DIGEST #8
August 1986

8A. In Situ ´86 Papers

The In Situ ´86 ASCE Specialty Conference took place at Virginia Tech, Blacksburg, VA in June, with over 500 attending. The ASCE published Geotechnical Publication No. 6, titled "Use of In Situ Tests in Geotechnical Engineering", edited by Samuel P. Clemence. This publication contains 77 written papers submitted to the Conference, of which 57 discuss different types of penetration tests, of which 16 mentioned the DMT. The enclosed Table 8A.1 lists these DMT papers, with an asterisk code to denote the relative importance of the DMT in the paper.

The Editor recommends this publication to anyone interested in keeping up with the state-of-the-art in insitu testing.

8B. HP 41CV Program for Dilatometer-based Settlement Calculation

The Editor wrote a paper for In Situ ´86 titled "Dilatometer to Compute Foundation Settlement". Since then he has prepared a computer program on the HP 41CV hand-held calculator to make the required calculations. Using the calculator offers a convenience. One can also use hand calculation.

Appendix 8B enclosed gives the details of the program. The total program consists of two parts: (1) A general spread sheet program of 284 steps

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(denoted #80), plus (2) A 200 step addition to the program to adapt the general spread sheet program to the settlement calculation problem.

8C. ASTM Suggested DMT Method

The Geotechnical Testing Journal, June 1986 issue, pp. 93-101, has a paper prepared by Committee D18.02.01 titled "Suggested Method for Performing the Flat Plate Dilatometer Test". This paper may be referenced when specifying the performance of the DMT. It has been published for use and comment, and as a preliminary to eventual approval and publication as a regular ASTM Standard Method. The Editor hopes that readers will use enclosed Suggested Method and feed back any suggestions for improvement.

8D. Calibration of High Strength Membranes

Professor Marchetti has developed and manufactured new DMT membranes that use stainless steel with significantly greater strength than previously available. These are now coming into more common use. The experience has been favorable in that membranes require less replacements in ordinary soils, and they sometimes permit testing in very difficult soils unsuitable for the previous lower strength membranes. GPE recommends the routine use of the stronger membranes.

The stronger membranes require a somewhat different exercise and

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calibration procedure. The enclosed pp. 3.8a, and 3.8b describe these new procedures. We suggest you place this into your DMT User's Manual for easy reference when using these new membranes.

John H. Schmertmann

Editor

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TABLE 8A.1

IN SITU ´86 PAPERS NOTING DMT

code: *** major use of DMT
** significant use of DMT
* minor use of DMT

**	Use of In Situ Tests for Foundation Design On Clay Gunnar Aas, Suzanne Lacasse, Tom Lunne and Kaare Hoeg	1
**	Deformation Characteristics of Cohesionless Soils from In Situ Tests R. Bellotti, V. Ghionna, M. Jamiolkowski, R. Lancellota and G. Manfredini	47
**	In Situ Testing for Lock and Dam 26 Cellular Cofferdam G. Wayne Clough and Patrick M. Goeke	131
*	Ground Improvement Evaluation by In-Situ Tests James K. Mitchell	221
***	Dilatometer to Compute Foundation Settlement John H. Schmertmann	303
**	In Situ Testing for Ground Modification Techniques Joseph P. Welsh	322
***	Flat Dilatometer Tests in Calibration Chambers G. Baldi, R. Bellotti, V. Ghionna, M. Jamiolkowski, S. Marchetti and E. Pasqualini	431
**	A Modern Cone Penetration Testing Vehicle John L. Davidson and David G. Bloomquist	502
*	Lateral Stress Measurement During Cone Penetration Scott R. Huntsman, James K. Mitchell, Lucien W. Klejbuk, and Sanjay B. Shinde	617
**	In Situ Tests on a Florida Peat Thomas J. Kaderbek, David Barreiro and Martin A. Call	649
***	Dilatometer Tests in Sand Suzanne Lacasse and Tom Lunne	686
**	In Situ Test with K_o Stepped Blade Alan J. Luttenegger and David A. Timian	730

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CHANGE (March,1985)

Since March 1985,new membranes (denoted H=hard) are in use,less vulnerable to tearing. The new membranes tolerate,outside the soil,relatively high internal pressure (even 15-20 bar) without getting damaged or overinflated.

Excercising the new membranes requires pressure higher than indicated in item 12 on page 3.7 of the Manual.Also the corrections,even after excercising,are higher,especially ΔB.

The new excercising procedure differs slightly from the previous one, as outlined below.

12. Exercise the membrane: If the membrane is new (typically the after installation ΔB of a new membrane is 0.8 to 3 bar) then the membrane must be exercised in order to reduce ΔB below 1.5 bar. The procedure follows:

(a) Set up the equipment in the same arrangement as it is when performing a test (Fig. 8), except that the dilatometer is now in free air.

(b) Slowly pressurize the membrane. Note on the gauge of the control box the pressure at which the galvanometer and the buzzer are activated. This pressure, which is the initial value of ΔB, is generally not higher than 3 bar. (If at 3 bar still no signal is emitted, check if the connections are correct. If the connections are correct, pressing on the center of the membrane should activate the signals). If the recorded ΔB is within tolerance, there is no need to exercise, in which case proceed to Step 13.

(c) Exercise the membrane several times, with a maximum pressure in the cycle of ~~3~~ 5 bar. Each time the pressure is increased starting from zero, the new value of ΔB should be noted. If ΔB falls to a value within tolerance then no further exercising is needed, in which case proceed to Step. 13.

(d) If ΔB is still too high, exercise the membrane raising the maximum pressure in the cycle to ~~3.5~~ 8 bar, and exercise several times noting the ΔB value each time as before.

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cont Change March 1985 - exercising new membranes

★ Repeat the exercise adding ~~0.5~~ 3 bar to the maximum pressure in the cycle, until ΔB decreases to a value less than ~~0.7~~ 1.5 bar or, better still, to approximately ~~0.4~~ 0.6 to 1 bar. Maximum pressures less than ~~6~~ 20 bar are normally sufficient to reduce ΔB as required. Pressures beyond 6 bar may be dangerous (may blow out the membrane). When using higher pressure, wrap the blade (face-down) in a cloth, for safety reasons (or use the leather sheath).

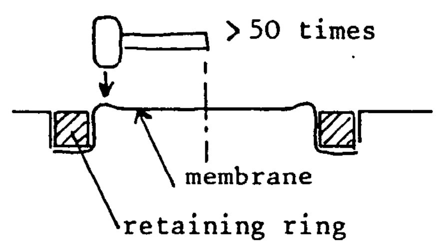
(e) When ΔB has dropped to an acceptable value according to the gauge of the control unit, proceed to Step 13.

13. Determine membrane corrections ΔA and ΔB: Follow the procedure described in section 2.2, requiring the use of the calibration device.

14. Mark ΔA, ΔB on sticker on Dilatometer: The membrane corrections marked on the sticker will be useful to the next user of the tip. Also the presence of the sticker means that that tip has not been used after servicing and therefore is ready to be sent to the field.

NOTE

Sometimes, when determining ΔA and ΔB of a blade just before a test, the values may differ (e.g. 0.05 to 0.1 bar) from the values determined earlier and marked in the sticker. This is quite normal. Consider the most recently determined values.



★ After having applied new maximum exercising pressures (e.g. 5, 10... bar) that have considerably strained the membrane, it is important to flatten down the periphery of the membrane, by hitting 50 to 70 times all around the periphery of the membrane with the plastic hammer. This hammering is not optional, but indispensable, to get a proper shape of the membrane and satisfactory values of the corrections.

