Designation: D 6635 – 01

Standard Test Method for Performing the Flat Plate Dilatometer[1]

This standard is issued under the fixed designation D 6635; 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 describes an in-situ penetration plus expansion test. The test is initiated by forcing the steel, flat plate, dilatometer blade[2], with its sharp cutting edge, into a soil. Each test consists of an increment of penetration, generally vertical, followed by the expansion of a flat, circular, metallic membrane into the surrounding soil. The test provides information about the soil's in-situ stratigraphy, stress, strength, compressibility, and pore-water pressure for use in the design of earthworks and foundations.

1.2 This method includes specific requirements for the preliminary reduction of dilatometer test data. It does not specify how to assess or use soil properties for engineering design.

1.3 This method applies best to those sands, silts, clays, and organic soils that can be readily penetrated with the dilatometer blade, preferably using static push (see 4.2). Test results for soils containing primarily gravel-sized particles and larger may not be useful without additional research.

1.4 This method is not applicable to soils that cannot be penetrated by the dilatometer[2] blade without causing significant damage to the blade or its membrane.

1.5 The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock and Contained Fluids[3]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[3]

D 2435 Test Method for One-Dimensional Consolidation Properties of Soil[3]

D 3441 Test Method for Mechanical Cone Penetration Tests of Soil[3]

D 3740 Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[3]

D 5778 Test Method for Performing Electronic Friction Cone and Piezocone Penetration of Soils[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *A-pressure*—the gage gas pressure against the inside of the membrane when the center of the membrane has lifted above its support and moved laterally 0.05-mm (tolerance +0.02, -0.00 mm) into the soil surrounding the blade.

3.1.2 *B-pressure*—the gage gas pressure against the inside of the membrane when the center of the membrane has lifted above its support and moved laterally 1.10-mm (± 0.03 mm) into the soil surrounding the blade.

3.1.3 *C-pressure*—The gage gas pressure against the inside of the membrane when the center of the membrane returns to the *A*-pressure position during a controlled, gradual deflation following the *B*-pressure.

3.1.4 *DMT*—abbreviation for the flat plate dilatometer test as described herein.

3.1.5 *DMT sounding*—the entire sequence of dilatometer tests and results along a vertical line of penetration in the soil.

3.1.6 *DMT test*—the complete procedure of penetration, membrane inflation and then deflation for a single test depth using the fiat plate dilatometer.

3.1.7 ΔA—the gage gas pressure inside the membrane (corrected for Z_m) required to overcome the stiffness of the

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

Current edition approved Feb. 10, 2001. Published November 2001.

[2] The dilatometer is covered by a patent held by Dr. Silvano Marchetti, Via Bracciano 38, 00189, Roma, Italy. Interested parties are invited to submit information regarding the identification of acceptable alternatives to this patented item to the Committee on Standards, ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428–2959. Your comments will receive careful consideration at the meeting of the responsible technical committee, which you may attend.

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

[4] *Annual Book of ASTM Standards*, Vol 04.09.

membrane and move it inward to a center-expansion of 0.05 mm (a negative gage or suction pressure, but recorded as positive) with only ambient atmospheric pressure acting externally.

3.1.8 ΔB—the gage gas pressure inside the membrane (corrected for Z_m) required to overcome the stiffness of the membrane and move it outward to a center-expansion of 1.10 mm against only the ambient atmospheric pressure.

3.1.9 E_D—the dilatometer modulus, based on linear elastic theory, and the primary index used in the correlation for the constrained and Young's moduli (see Section 9).

3.1.10 G_m—bulk specific gravity = moist soil unit weight divided by the unit weight of water.

3.1.11 I_D—the dimensionless dilatometer material index, used to identify soil type and delineate stratigraphy (see Section 9).

3.1.12 K_D—the dimensionless dilatometer horizontal stress index, the primary index used in the correlation for in-situ horizontal stress, overconsolidation ratio, and undrained shear strength in cohesive soils. K_D is similar to the at-rest coefficient of earth pressure except that it includes blade penetration effects.

3.1.13 *membrane*—a thin, flexible, 60-mm diameter circular piece of sheet metal (usually stainless steel), fixed around its edges, that mounts on one side of the dilatometer blade and which, as a result of an applied internal gas pressure, expands into the soil in an approximate spherical shape along an axis perpendicular to the plane of the blade.

