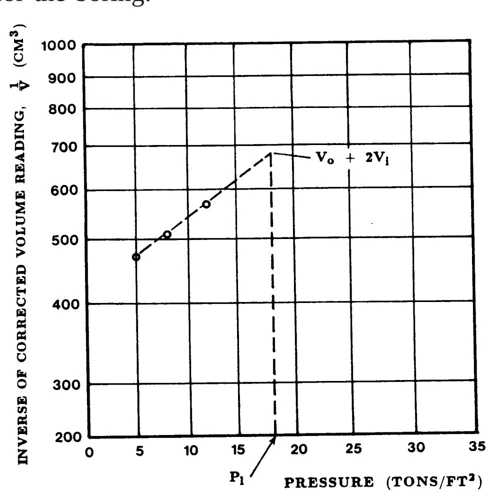


FIG. 11 Determination of Limit Pressure from Inverse of Volume Versus Pressure

11.2.1 Boring number.
11.2.2 Log of soil conditions.
11.2.3 Reference elevation.
11.2.4 Depth of water in the hole at the time of test.
11.2.5 Method of making the hole and method of preparing the cavity.
11.2.6 Type of testing equipment used.
11.2.7 Notes on driving resistance in the boring (SPT test *N* value).
11.2.8 Weather and temperature.
11.2.9 Name of drilling foreman.

12. Precision and Bias

12.1 The single most important factor in the successful completion of a preboring pressuremeter test is the preparation of a good hole. A good hole is very difficult to prepare in very soft clays and very loose sands. The pressuremeter limit pressure is less sensitive to the quality of the borehole; however, the pressuremeter modulus is much more sensitive to the quality of the borehole.

12.2 The subcommittee is seeking pertinent data from users of this test method to develop a precision statement.

13. Keywords

13.1 in situ test; modulus; limit pressure; stress-strain

SUMMARY OF CHANGES

In accordance with Committee D 18 policy, this section identifies the location of the changes to this standard since the last edition (D 4719–87(1994)$^{\epsilon 1}$) that may impact the use of this test method.

(*1*) Changed the title to prebored pressuremeter testing in soils to reflect the method of probe installation.
(*2*) Added Section 3 on Terminology and renumbered all subsequent sections.
(*3*) Added a sentence in 5.2 (formerly 4.2) to clarify that disturbance during installation is not to be completely eliminated but simply minimized for the design rules to be directly applicable.
(*4*) Added a schematic of the pressuremeter probe on Fig. 1.
(*5*) Modified Fig. 2 and associated 7.2.1 and 7.3 (formerly 6.2.1 and 6.3) to clarify calibration procedures and corrections.
(*6*) Modified 7.5 (formerly 6.5) and deleted former 9.1.1.
(*7*) Added a statement in 9.8 (formerly 8.8) encouraging the performance of unload-reload cycles.
(*8*) Renamed the reload modulus to unload-reload modulus.
(*9*) Renumbered Note 9 to Note 2.
(*10*) Corrected the expression for limit pressure in 10.6 (formerly 9.6).
(*11*) Fig. 11 was replaced to show the extrapolation to the limit pressure using an arithmetic scale rather than an inverse (l/V) scale.
(*12*) Modified and renumbered Section 11.