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SUGGESTED METHOD FOR PERFORMING THE FLAT DILATOMETER TEST

John H. Schmertmann
Chairman of ASTM Subcommittee D18.02.10 on the Flat Plate Dilatometer

Authorized Reprint from
Geotechnical Testing Journal, June 1986

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SUGGESTED METHOD

*ASTM Subcommittee 18.02**

Suggested Method for Performing the Flat Dilatometer Test

REFERENCE: Schmertmann, J. H., "**Suggested Method for Performing the Flat Dilatometer Test,**" *Geotechnical Testing Journal*, GTJODJ, Vol. 9, No. 2, June 1986, pp. 93-101.

KEYWORDS: penetration tests, dilatometer tests, pressures, stress soil, deformation

Introduction

The ASTM Committee D18.02 on Sampling and Related Field Testing for Soil Investigation, with Mr. Ralph Brown as Chairman, requested that this proposed Standard Method be published herein to provide exposure and to solicit comments from users. The objective is to improve its accuracy, usefulness, and acceptability, when in the future, Committee D18.02 hopes to submit it for publication in the *ASTM Book of Standards*. Comments should be sent to John H. Schmertmann, Chairman Committee D18.02.10. The Committee will consider all critical comments that include specific suggestions for improving the accuracy, usefulness, or acceptability of the proposed method.

Work on this method began in June 1983, at the suggestion of Mr. Hank Davis, former chairman of D18.02. He appointed an *ad hoc* committee consisting of two members. In Jan. 1985, Mr. Brown created a formal committee, D18.02.10 on the Flat Plate Dilatometer with the mandate to develop a Standard Method for the dilatometer test. D18.02.10 consists of Messrs. Alan Luttenegger, Gary Norris, John Schmertmann (Chairman), Mehmet Tumay, and Dick Woods. This committee has reviewed five successive drafts of the proposed Standard Method and believes it has evolved to the point where they recommended it for further exposure and comments in the *Geotechnical Testing Journal*. Committee D18.02 accepted this recommendation at their June 1985 meeting.

John H. Schmertmann
Chairman of ASTM Subcommittee D18.02.10
on the Flat Plate Dilatometer

*ASTM Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

1. Scope

1.1 This practice describes a potential in-situ penetration plus dilation (expansion) test. The operator performs the test by first forcing the steel dilatometer blade, with its sharp cutting edge, into a soil or soft rock. Each test consists of this increment of vertical penetration followed by the expansion of a 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 earth works and foundations.

1.2 This method includes specific requirements for the reduction of dilatometer test data to assess soil properties for engineering design. It does not specify how the engineer shall use the determined property values.

1.3 This method applies best to those sands, silts, clays, and organic soils that the engineer can penetrate with the dilatometer blade using either static push or the dynamic impact from a hammer (see Section 6.2).

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

2. Summary of Method

2.1 Performing a dilatometer test consists of forcing the dilatometer blade vertically into the soil to a desired test depth, measuring the thrust to accomplish this penetration (see Notes 1 and 5), 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 and advances the blade the desired increment of depth and repeats the test. Each test sequence typically requires about 2 min. A dilatometer sounding consists of the results from all the tests at one location presented in a fashion indicating variation with depth.

NOTE 1—The quasi-static thrust to advance the blade is an important part of the data interpretation in sands and silty sands. Engineers have also found it useful to help evaluate stratigraphy in all soils. Engineers have found the magnitude of thrust insensitive to rate of penetration in all but the loosest sands and silty sands (which may liquefy at high rate). Also see Section 5.2.1.

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2.2 The operator may advance the blade using either a static push or dynamic impact from a hammer, with static preferred.

NOTE 2—In soils sensitive to impact and vibrations, such as very loose sand or very 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 conservatively more compressible when tested using dynamic insertion methods. In such cases the engineer may need to check such dynamic effects and, if important, calibrate and adjust test interpretations accordingly.

2.3 The vertical depth increment typically used in a dilatometer test (DMT) sounding varies from 0.15 to 0.30 m (0.5 to 1.0 ft). Testing below impenetrable layers will require preboring and supporting (if required) a borehole with a diameter of at least 100 mm (4 in.).

2.4 The operator performs a membrane calibration before and after each DMT sounding. The calibration requires about 5 min.

2.5 The engineer then interprets the field data to obtain vertical profiles of those engineering soil properties of interest over the depth range of the DMT sounding.

3. Definitions

3.1 A-pressure = the gas pressure against the inside of the membrane when the center of the membrane has lifted above its support and moved horizontally 0.05 (+0.02, −0.00) mm into the soil surrounding the vertical blade.

3.2 B-pressure = the gas pressure against the inside of the membrane when the center of the membrane has lifted above its support and moved horizontally 1.10 ± 0.03 mm into the soil surrounding the vertical blade.

3.3 DMT = abbreviation for the flat plate dilatometer test as described herein.

3.4 DMT sounding = the entire sequence of dilatometer data and results along a single, vertical, line of testing in the soil.

3.5 ΔA = the gage gas pressure inside the membrane required to overcome the stiffness of the membrane and move it inward to a center-expansion of 0.05 mm (a negative gage or suction pressure, but recorded as positive).

3.6 ΔB = the gage gas pressure inside the membrane required to overcome the stiffness of the membrane and move it outward to a center-expansion of 1.10 mm.

3.7 E_{25} = Young's modulus, secant value at triaxial compression test stress of 25% of the failure stress.

3.8 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, $E_D = 34.7\,(p_1 - p_0)$ (see Sections 3.18 and 3.19).

3.9 ϕ'_{ops} = the secant plane strain friction angle in noncohesive soils, determined at a reference stress level (because of Mohr envelope curvature).

3.10 I_D = the dimensionless dilatometer index, used to identify soil type and delineate stratigraphy, $I_D = (p_1 - p_0)/(p_0 - u_0)$ (See Section 3.23).

3.11 K_D = the dimensionless dilatometer horizontal stress index, the primary index used in the correlation for in-situ horizontal stress and undrained shear strength in cohesive soils, $K_D = (p_0 - u_0)/\sigma'_v$. (See Section 3.21.)

3.12 K_o = the ratio of the in-situ horizontal effective stress at the depth of the center of the blade membrane to the computed vertical effective stress at the same point, all for the undisturbed condition before insertion of the blade.

3.13 M = the constrained modulus of soil compressibility. Tangent value from vertical, drained loading, applicable at the in-situ effective stress. Also $= 1/m_v$, where m_v = the coefficient of volume change in one-dimensional compression.

3.14 Membrane = a flexible 60-mm-diameter piece of sheet metal (usually stainless steel) that mounts on one side of the dilatometer blade and, which as a result of an applied gas pressure, expands into the soil in an approximate spherical shape along an axis perpendicular to the plane of the blade.

3.15 OCR = overconsolidation ratio.

3.16 P = the total push, or thrust force required to advance only the dilatometer blade to its test depth, exclusive of soil friction along the pushrods. Used to calculate q_D (see Sections 3.20 and 10.3 and Note 5).

3.17 p'_c = the vertical effective stress in one-dimensional compression at which the soil structure changes relatively abruptly and becomes significantly more compressible than at lower pressures. For the case of a young soil subjected to one or more cycles of loading and unloading, p'_c = the maximum previous effective stress to which the soil has been subjected. For the case of an older soil, p'_c includes the quasi-preconsolidation effect caused by secondary aging, and also any cementation effects.