3.1.14 *P*—the total push, or thrust force required to advance only the dilatometer blade to its test depth, measured at its test depth and exclusive of soil or other friction along the pushrods.

3.1.15 p_0—the *A*-pressure reading, corrected for Z_m, the ΔA membrane stiffness at 0.05-mm expansion, and the 0.05-mm expansion itself, to estimate the total soil stress acting normal to the membrane immediately before its expansion into the soil (0.00-mm expansion, see Section 9).

3.1.16 p_1—the *B*-pressure reading corrected for Z_m and the ΔB membrane stiffness at 1.10-mm expansion to give the total soil stress acting normal to the membrane at 1.10-mm membrane expansion (see Section 9).

3.1.17 p_2—The *C*-pressure reading corrected for Z_m and the ΔA membrane stiffness at 0.05-mm expansion and used to estimate pore-water pressure (see 9.3).

3.1.18 σ'_v—vertical effective stress at the center of the membrane before the insertion of the DMT blade.

3.1.19 σ_v—total vertical stress at the center of the membrane before the insertion of the DMT blade, generally calculated from unit weights estimated using the DMT results.

3.1.20 u_0—the pore-water pressure acting at the center of the membrane before the insertion of the DMT blade (often assumed as hydrostatic below the water table surface).

3.1.21 Z_m—the gage pressure deviation from zero when vented to atmospheric pressure (an offset used to correct pressure readings to the true gage pressure).

4. Summary of Test Method

4.1 A dilatometer test (DMT) consists of forcing the dilatometer blade into the soil, with the membrane facing the horizontal direction, to a desired test penetration, measuring the thrust to accomplish this penetration and then using gas pressure to expand a circular steel membrane located on one side of the blade. The operator measures and records the pressure required to produce expansion of the membrane into the soil at two preset deflections. The operator then deflates the membrane, possibly recording an optional third measurement, advances the blade the desired penetration increment and repeats the test. Each test sequence typically requires about 2 minutes. A dilatometer sounding consists of the results from all the tests at one location presented in a fashion indicating variation with depth.

4.2 The operator may advance the blade using either a quasi-static push force or dynamic impact from a hammer, with quasi-static push preferred. A record of the penetration resistance (thrust force or blows per penetration increment) is desirable both for control of the penetration and later analyses.

NOTE 1—In soils sensitive to impact and vibrations, such as medium to loose sands or sensitive clays, dynamic insertion methods can significantly change the test results compared to those obtained using a quasi-static push. In general, structurally sensitive soils will appear more compressible when tested using dynamic insertion methods. In such cases check for dynamic effects and, if important, calibrate and adjust test interpretations accordingly.

4.3 The penetration increment typically used in a dilatometer test (DMT) sounding varies from 0.15 to 0.30 m (0.5 to 1.0 ft). Most soundings are performed vertically and this Test Method requires that the membrane face the horizontal direction. Testing below impenetrable layers will require preboring and supporting (if required) a borehole with a diameter of at least 100 mm (4 in.).

4.4 The operator performs a membrane calibration before and after each DMT sounding.

4.5 The field data is then interpreted to obtain profiles of those engineering soil properties of interest over the depth range of the DMT sounding.

5. Significance and Use

5.1 Soundings performed using this test method provide a detailed record of dilatometer results which are useful for evaluation of site stratigraphy, homogeneity, depth to firm layers, voids or cavities, and other discontinuities. The penetration resistance and subsequent membrane expansion are used for soil classification and correlation with engineering properties of soils. When properly performed at suitable sites, the test provides a rapid means of characterizing subsurface conditions.

5.2 The DMT test provides measurements of penetration resistance, lateral stress, deformation modulus and pore-water pressure (in sands). However, the in-situ soil properties are affected by the penetration of the blade. Therefore, published correlations are used to estimate soil properties for the design and construction of earthworks and foundations for structures, and to predict the behavior of soils subjected to static or dynamic loads.

5.3 This test method tests the soil in-situ and soil samples are not obtained. However, the interpretation of the results from this test method does provide an estimate of the types of soil penetrated. Soil samples from parallel borings may be obtained for correlation purposes, but prior information or experience may preclude the need for borings.