3.18 p_0 = the A-pressure reading, corrected for both the ΔA membrane stiffness at 0.05-mm expansion and the 0.05-mm expansion itself, to give the net soil pressure against the membrane immediately before its expansion into the soil (0.00-mm expansion)

$$[p_0 = 1.05(A - Z_M + \Delta A) - 0.05(B - Z_M - \Delta B)]$$

3.19 p_1 = the B-pressure reading corrected for the B membrane stiffness at 1.10-mm expansion to give the net soil pressure at 1.10-mm membrane expansion

$$[p_1 = (B - Z_M - B)]$$

3.20 q_D = the quasi-static bearing capacity of the soil along the bottom edge of the dilatometer blade at the instant it penetrates to the new test depth.

NOTE 3—Both theory and experience show that q_D roughly equals the cone bearing capacity q_c from the electric quasi-static cone penetration test (CPT, see ASTM Test Method for Deep, Quasi-Static Cone and Friction-Cone Penetration Tests of Soils [D 3441]).

3.21 σ'_v = vertical effective stress at the depth of the center of the membrane before the insertion of the DMT blade.

3.22 s_u = (also c_u = the undrained shear strength of cohesive soils, based on correlations versus unconfined compression and field vane tests.

3.23 u_o = the pore-water pressure acting at the depth of the center of the membrane before the insertion of the DMT blade (often assumed as hydrostatic below the water table surface).

3.24 Z_M = the gage pressure deviation from zero when vented to atmospheric pressure.

4. Apparatus

4.1 The annotated Fig. 1 illustrates the major components of the DMT equipment, exclusive of that required to insert the blade.

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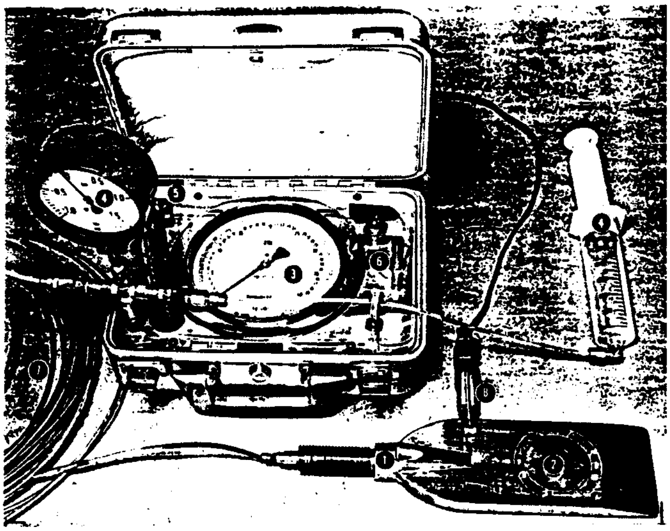

FIG. 1—*The 1985 model dilatometer equipment.*

The dimensions, tolerances, deflections, and so forth have been set by the inventor, and holder of the dilatometer patent, S. Marchetti. See Ref *2* for details.

- Blade (1) and membrane (2).
- Control unit with a pressure readout system (3) that can vary in type, range, and sensitivity as required. The unit shown has a single, manually read Bourdon gage. The control unit also includes a pressure source quick connect (5), a quick connect for the pneumatic-electrical cable (shown with calibration unit in place), an electrical ground cable connection and valves to control gas flow and vent the system (6).
- Calibration unit (4) with a pressure gage and vacuum and pressure source for determining the ΔA and ΔB membrane calibrations.
- Pneumatic-electrical cable (7) to transmit gas pressure and electrical continuity from the control unit to the blade.
- Ground cable (8) to provide electrical continuity between the push rod system and the calibration unit.

4.2 Appropriate equipment to insert the dilatometer blade vertically into the soil. This may be accomplished by means of quasi-static thrust from cone penetration test equipment (CPT) (see ASTM Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil [D 3441]), blows from a hammer such as that used in the standard penetration test (SPT) (see ASTM Method for Penetration Test and Split-Barrel Sampling of Soils [D 1586] and Note 2), or other equipment suitable for forcing the dilatometer blade into the soil. Drill rig support may be required to bore through impenetrable soil or rock layers above the layer(s) to be tested.

4.3 Push rods 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 (ASTM D 3441) or SPT (ASTM D 1586) equipment. Suitable adaptors are required to attach the blade to the bottom of the rod string and to allow the cable to exit below the tops of the rods so as not to interfere with the action of the quasi-static or dynamic insertion equipment. When testing from the bottom of a borehole, the operator will usually use another adaptor to allow the cable to exit from the rod string some suitable distance above the blade. The cable is then taped to the outside of the rods at approximate 3-m intervals to the surface. This facilitates the addition and removal of rods from the rod string when entering or exiting the borehole. The exposed length of cable should not penetrate the soil.

4.4 A gas pressure tank with suitable regulator and tubing to connect it to the control unit. The operator may use any nonflammable, noncorrosive gas as a pressure source.

NOTE 4—Dry nitrogen has proven to be generally available, inexpensive, and maintenance free.

4.5 A suitable load cell to measure the thrust P required to produce the blade penetration (see Notes 1 and 5, and Ref *3*).

NOTE 5—The primary purpose of measuring P is to permit calculating q_D, which is needed to obtain K_o, ϕ, and p_c' in sandy soils (see Table 1). While it is desirable to measure the thrust by a suitable load cell immediately above the blade, this is presently impractical and not done except for research purposes. As an alternative, the engineer can measure P at the ground surface and subtract the parasitic soil-rod friction (and bearing against the friction reducer, if any) above the blade. Another alternative involves measuring the thrust needed for downward penetration and the pull required for upward withdrawal. The difference gives a measure of the end bearing capacity of the blade. A third alternative uses q_c values from adjacent CPT data by using a previously determined or estimated ratio of q_D/q_c (see 3.20). A fourth alternative is to convert a dynamic blowcount to an equivalent static thrust by

TABLE 1—*Measurements used to convert dilatometer data to soil properties for engineering design.*

Field Data:		
(a) test readings A and B corrected using equipment calibrations: $p_o = f(A)$, $p_l = f(B)$.		
(b) est'd. (or C-reading) in-situ pore water: u (see Note 10) pressure.		
(c) est'd. in-situ effective vertical stress: $\sigma_v' = (\sigma_v - u_o)$		
(d) est'd. DMT bearing capacity, q_D. Obtained from thrust $= P$ data:		
DMT Indices:		
Material Index (a normalized modulus)		
$I_D = f(A,B,u) = (p_l - p_o)/(p_o - u_o)$		
Horizontal Stress Index (a normalized lateral stress)		
$K_D = f(A,u,\sigma_v') = (p_o - u_o)/\sigma_v'$		
Dilatometer Modulus (theoretical elastic modulus)		
$E_D = f(A,B) = 34.7\,(p_l - p_o)$		
Interpreted Soil Engineering Properties:		
Soil Type		Reference[a]
$I_D = f(p_o, p_l, u_o) = f(A,B,u)$	empirical	*2*
Lateral Stress (drained)		
K_o (sand) $= f(K_D, \phi') = f(A, \sigma_v', u_o, q_D)$	semi-empirical	*1*
K_o (clay) $= f(K_D) = f(A, \sigma_v', u_o)$	empirical	*2*
Strength		
ϕ' (sand) $= f(K_o, \sigma_v', P) = f(A, \sigma_v', u_o, q_D)$	theoretical	*1,4*
s_u (OC clay) $= f(K_D, \sigma_v') = f(A, \sigma_v', u)$	empirical	*2*
s_u (NC clay) $= f(p_o) = f(A, u_o)$	empirical	*2*
Compressibility (drained)		
$M = (1/m_v) = f(E_D, I_D) = f(A,B,u_o)$	semi-empirical	*2*
p_c' (sand) $= f(K_D, \phi') = f(A, \sigma_v', u_o, q_D)$	semi-empirical	*1*
p_c' (clay) $= f(K_D) = f(A, \sigma_v', u_o)$	empirical	*2*
Modulus (drained, ν = Poisson's ratio)		
E_{25} (sand) $= f(E_D) = f(A,B)$	semi-empirical	*1*
E (clay) $= f(M, \nu) = f(A,B,u_o,\nu)$	semi-empirical	*2*

[a]See the Reference section appended to this paper.

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the use of published correlations, on-site experiment or previous experience.

5. Procedures

5.1 Preparation for Testing

5.1.1 Select for testing only blades that are known to be in conformance with 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 to its axis. Its penetrating edge should not deviate more than 2 mm from the axis of the rods to which the blade attaches. Other requirements include a straight and sharp penetration edge, and a membrane free of any deep scratches, wrinkles, or dimples. When in doubt, check the membrane using the calibration procedure described in Section 5.1.4. The membrane should expand smoothly upon pressurization without popping or snapping sounds.

5.1.2 Attach the pressure source and pneumatic-electrical cable to the control box. Check for gas leakage in the control unit and cable by plugging the blade end of the cable with an appropriate fitting and applying pressure to the cable through the control unit. Then close the flow control valve and observe the gage for any pressure drop that would indicate a leak in the system. Leakage in excess of 100 kPa/min is unacceptable and requires repair. Smaller leaks, though undesireable and indicative of a potential problem, will not affect the test results significantly. In a field situation the operator should note and monitor a small leak but may wait to return to the office to make repairs.

5.1.3 Attach the pneumatic-electrical cable to the dilatometer and connect the two ends of the electrical ground cable to the control unit and blade, respectively. Press the center of the membrane down until it makes contact with its support pedestal. At this contact the electrical or audio signal or both must go on. If not, make the appropriate repair.

5.1.4 Use the calibration equipment to determine the ΔA and ΔB membrane stiffness calibration pressures. These calibrations should fall within the tolerances given by the manufacturer for the type of membrane used and are recorded as positive values. See Note 6. During this calibration the electrical/audio signal should stop unambiguously at the 0.05-mm expansion and return unambiguously at the 1.10-mm expansion. Replace any membrane that fails these checks.

NOTE 6—New membranes typically require about 20 cycles of preconditioning expansion/deflation to reach an approximately stable ΔB value. Use the maximum expansion pressure recommended by the membrane manufacturer to avoid permanent membrane distortion.

5.1.5 Thread the pneumatic-electrical cable through as many of the push rods as needed and connect it to the blade. Include the lower blade adaptor and the upper adaptor to exit the cable from the rods. Disconnect the cable and reconnect it to the blade or the control box as required. Caution: Always cap the ends of all cables immediately after releasing from any connection. This helps prevent contamination of the cables and corrosion of the terminals.

5.2 Testing

5.2.1 With the vent valve open and the push rods vertical, advance the dilatometer blade to the first depth. Measure the maximum thrust required during the last 10 mm of penetration or count the number of blows for each 150 mm of penetration. Record this value. If using blow count, average the counts for the 150 mm above and below the test depth to estimate the static force. Borehole predrilling with casing or drilling mud is acceptable as required. The rate of quasi-static penetration has minor importance in sands and can vary between 10 and 100 mm/s. In silts and clays use 10 to 30 mm/s.

5.2.2 The blade advance described in Section 5.2.1 must produce an electrical/audio signal to indicate the membrane has been pressed flush against the plane of the blade and is ready to begin the Section 5.2.3 DMT sequence. See Note 11.

5.2.3 Within 15 s after reaching test depth unload any static force on the rods, close the vent valve, and use the gas flow valve on the control unit to pressurize the membrane. The gage pressure at the instant the electrical/audio signal stops is the A-pressure reading. Observe and record it by any appropriate method. Obtain this reading within 15 to 30 s after beginning the gas flow. Then, within the next 15 to 30 s continue increasing the gas pressure until the signal returns. At this instant the gage indicates the B-pressure reading. After mentally noting or otherwise recording this value, immediately open the vent valve to depressurize the cable to the dilatometer and then close the gas flow control valve. This procedure prevents further expansion of the membrane, which may permanently deform it and change its calibrations. See Note 10 for an alternative, controlled depressurization procedure to obtain an additional "C-pressure."

NOTE 7—Experiments have determined that testing within the above time limits results in essentially drained conditions in sands and undrained conditions in clays. They also indicate that the results are not sensitive to time-for-reading changes by a factor of 2 from those given above. However, in saturated silty soils and sand/clay mixtures with intermediate permeabilities, partially drained conditions probably exist, and the results and correlations depend more importantly on the proper time intervals. Unsaturated soils are not as well understood, but probably behave in a drained fashion.

NOTE 8—For the most accurate pressure readings the operator should use the gas flow control valve to allow the pressure to increase rapidly to some value just below the lowest expected A-pressure and then decrease the pressurization rate to better read the value at the instant the signal goes off. He or she then repeats the increase-decrease technique for the B-pressure reading. The above technique involves the risk of getting a poor A- or B-pressure reading if it occurs at an unexpectedly low pressure.

NOTE 9—The operator may check the adequacy of any chosen flow rate by closing the gas flow control valve during the test procedure and then observing the gage for a drop in pressure before stabilizing. If the pressure drops in excess of 2%, the rate is too fast and requires reduction. Longer cables will require a slower flow rate for accurate readings.

NOTE 10—Recent research and testing indicate that the pressure against the membrane when it deflates and returns to its initial A liftoff position provides a measure of the initial in-situ water pressure u_o in sand soils or in sand layers in clay soils when I_D is equal or greater than approximately 2. The signal returns at this point. Dilatometer equipment may include another gas flow regulator to allow a controlled depressurization from the B-pressure to a subsequent "C-pressure" reading at the return of the signal. Allow 15 to 30 s for depressurization to the signal return. In sands with $I_D \geqslant 2$,

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and after the ΔA membrane stiffness correction, the C-pressure data may give the value of "u_o" (see Section 3.23) needed by direct field measurement rather than by estimation (see Section 7.7 and Table 1). A profile of in-situ u_o may also prove of value for the geotechnical evaluation of a site.

NOTE 11—At shallow depths in very weak soils, especially when above the water table, P_o may not suffice to overcome the ΔA membrane stiffness and thus not produce the required initial signal. For sensitive testing of this type the operator needs to choose a blade whose membrane has low and consistent calibration values. An alternative is to apply an initial suction behind the membrane and then close the flow control valve before advancing to the test depth. This can be accomplished using the calibration unit which then remains in place during the test. The operator reads the A-pressure (vacuum), records it as a negative value, and then continues the pressurization to obtain the B-pressure. If the B-pressure is out of the range of an unprotected calibration unit gage, this method should not be used. Also, the operator can bypass shallow testing until reaching a depth that produces the initial signal.

5.2.4 The electrical/audio signal usually returns during the depressurization following the B-pressure reading, but not always. The blade is then advanced to the next test depth. At this point the audio/electrical signal must have returned. If not, and the problem cannot be identified, remove the blade and repair as required.

5.2.5 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.