6. Apparatus

6.1 The annotated Fig. 1 illustrates the major components of the DMT equipment, exclusive of that required to insert the blade. The dimensions, tolerances, deflections, etc. have been set by the inventor, and holder of the dilatometer patent, S. Marchetti.

6.1.1 *Blade*, (1), 96 mm wide (95 to 97 mm) and 15 mm thick (13.8 to 15 mm).

6.1.2 *Membrane*, (2), 60 mm diameter.

6.1.3 *Control Unit*, with a pressure readout system (3) that can vary in type, range, and sensitivity as required. Gages with an accuracy better than ¼ percent of span are recommended. The unit shown has both low-range and high-range Bourdon gages that are read manually. Older units have a single Bourdon gage, typically medium-range. The gages should be annually calibrated against a traceable standard, more often if heavily used. The control unit also includes connections (5) for a pressure source, a pneumatic-electrical cable, and an electrical ground cable, and has valves to control gas flow and vent the system (6).

6.1.4 *Calibration Syringe*, (4) for determining the ΔA and ΔB membrane calibrations using the low-range Bourdon gage. Some control units have a separate low-range pressure gage which attaches to the control unit for determining the ΔA and ΔB membrane calibrations

6.1.5 *Pneumatic-Electrical Cable*, (7) to transmit gas pressure and electrical continuity from the control unit to the blade.

6.1.6 *Ground Cable*, (8) to provide electrical continuity between the push rod system and the calibration unit.

6.2 Insertion equipment is required to advance the blade to the test depth. The blade may be pushed using the quasi-static thrust of a drill rig or cone penetrometer rig (CPT, see Test Method D 3441/D 5778), driven using a hammer such as in the standard penetration test (SPT, see Test Method D 1586 and Note 1), or inserted using other suitable equipment. Drill rig support may be required to born through impenetrable soil or rock layers above the desired test depth.

6.3 Push rods are required to transfer the thrust from the surface insertion equipment and to carry the pneumatic-electrical cable from the surface control unit to the dilatometer blade. The rods are typically those used with the CPT (Test Method D 3441/D 5778) or SPT (Test Method D 1586) equipment. Suitable adapters are required to attach the blade to the bottom of the rod string and allow the cable to exit near the top of the rods. When testing from the bottom of a borehole, the cable may exit from the rod string some suitable distance above the blade and then be taped to the outside of the rods at appropriate intervals. The exposed cable should not be pinched or allowed to penetrate the soil.

6.4 A gas pressure tank with a suitable regulator and tubing to connect it to the control unit is required. The operator may use any nonflammable, noncorrosive, nontoxic gas as a pressure source. Dry nitrogen is recommended.

6.5 A suitable load cell, just above the blade or at the top of the rods, is required to measure the thrust *P* applied during the blade penetration. Hydraulic ram pressure may also be used to measure thrust with proper correlation. Parasitic soil-rod friction is generally insignificant in sands, but may be measured during upward withdrawal.

7. Procedure

7.1 *Preparation for Testing and Calibration*:

7.1.1 Select for testing only blades that conform to the manufacturer's internal tolerance adjustments and that are in good visual external condition. The blade should have no discernible bend, defined as a clearance of 0.5 mm or more under a 150-mm straight edge placed along the blade parallel