5.3 *After Completion of Testing*

5.3.1 After completion of the final DMT, withdraw the blade to the surface, inspect it, and note any significant cutting edge damage, blade bending, or membrane damage. Repeat the calibration procedure as described in Section 5.1.4 to check the magnitude of the ΔA and ΔB readings and the proper operation of electrical/audio signals. Record these ΔA and ΔB values. If the blade or the membrane has sustained major damage, if the A- and B-pressure electrical signals do not occur satisfactorily in proper sequence, or if the membrane calibration values differ from the initial values by an amount significant to the interpretation of the data (see Note 12), then repair or replace the blade or membrane or both and repeat the sounding. If the damage is attributable to a specific depth in the sounding, then only tests below this depth need to be repeated.

NOTE 12—Significance will vary with the strength of the soil and the intended use of the DMT results by the engineer. Trial calculations using both the initial and final membrane calibration values will show their importance to the results.

5.3.2 Reduce the field data using the DMT indices and formulas for interpreted soil engineering properties as described in Section 7 and present the complete results in a tabular format. Also plot those of special interest in a graphical sounding format. Data reduction is most easily accomplished by using a computer program designed for the purpose.

6. Special Precautions

6.1 Damage to the membrane typically occurs when brushing against or pushing aside or through gravel, large shells, unweathered rock, concretions, miscellaneous fill, and so forth particles. When in soils containing such particles be alert for membrane malfunction (see Section 6.9) and be prepared to replace membranes when required. Continued usage in highly abrasive soils, such as dense quartz sands, gradually wears down membranes and makes them more susceptible to wrinkling and tearing. Replace them when wear or wrinkling appears excessive.

6.2 Bending of the blade or wrinkling of its cutting edge typically occurs with a high thrust P required to advance the blade, as when penetrating hard clays or dense sands, combined with coarse-particle inclusions in the soil such as gravel, large shells, unweathered rock, cemented inclusions, and so forth. Experience has shown that the probability of bending becomes significant when the thrust P reaches approximately 50 kN (5 ton) and becomes high when P exceeds approximately 100 kN (10 ton). Blade bending can also occur because of buckling of the overhead connector rods when penetrating a strong soil after just passing through 1 m (3.3 ft) or more thickness of very weak soil that provides little lateral support against buckling.

NOTE 13—Bent, wrinkled, or scratched cutting edges are often repairable in the field using hammer and file methods. Bent blades are often repairable by a machinist. Recheck blade alignment and the membrane support and movement mechanism and tolerances after each repair (see Sections 3.1, 3.2, 5.1.1, and 5.1.4).

6.3 The blade and its connections are not designed for high torsion forces. Make all rod connections using no more torsion than produced by hand wrench tightening. Do not allow the making of connections with the aid of engine power.

6.4 The dilatometer blade is subject to drifting out of plumb when inserted with initial horizontal forces acting, or when encountering obstructions which the blade must bypass. The deeper the sounding the more likely that appreciable deflection may occur. The presence of stones, gravel layers, large shells, irregular cementation, and so forth also increases the likelihood of appreciable deflection. Experience has shown that with usual care this problem is not significant in ordinary sands and clays for sounding depths of less than 15 m. However, the user needs to be alert for indications, such as unusual "crunching" or "scraping" or "snapping" sounds transmitted up the pushrods, the pushrods becoming nonplumb at the surface, suspicious data, or encountering marker soil layers at greater apparent sounding depth than expected from nearby borings or other data.

6.5 Ensure that the pneumatic-electrical cable does not pass through or over any objects with sharp edges that might cut the cable when accidentally pulled or stepped on. Avoid having the cable exposed at locations where such accidents might happen.

6.6 The operator can periodically and easily check for any leaks in the lines or connections by momentarily closing the control valve during the pressure increase interval between the A- and B-pressures and noting the behavior of the pressure gage. If the pressure remains constant then the system has no leaks, as required. Any leak severe enough to interfere with the required accuracy of the A- and B-pressures (refer to Section 5.1.2.) means that the sounding must be stopped and the leak repaired before continuing. In the event that leakage forces the termination of the sounding, it is wise to maintain a pressure of 100 to 200 kPa above u_o in the system while withdrawing the blade. If done quickly enough, this may prevent entry of soil and water into the blade.

6.7 Experience has shown that during field testing it is prudent to have spares of some of the more critical items. These include extra membranes, an extra blade, and additional cables.

6.8 In very noisy testing environments or poor electrical

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grounding conditions or both it can become difficult to hear the audio signal that prompts the A- and B-pressure readings. The user must then rely on the visual cue given by the galvanometer or use an earphone or headset to insure timely detection of the audio signal.

6.9 If the signal does not cease at a reasonable A-pressure then it is possible that the membrane has ruptured and water has entered the mechanism behind the membrane, causing an electrical short. Remove the blade, inspect it, and repair as necessary.

7. Methods for Data Reduction

7.1 The blade can be considered to produce a deep bearing capacity failure in cohesionless soils and a lateral passive limit pressure failure in cohesive soils, thus forming the basis for evaluating friction angle and undrained shear strength properties, respectively.

7.2 The A-pressure reading forms the basis for predicting in-situ horizontal effective stress, and therefore also the related predictions for OCR and p_c'.

7.3 The difference between the B- and A-pressures, obtained over a precise and relatively small increment of membrane displacement, forms the basis for evaluating the in-situ, drained modulus and compressibility behavior.

7.4 The stress and modulus measurements occur after the disturbance of the blade penetration. Therefore, research and experience are used to establish reliable correlations between the desired in-situ properties before the insertion of the blade and those measured after its insertion.

NOTE 14—The shape of the dilatometer blade represents a compromise between minimizing insertion disturbance and providing adequate structural strength for practical use.

7.5 The ratio of modulus to horizontal stress depends on the soil's rigidity, pore-pressure generation, and permeability properties, and thus provides an indicator of soil type.

7.6 Table 1 presents a summary of the steps from the collection of the field data, through the calculation of two normalized dilatometer indices for material type and lateral stress and a theoretical modulus index, to the determination of generic engineering properties for design. The engineer has as many as four field measurements per DMT to work with and also must estimate vertical effective stress at each test depth. Table 1 shows which parameters are needed for correlation with each engineering property and indicates the reference publication. It also notes the empirical, semi-empirical (combined theoretical-empirical), or theoretical nature of each correlation.

NOTE 15—In the interest of a common understanding of the way in which users of this practice communicate their findings, all should report their interpreted results using the correlations referenced in Table 1. However, local experience may demonstrate the need to somehow modify or apply correction factors to the results obtained to make them more accurate for the local conditions. In that event they should also report the corrections they used. New correlations with other soil properties should likewise be reported.

7.7 The calculations of Section 7.6 include those for the vertical effective stress at the test depth. This requires knowledge of soil unit weights and equilibrium pore-water pressures. Marchetti [2] recommends the unit weight matrix chart shown in Fig. 2. Most of the current computer programs incorporate this matrix for the automatic summation of total overburden pressure. Pore-water pressure u_o is normally taken as the hydrostatic value from a given water table condition, with values of zero assumed above the water table. If pore-pressure conditions differ significantly from hydrostatic, or a better estimate of soil unit weight is available, or both, then, these data should be used in place of the above assumptions. Note that the effective stress and pore-water pressures referred to here are those existing before the insertion of the DMT blade. (See Note 10 for the possible direct measurement of u_o.)