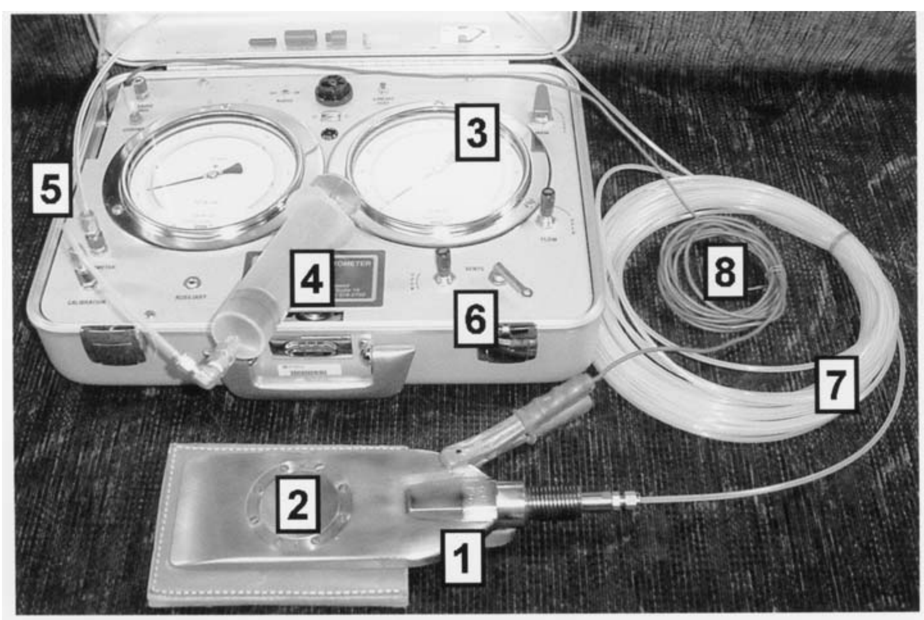

FIG. 1 DMT Equipment

to its axis. Its penetrating edge should be straight and sharp, and it should not deviate more than 2 mm transverse to the axis of the rods.

7.1.2 Attach the pressure source and pneumatic-electrical cable to the control unit. Plug the blade end of the cable with an appropriate fitting and apply 4000-6000 kPa pressure to the cable through the control unit. Close the flow control valve and observe the gage for any pressure drop that would indicate a leak in the system. Locate and repair any leaks in the cable. Small leaks (less than 100 kPa/min) in the control unit, though undesirable and indicative of a potential problem, should not significantly affect the test results.

7.1.3 Thread the pneumatic-electrical cable through the lower blade-rod adapter, as many of the push rods as needed and any other adapters, stabilizers or push frames as required. Always cap the cable ends to prevent contamination of the cables and corrosion of the terminals. Connect and tighten the cable to the blade. Insure that the blade and any lower adapters shoulder squarely and tightly to the bottom rod.

7.1.4 Attach the pneumatic-electrical cable to the control unit and connect the ends of the electrical ground cable to the control unit and blade, respectively. To check the circuitry, press the center of the membrane down to activate the electrical/audio signal on the control unit.

7.1.5 With the membrane unrestrained, use the calibration equipment to determine and record the ΔA and ΔB membrane stiffness pressures. Correct the ΔA and ΔB for the gage offset, Z_m. The calibrations should fall within the manufacturer tolerances and are recorded as positive values. The electrical/audio signal should stop and start unambiguously at the 0.05-mm and 1.10-mm expansions. The membrane should be free of wrinkles and deep scratches and should expand smoothly during pressurization without popping or snapping sounds. Repeat the calibration procedure several times to verify consistency. Replace any membrane that fails these checks.

7.1.6 The calibration procedure provides a final check of the equipment prior to testing. If the equipment is disassembled for any reason, the operator should verify the calibrations before proceeding.

7.2 *DMT Tests*:

7.2.1 With the vent valve open and the push rods vertical, advance the dilatometer blade to the first depth. Advance the blade by means of quasi-static push at a rate of 10-30 mm/sec. If possible, measure and record the thrust just before reaching the test depth. An example field data sheet is shown in Fig. X1.2. Alternatively advance the blade using a drop hammer and record the number of blows required for each 100-150 mm of penetration. If estimating the equivalent static thrust from blow counts, use an average of above and below the test depth. Borehole predrilling with casing or drilling mud is acceptable as required.

7.2.2 The blade penetration must produce an electrical/audio signal to indicate the membrane has been pressed flush against the blade to start the 7.2.3 DMT sequence. See 8.3.

7.2.3 Within 15 seconds after reaching the test depth, unload any static force on the push rods, close the vent valve, and pressurize the membrane. The gage pressure at the instant the electrical/audio signal stops (0.05-mm membrane displacement) is recorded as the *A*-pressure reading. Obtain this reading within 15 to 30 seconds after beginning the gas flow. Without stopping the gas flow at the *A*-pressure, continue pressurization of the membrane until the signal comes on again at a 1.10-mm displacement. This is the *B*-pressure reading and-should be obtained 15 to 30 seconds after beginning the gas flow. Without stopping the gas flow at the *A*-pressure, continue pressurization of the membrane until the signal comes on again at a 1.10-mm displacement. This is the *B*-pressure reading and should be obtained 15 to 30 seconds after the *A*-pressure. These time limits require that the pressurization rate be varied according to the anticipated pressure readings, faster in stiff soils and dramatically slower in soft soils. Read the gages with the best possible accuracy, typically 1 kPa for a low-range gage and 5-10 kPa for a high-range gage. Upon reaching the *B*-pressure, immediately open the vent valve and stop the gas flow. Immediate depressurization prevents over-expansion of the membrane, which may change its calibrations. See 7.2.4 for an alternative, controlled depressurization procedure to obtain the "*C*-pressure" (strongly recommended).

NOTE 2—The difference between the *A*-pressure and *B*-pressure readings should always be greater than the sum of the ΔA and ΔB calibrations.

7.2.4 At least every other DMT test in a sounding (preferably more) should include a smooth, controlled depressurization to measure the *C*-pressure. Newer control units include a flow control vent valve for this purpose. Read the *C*-pressure on the low-range gage when the membrane has deflated to the *A*-pressure position (0.05-mm deflection) and the electric signal comes on again (not when the *B*-pressure signal stops). Obtain the *C*-pressure within 15 to 30 seconds immediately following the *B*-pressure. Readings to the nearest 1 kPa are recommended.

NOTE 3—The pore-water pressure must exceed the ΔA calibration to result in a positive *C*-pressure reading. If the electric signal does not activate during the *C*-pressure deflation then use the calibration syringe to apply a suction and obtain a negative *C*-pressure. The value of p_2 will remain positive provided the magnitude of the negative *C*-pressure does not exceed the ΔA calibration (see Table 1).

NOTE 4—The *C*-pressure is sensitive to operator technique. Abrupt pressure changes during the membrane deflation may collapse the soil in front of the membrane and yield a poor measurement. In free-draining soils, the *C*-pressure will not change significantly with time and the operator may check it by repeating the (A-B-C) sequence. The *A*- and *B*-pressures will change from the initial test but the *C*-pressure should remain constant. The repeated *A*- and *B*-pressures are not generally useful. Soils which are not freely-drained will behave differently (see 7.3).

7.2.5 Repeat the test sequence for a new set of *A*-, *B*-, and possibly *C*-pressures, at each depth interval down to the maximum depth of the sounding. The minimum penetration increment between tests is 100 mm (4 in.). Pressure check the system every third or fourth test during the sounding. See 8.8 for details.

7.3 *A-Pressure Dissipation Tests*:

7.3.1 In poorly drained soils, with $I_D < 2$, the excess pore-water pressure induced by the blade penetration usually dissipates over a period of time longer than required for the DMT tests. The coefficient of consolidation may be estimated by observing the dissipation of the *A*-pressure. To perform a

TABLE 1 Calculations for Preliminary Reduction of Dilatometer Test Data[A,B,C]

Parameter	Symbol	Formula	Notes
		Preliminary Calculations	
Corrected *A*-pressure	p_0	$1.05(A–Z_m+\Delta A) – 0.05(B–Z_m–\Delta B)$	
Corrected *B*-pressure	p_1	$(B–Z_m–\Delta A)$	
Corrected *C*-pressure	p_2	$(C–Z_m+\Delta A)$	
		Estimate of Pore-Pressure and Effective Vertical Stress	
In-situ Water Pressure	u_0	Estimate from groundwater table or p_2	use p_2 depth profile, see 9.3
Bulk Specific Gravity	G_M	use best estimate	see Fig. X1.1
Total Vertical Stress	σ_v	Σ(layer unit weight × height) where layer unit weight = G_m × unit weight of water	see 9.4
Effective Vertical Stress	σ_v'	$(\sigma_v – u_0)$	
		DMT Indices (include effect of blade penetration)	
Material Index	I_D	$(p_1–p_0) / (p_0–u_0)$	see Fig. X1.1
Horizontal Stress Index	K_D	$(p_0–u_0) / \sigma_v'$	correlate with K_0
Dilatometer Modulus	E_D	$34.7(p_1–p_0)$	correlate K_D and E_D with M

[A] Schmertmann, John H., "Guidelines for Using the CPT, CPTU and Marchetti DMT for Geotechnical Design," U.S. Dept. of Transportation, Federal Highway Administration, Report No. FHWA-PA-024+84-24, Vol 3.