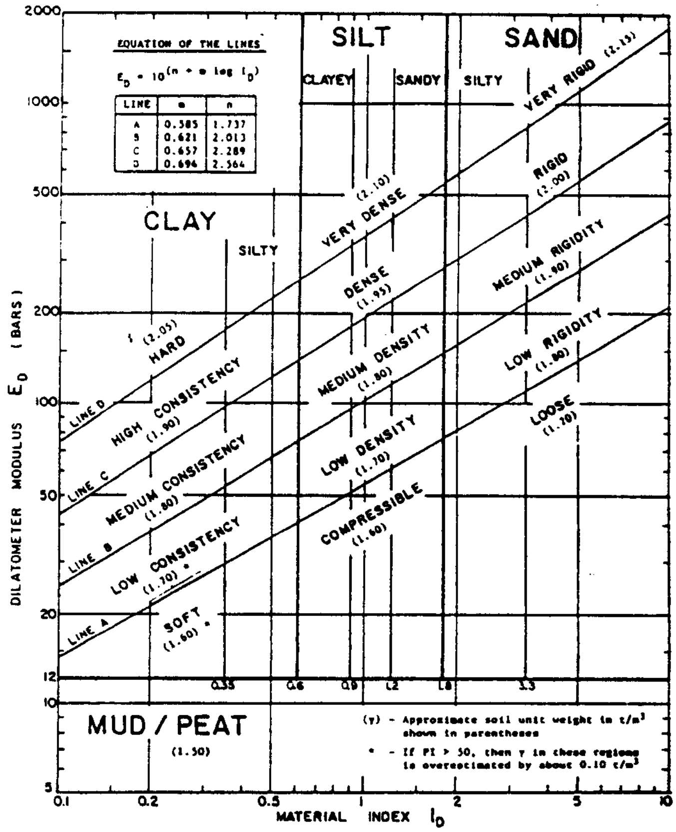

FIG. 2—*Chart for determination of soil description and unit weight.*

7.8 The engineering properties determined by the DMT are listed in Table 1. An example of interpreted engineering properties using current correlations is shown in Figs. 3 and 4. These are basic or generic soil properties that an engineer can use in any design method requiring such values. They are not linked to any analysis or design methods developed especially for DMT data.

8. Precision and Accuracy

8.1 Table 2 presents the currently (Jan. 86) compiled information concerning the average accuracy and variability with which the DMT predicts engineering soil properties. This compilation does not include any refinements for plasticity, geologic soil origin, stress history, and so forth.

8.2 Recent research shows that the DMT tests sand in approximately fully drained conditions and clays in approximately fully undrained conditions. The best results are obtained at these extremes. Silts, clayey sands, fissured clays, and other soils may have only partial drainage during the DMT, to an unknown and possi-

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ACME ENGINEERING INC. TEST NO. DMT-1
FILE NAME: EXAMPLE SOUNDING
FILE NUMBER: 85-500

RECORD OF DILATOMETER TEST NO. DMT-1
USING DATA REDUCTION PROCEDURES IN MARCHETTI (ASCE,J-GED,MARCH 80)
KO IN SANDS DETERMINED USING SCHMERTMANN METHOD (1983)
PHI ANGLE CALCULATION BASED ON DURGUNOGLU AND MITCHELL (ASCE,RALEIGH CONF,JUNE 75)
PHI ANGLE NORMALIZED TO 2.72 BARS USING BALIGH'S EXPRESSION (ASCE,J-GED,NOV 76)
MODIFIED MAYNE AND KULHAWY FORMULA USED FOR OCR IN SANDS (ASCE,J-GED,JUNE 82)

LOCATION: 6 FT. NORTH OF CPT-1 (CPT SOUNDING)
PERFORMED - DATE: 1 APRIL 1985
BY: J.SMITH & W.JONES — HYDRAULIC PUSH WITH CPT TRUCK

CALIBRATION INFORMATION:
DA= .15 BARS DB= .68 BARS ZM= .10 BARS ZW= .70 METERS
ROD DIA.= 3.60 CM FRICTION RED. DIA.= 4.70 CM ROD WEIGHT= 6.50 KG/M DELTA/PHI= .50