[B] Marchetti, S., "In-Situ Tests by Flat Dilatometer," *Journal of Geotechnical Engineering Division*, American Society of Civil Engineers, Vol. 106, No. GT3, March, 1980, pp. 299–321.

[C] Briaud, J.L., and Miran, J., "The Flat Dilatometer Test", FHWA-SA-91–044, Federal Highway Administration, Feb., 1992.

dissipation test, stop the blade penetration at the chosen test depth and make successive *A*-pressure readings over time. Dissipation tests can be time consuming and are performed only as needed. Two similar test procedures, the A_2-method and the A-method, are described in 7.3.2 and 7.3.3 respectively. Either is acceptable.

NOTE 5—Before making a detailed analysis of the time-dissipation curves in 7.3.2 and 7.3.3, the *A*-pressure measurements may be corrected to obtain p_0 values. If a paired *B*-pressure measurement is available, as for the final *A*-pressure, then p_0 may be calculated as shown in Table 1. For dissipation analysis a paired *B*-pressure is generally not available, and the following equation may be used to correct *A*-pressure readings:

$$p_0\,(dissipation) = (A - Z_m + \Delta A)$$

7.3.2 *A_2-method Dissipation*—This procedure attempts to measure the pore-water pressure directly and determine consolidation parameters from analysis of the resulting pore-pressure curve. The A_2-method requires a complete DMT test (A-B-C) before beginning a series of *A*-pressure only measurements. When carried to complete dissipation in free-draining soils, the final value of p_0 (see Note 5) should equal the in-situ pore-water pressure, u_0. Ideally, the initial DMT test opens a 1.10-mm cavity and the subsequent *A*-pressures measure only the pore-water pressure in the open cavity (or greatly disturbed soil zone) immediately adjacent to the membrane. If the time-dissipation curve approaches u_0 asymptotically, then this assumption is justified.

7.3.2.1 After penetration to the test depth, follow the full DMT sequence of readings (A-B-C). Start a stopwatch or record initial time at the instant of the thrust removal. Note the time elapsed in seconds at the instant of the *C*-pressure reading and record the data.

7.3.2.2 Immediately repressurize the system, obtain an *A*-pressure reading, and then vent the pressure without further membrane expansion. Record the reading and elapsed time in seconds at the instant of this *A*-pressure reading. Obtain *A*-pressure readings to the nearest 1 kPa.

7.3.2.3 Continue performing the test sequence in 7.3.2.2 to obtain reasonably spaced data points for the time-dissipation curve (see 7.3.2.4). A factor of 2 increase in time at each *A*-pressure is satisfactory (i.e. *A*-pressures at 1, 2, 4, 8, 15, 30 minutes...). A *B*-pressure should be obtained following the final *A*-pressure.

7.3.2.4 Plot the *A*-pressure readings obtained as soon as convenient and continue the plot for each successive reading. Plot the *A*-pressure (uncorrected) vs. the elapsed time for each reading. A square-root-of-time scale works well for the extrapolations described below. (See Fig. 2 for an idealized example field plot.)

7.3.2.5 Stop the dissipation test only after making enough measurements to determine t_{50}, the time at 50 percent dissipation of the *A*-pressure. Use t_{50} to calculate the coefficient of consolidation.[5] If convenient, continue the test long enough for the dissipation curve to approach its eventual asymptote at 100 percent dissipation, A_{100}. This helps define A_{100} (ideally = u_0 when corrected). A possible method for obtaining t_{50} is outlined below:

(*1*) Extrapolate the beginning of the dissipation curve back to the *A*-pressure intercept at time = 0, A_0, mathematically or graphically. A straight line through the early data points is usually adequate.

(*2*) Extrapolate the end of the dissipation curve forward to estimate the asymptotic *A*-pressure, A_{100}. Alternatively, estimate A_{100} from the expected in-situ pore-water at the test depth:

$$A_{100}\,(estimated) = (u_0 - \Delta A + Z_m)$$

(*3*) Average A_0 and A_{100} to find A_{50} at 50 percent dissipation.