1 BAR = 1.019 KG/CM2 = 1.044 TSF = 14.51 PSI ANALYSIS USES H2O UNIT WEIGHT = 1.000 T/M3

Z (M)	THRUST (KG)	A (BAR)	B (BAR)	ED (BAR)	ID	KD	UO (BAR)	GAMMA (T/M3)	SV (BAR)	PC (BAR)	OCR	KO	CU (BAR)	PHI (DEG)	M (BAR)	SOIL TYPE
*****	******	*****	*****	*****	*****	*****	******	******	******	*****	*****	*****	*****	*****	******	***********
1.00	781.	1.17	5.32	121.	3.40	5.99	.029	1.800	.171	.68	3.96	.74		39.4	248.6	SAND
1.20	1033.	1.69	6.95	161.	3.17	7.87	.049	1.800	.187	1.23	6.57	.95		39.9	369.9	SILTY SAND
1.40	1535.	3.38	15.55	413.	4.26	13.67	.069	1.900	.204	4.04	19.75	1.66		39.7	1145.2	SAND
1.60	1451.	3.52	13.75	342.	3.28	13.56	.088	1.900	.222	4.52	20.36	1.69		38.7	946.9	SILTY SAND
1.80	1409.	3.85	15.05	378.	3.33	13.66	.108	1.900	.240	5.12	21.37	1.74		37.9	1046.9	SAND
2.00	907.	2.84	10.72	257.	3.07	9.36	.128	1.900	.257	2.94	11.41	1.29		35.6	627.5	SILTY SAND
2.20	279.	.81	2.31	24.	1.04	2.52	.147	1.600	.269	.39	1.44	.68			27.5	SILT
2.40	258.	.84	4.76	113.	5.71	2.01	.167	1.700	.283	.42	1.48	.54		29.6	124.6	SAND
2.60	405.	1.21	7.55	201.	7.25	2.67	.186	1.800	.299	.54	1.81	.57		32.4	271.8	SAND
2.80	488.	1.64	3.03	20.	.40	4.69	.206	1.600	.310	1.17	3.78	1.11	.198		35.2	SILTY CLAY
3.00	405.	1.79	3.02	15.	.26	4.95	.226	1.600	.322	1.32	4.11	1.15	.220		25.9	CLAY
3.20	237.	.95	2.37	21.	.85	2.17	.245	1.600	.334	.38	1.14	.59	.081		20.6	CLAYEY SILT
3.40	237.	.90	2.57	31.	1.37	1.86	.265	1.600	.346	.53	1.53	.58		27.6	26.3	SANDY SILT
3.60	279.	.91	3.54	66.	3.23	1.63	.285	1.700	.359	.45	1.25	.52		29.1	60.6	SILTY SAND
3.80	321.	1.07	3.51	59.	2.30	1.97	.304	1.700	.373	.55	1.48	.55		29.6	59.5	SILTY SAND
4.00	300.	1.16	3.56	57.	2.04	2.09	.324	1.700	.387	.64	1.65	.59		28.6	59.6	SILTY SAND
4.20	237.	1.43	3.37	40.	1.08	2.71	.343	1.600	.399	.64	1.61	.72			48.7	SILT
4.40	258.	1.63	2.78	12.	.26	3.18	.363	1.500	.408	.84	2.07	.82	.161		15.5	MUD
4.60	279.	1.28	2.69	21.	.66	2.18	.383	1.600	.420	.48	1.15	.59	.103		20.0	CLAYEY SILT
4.80	279.	1.28	2.66	20.	.64	2.08	.402	1.600	.432	.46	1.07	.57	.100		18.0	CLAYEY SILT
5.00	405.	1.56	4.69	84.	2.25	2.41	.422	1.700	.446	.82	1.84	.60		29.9	100.0	SILTY SAND
5.20	551.	1.89	7.60	178.	4.08	2.72	.442	1.800	.461	.90	1.95	.60		32.0	243.3	SAND
5.40	572.	1.72	6.61	148.	3.86	2.32	.461	1.800	.477	.75	1.58	.54		32.6	181.9	SAND
5.60	530.	2.33	9.10	216.	3.89	3.25	.481	1.800	.493	1.28	2.60	.70		30.5	329.8	SAND
5.80	593.	1.69	6.40	141.	3.90	2.06	.500	1.800	.509	.70	1.37	.51		32.7	159.2	SAND
6.00	719.	2.41	7.74	164.	2.76	3.27	.520	1.800	.524	1.26	2.41	.65		32.9	247.8	SILTY SAND
6.20	1284.	3.73	13.18	314.	3.22	5.18	.540	1.900	.542	2.28	4.20	.81		36.0	605.9	SILTY SAND
6.40	907.	3.17	10.07	221.	2.70	4.21	.559	1.900	.560	1.89	3.37	.75		33.5	383.1	SILTY SAND
6.60	593.	2.18	8.55	202.	4.23	2.39	.579	1.800	.575	1.00	1.74	.58		31.5	253.6	SAND
6.80	405.	1.67	6.21	135.	4.16	1.58	.599	1.800	.591	.77	1.30	.54		29.0	121.6	SAND
7.00	342.	1.82	5.95	120.	3.19	1.79	.618	1.800	.607	.97	1.61	.62		26.9	121.0	SILTY SAND
7.20	447.	1.66	4.97	90.	2.75	1.53	.638	1.700	.620	.76	1.22	.52		29.6	76.8	SILTY SAND
7.40	321.	1.83	3.35	25.	.61	1.88	.658	1.600	.632	.57	.91	.51	.129		21.4	CLAYEY SILT
7.60	279.	2.01	3.78	34.	.74	2.07	.677	1.600	.644	.68	1.06	.56	.148		30.9	CLAYEY SILT
7.80	237.	2.23	4.07	37.	.69	2.34	.697	1.600	.656	.84	1.28	.63	.175		37.5	CLAYEY SILT
8.00	279.	1.62	3.28	30.	.96	1.37	.716	1.600	.668	.37	.55	.36			25.7	SILT
8.20	258.	1.22	2.17	4.	.24	.78	.736	1.500	.677	.16	.23	.14	.046		3.7	MUD
8.40	154.	1.17	1.95	-2.	-.11		.756	P01 =	1.22	PO =	1.22	P1 =	1.17			QUESTIONABLE
8.60	175.	.93	1.90	5.	.74	.28	.775	1.500	.697	.03	.05	-.14	.013		4.3	MUD
8.80	175.	.98	2.24	16.	2.11	.30	.795	1.700	.711	.56	.79	.52		23.6	13.3	SILTY SAND
9.00	195.	1.13	2.77	30.	2.62	.45	.815	1.700	.724	.62	.86	.53		23.9	25.1	SILTY SAND
9.20	216.	1.37	3.42	44.	2.44	.71	.834	1.700	.738	.75	1.01	.56		24.0	37.8	SILTY SAND
9.40	258.	1.05	2.04	6.	.71	.32	.854	1.500	.748	.04	.06	-.12	.017		5.0	MUD
9.60	342.	2.03	7.55	171.	5.07	1.27	.873	1.800	.764	.98	1.28	.58		26.3	145.2	SAND

END OF SOUNDING

FIG. 3—*Example computer output from a FORTRAN program.*

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ANALYSIS OF DILATOMETER TEST NO. 32-4943
REFERENCE: MARCHETTI(ASCE,J-GED,MARCH 1980);
SCHMERTMANN (ESOPT II, MAY 1982);BULLOCK(DILLY 4,1982,S & C,INC.)
PROGRAMMED BY: RAMESH C. GUPTA, PROJECT ENGINEER, HBC
LOCATION: DMT# 32-4943
PERFORMED BY- DATE: 17 MAY 1983
BY: J. Russel and L. Bennett SURFACE EL. 14
CALIBRATION INFORMATION:
DA= .1 DB= .53 ZM= .05 ZW= 3.05 M
1 BAR = 1.019 KG/CM2 = 1.044 TSF = 14.51 PSI H2O UNIT WT. = 1.0 TONNE/M3

Z (M)	A (BAR)	B (BAR)	THRUST (KG)	ED (BAR)	UO (BAR)	ID	GAMA (T/M3)	SV (BAR)	KD	OCR	KO	CU (BAR)	PHI (DEG)	SIGFF (BAR)	M (BAR)	SOIL TYPE
2.00	5.90	17.70	3085.	401.	0.00	2.14	2.00	0.353	15.38	24.60	1.86		43.0	0.59	1163.	SILTY SAND,RIGID
2.20	4.60	17.40	3212.	431.	0.00	2.90	2.00	0.392	10.93	11.77	1.27		44.1	0.67	1110.	SILTY SAND,RIGID
2.40	4.90	18.00	3065.	449.	0.00	2.97	2.00	0.432	10.11	10.49	1.20		43.5	0.73	1126.	SILTY SAND,RIGID
2.60	5.20	19.40	3339.	489.	0.00	3.07	2.00	0.471	9.79	9.80	1.16		43.5	0.79	1212.	SILTY SAND,RIGID
2.80	5.50	23.20	3593.	616.	0.00	3.76	2.00	0.510	9.29	8.71	1.09		43.7	0.86	1499.	RIGID SAND
3.00	5.50	21.20	3657.	543.	0.00	3.25	2.00	0.549	8.60	7.95	1.04		43.5	0.93	1297.	SILTY SAND,RIGID
3.20	6.10	21.70	3593.	540.	0.01	2.88	2.00	0.574	9.45	9.60	1.16		42.8	0.96	1322.	SILTY SAND,RIGID
3.40	6.50	23.00	3721.	572.	0.03	2.87	2.00	0.593	9.70	10.18	1.19		42.6	1.00	1415.	SILTY SAND,RIGID
3.60	7.10	24.60	3657.	609.	0.05	2.80	2.00	0.613	10.26	11.71	1.28		42.1	1.02	1535.	SILTY SAND,RIGID
3.80	6.30	23.00	3721.	579.	0.07	3.04	2.00	0.633	8.71	8.26	1.07		42.6	1.06	1379.	SILTY SAND,RIGID
4.00	6.70	26.10	4102.	678.	0.09	3.40	2.00	0.652	8.82	8.25	1.07		43.0	1.10	1620.	RIGID SAND
4.20	8.20	28.50	4166.	710.	0.11	2.86	2.00	0.672	10.70	12.66	1.33		42.1	1.12	1818.	SILTY SAND,RIGID
4.40	7.60	27.30	3911.	688.	0.13	3.01	2.00	0.692	9.54	10.25	1.20		42.0	1.15	1693.	SILTY SAND,RIGID
4.60	6.50	28.40	4484.	766.	0.15	4.14	2.00	0.711	7.55	5.78	0.88		43.6	1.20	1733.	RIGID SAND
4.80	9.10	29.90	5120.	728.	0.17	2.63	2.15	0.734	10.91	12.65	1.33		42.9	1.23	1878.	SILTY SAND,V.RIGID
5.00	6.90	24.90	3975.	627.	0.19	3.06	2.00	0.753	7.87	6.97	0.99		42.2	1.26	1436.	SILTY SAND,RIGID
5.20	6.70	19.90	3466.	452.	0.21	2.20	2.00	0.773	7.69	7.13	1.01		41.1	1.28	1022.	SILTY SAND,RIGID
5.40	7.20	19.70	3085.	427.	0.23	1.91	2.00	0.793	8.15	8.46	1.11		39.8	1.30	985.	SILTY SAND,RIGID
5.60	5.80	19.20	3212.	460.	0.25	2.66	2.00	0.812	6.15	4.76	0.83		41.0	1.35	950.	SILTY SAND,RIGID
5.80	5.90	18.60	3085.	434.	0.27	2.45	2.00	0.832	6.15	4.89	0.84		40.6	1.37	894.	SILTY SAND,RIGID
6.00	6.00	17.30	2957.	383.	0.29	2.10	2.00	0.852	6.18	5.09	0.87		40.1	1.40	787.	SILTY SAND,RIGID
6.20	5.70	18.20	3085.	427.	0.31	2.53	2.00	0.871	5.61	4.16	0.78		40.5	1.44	845.	SILTY SAND,RIGID
6.40	5.80	17.70	3085.	405.	0.33	2.34	2.00	0.891	5.61	4.21	0.79		40.4	1.47	799.	SILTY SAND,RIGID
6.60	6.10	20.10	3212.	481.	0.35	2.69	2.00	0.910	5.68	4.27	0.79		40.5	1.50	961.	SILTY SAND,RIGID
6.80	5.70	17.10	3212.	387.	0.37	2.29	2.00	0.930	5.25	3.69	0.74		40.6	1.53	739.	SILTY SAND,RIGID
7.00	5.00	17.40	3212.	423.	0.39	2.98	2.00	0.950	4.33	2.55	0.61		41.0	1.57	750.	SILTY SAND,RIGID
7.20	6.40	20.50	3339.	485.	0.41	2.59	2.00	0.969	5.58	4.17	0.78		40.3	1.60	959.	SILTY SAND,RIGID
7.40	5.00	19.20	3085.	489.	0.43	3.55	2.00	0.989	4.03	2.33	0.59		40.6	1.63	835.	RIGID SAND
7.60	6.90	25.80	4229.	659.	0.45	3.39	2.00	1.009	5.58	3.77	0.73		41.8	1.68	1314.	RIGID SAND
7.80	6.70	23.70	3975.	590.	0.47	3.10	2.00	1.028	5.35	3.62	0.72		41.3	1.71	1155.	SILTY SAND,RIGID
8.00	6.90	25.80	3848.	659.	0.49	3.41	2.00	1.048	5.33	3.70	0.73		41.0	1.73	1288.	RIGID SAND
8.20	6.50	23.00	3846.	572.	0.51	3.13	2.00	1.067	4.95	3.22	0.68		41.1	1.77	1081.	SILTY SAND,RIGID
8.40	7.30	24.40	3848.	594.	0.53	2.84	2.00	1.087	5.55	4.09	0.77		40.6	1.79	1178.	SILTY SAND,RIGID
8.60	6.60	21.70	3466.	521.	0.54	2.78	2.00	1.107	4.90	3.39	0.71		40.1	1.82	975.	SILTY SAND,RIGID
8.80	7.50	25.60	4229.	630.	0.56	2.96	2.00	1.126	5.46	3.83	0.74		41.1	1.87	1243.	SILTY SAND,RIGID
9.00	9.60	31.40	5374.	765.	0.58	2.75	2.15	1.149	7.00	5.76	0.90		41.8	1.91	1671.	SILTY SAND,V.RIGID
9.20	10.00	34.10	5374.	848.	0.60	2.95	2.15	1.171	7.09	5.97	0.92		41.6	1.95	1867.	SILTY SAND,V.RIGID
9.40	9.30	30.80	4738.	754.	0.62	2.82	2.00	1.191	6.48	5.28	0.87		40.9	1.97	1597.	SILTY SAND,RIGID
9.60	10.70	37.70	6137.	954.	0.64	3.12	2.15	1.214	7.27	6.02	0.92		42.2	2.03	2120.	SILTY SAND,V.RIGID

FIG. 4—*Example computer output from a BASIC program.*

bly variable degree. This may lead to more variable and possibly less accurate predictions of their soil engineering properties.

8.3 Use the average of at least three DMTs for the interpretation of the properties of any single soil layer. For a variety of reasons the results from any one DMT can deviate significantly from the average accuracy noted in Table 2. If the results from a single deviant test may have special importance, then repeat the test using parallel soundings as a check on accuracy.

8.4 Experience has shown the DMT to be exceptionally reproducible and operator insensitive. Engineers with experience estimate results are reproducible with a coefficient of variation of approximately 10%.

9. Report

9.1 Figures 3 and 4 show example reports of the findings from two DMT soundings, as produced by computerized data reduction in the office. In addition to these tabulated results, the engineer will usually produce graphical depth logs of one or more of the DMT-interpreted soil properties.

9.2 Although computerized output is desirable, and common, the engineer can also obtain and present results by hand calculator and graphs. This may be convenient for data reduction and presentation in the field.

9.3 It is anticipated that some users will have the DMT equip-

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TABLE 2—*Summary of accuracy experience with results from DMT soundings (as compiled 9 Jan. 86). Based on data from 24 field sites and lab studies, using averages from individual distinct layers or groups of tests where the alternate test results were probably superior or might be judged as superior to DMT results.*

	(DMT-Measured/Measured) "Error" Comparisons, %					
Soil Property	Number	Mean	Standard Deviation	Range	Usual Superior Data	Range of Average DMT Values[a]
Stress					NC geology,	
OCR[b] (sand and silt)	5	+17	21	+50 −50	chamber tests	0.9 to 1.5
OCR (clay and org)	17	+4	30	+44 −60	oedometer tests	1.0 to 9
					NC geology,	0.3 to 0.9
K_o (sand and silt)	6	+10	23	+53 −40	chamber tests	0.4 to 3.4
K_o (clay and org)	10	+7	28	+32 −40	triax, PMTs	
u_o in sands[c]	12	+1	12	+30 −20	calculated from known GWT	0.00 to 1.2
Deformation, settlement[d]						
M (sand and silt)	7	+1	20	+20 −29	oedometer tests or	10 to 2000
M (clay and organic soil)	22	−11	40	+55 −79	measured settlements	1.5 to 440
Strength						
ϕ_{tr} (sands)	4	+0.1	7	+10 −8	triaxial tests	33 to 41[f]
s_u (clay and organic soil)	38	−0.2	22	+80 −38	field vane	0.007 to 4.7
			(DMT − Measured), m		free water	abveviated surface
Depth to ground water table[g]	12 (8 sites)[h]	−0.08	0.23	+0.3 −0.6	surface, borehole	to 5 m

[a] All stresses in bars = 100 kPa (≅1 tsf).
[b] Or preconsolidated stress = p_c'
[c] $I_D \geq 2.0$.
[d] Similar errors expected for E = Young's modulus.
[e] $I_D \leq 0.6$.
[f] ϕ_{ps} from DMT converted to $\phi_{tr} = \phi_{ps} - (\phi_{ps} - 32)/3$.
[g] From upward projections of linear fits through C readings to depth where $C = 0$.
[h] 6 sand, 2 silt and clay.

ment connected to transducers and computers for automatic data acquisition, processing, and presentation directly in the field.

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