[5] Schmertmann, John H., "Guidelines for Using the CPT, CPTU and Marchetti DMT for Geotechnical Design," U.S. Dept. of Transportation, Federal Highway Administration, Report No. FHWA-PA-024+84-24, Vol 3.

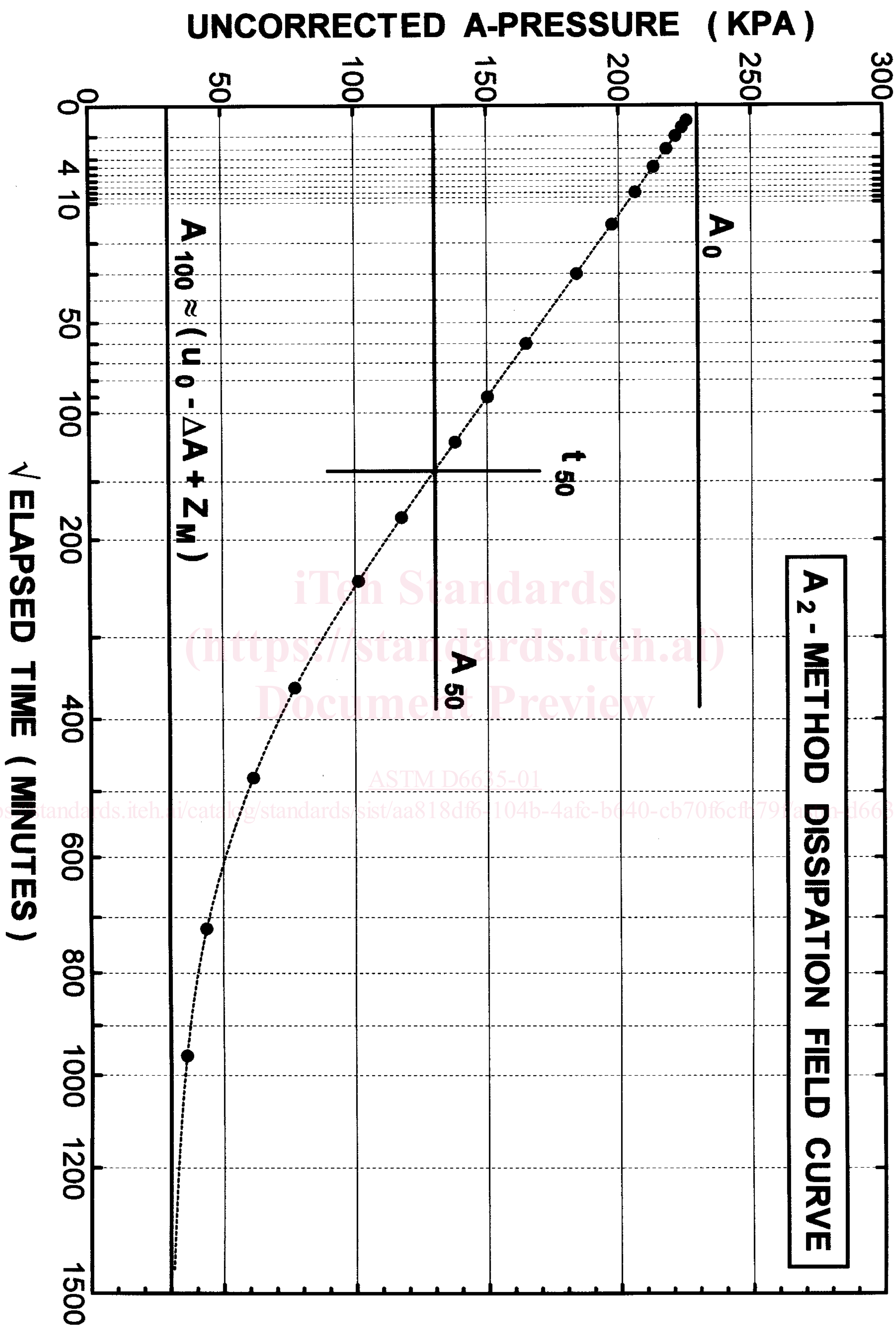

FIG. 2 Idealized Example Field Plot of Uncorrected A_2-Method Dissipation Data