SHORT COURSE on FLAT DILATOMETER (DMT)

BALI 21 MAY 2001

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- **Most of the information presented here is in the first 15 pages of:**

  ISSMGE Committee TC16 : "DMT in Soil Investigations", Proc. Bali (41 pp).

- **SCOPE : Mainly test execution (hardware, procedure, checks)**

CONTENTS

BACKGROUND and REFERENCES

INITIAL PAPER on DMT

Marchetti, S. (1980). "In Situ Tests by Flat Dilatometer". ASCE Jnl GED, Vol. 106, No. GT3, Mar., 299-321.

STANDARDS

ASTM Subcommittee D 18.02.10 - Schmertmann, J.H., Chairman (1986). "Suggested Method for Performing the Flat Dilatometer Test". ASTM Geotechnical Testing Journal, Vol. 9, No. 2, June.

Eurocode 7 (1997). Geotechnical design - Part 3: Design assisted by field testing, Section 9: Flat dilatometer test (DMT).

ASTM (2001). "Standard Test Method for Performing the Flat Plate Dilatometer ". Approved Draft, 2001.

MANUALS

Marchetti, S. & Crapps, D.K. (1981). "Flat Dilatometer Manual". Internal Report of G.P.E.

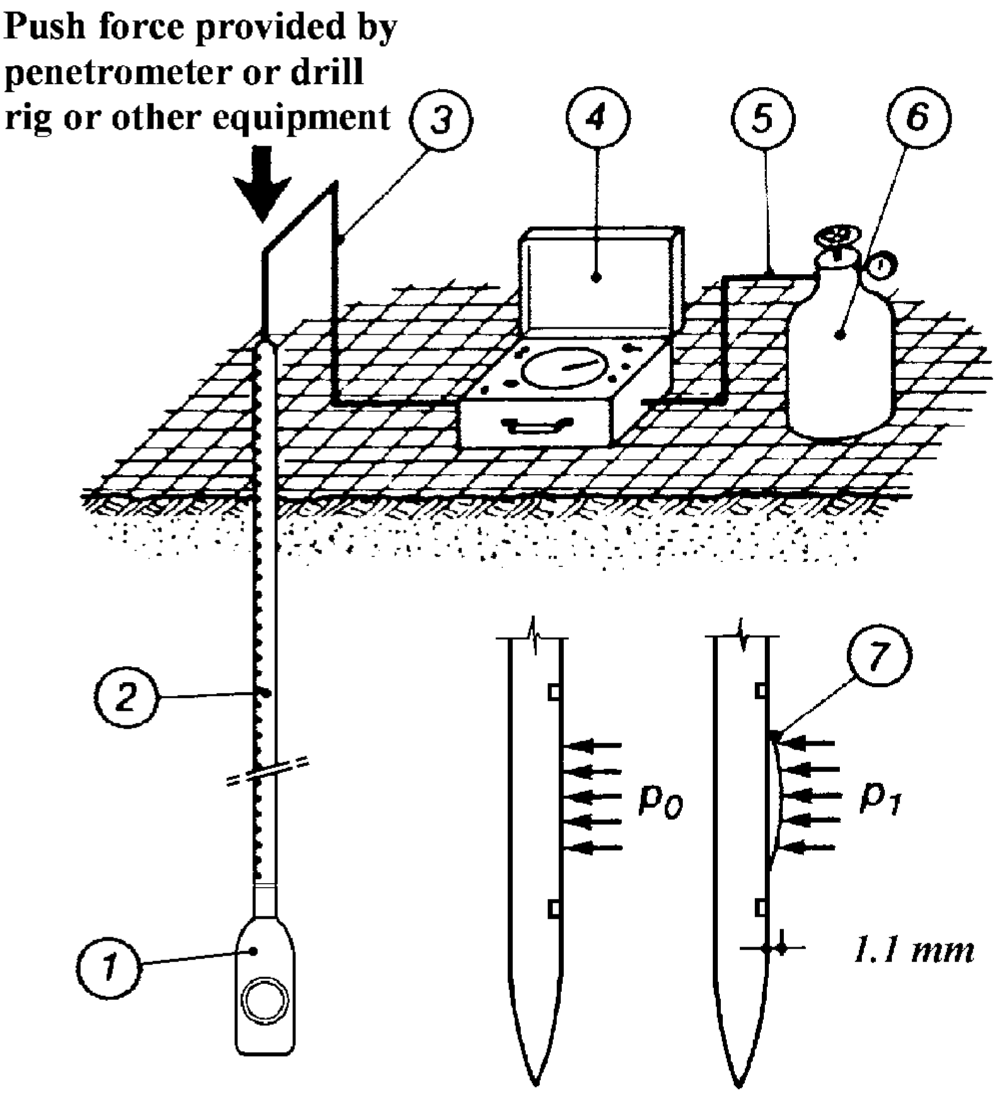
Schmertmann, J.H. (1988). Rept. No. FHWA-PA-87-022+84-24 to PennDOT, Office of Research and Special Studies, Harrisburg, PA, in 4 volumes.

US DOT - Briaud, J.L. & Miran, J. (1992). "The Flat Dilatometer Test". Departm. of Transportation - Fed. Highway Administr., Washington, D.C., Publ. No. FHWA-SA-91-044, 102 pp.

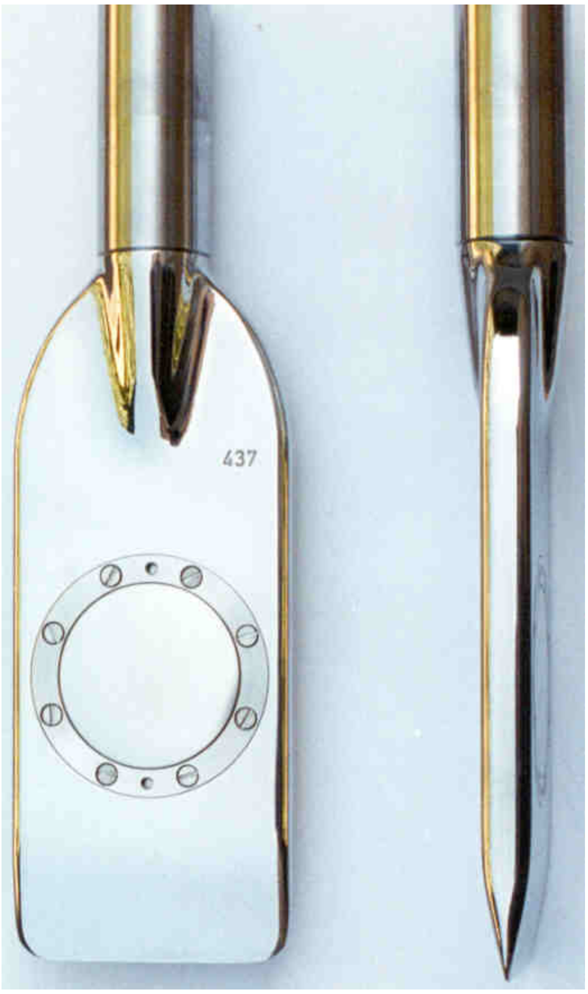
DMT ON THE INTERNET

Key papers on the DMT can be downloaded from the bibliographic site: http://www.marchetti-dmt.it

GENERAL LAYOUT OF THE DILATOMETER TEST (DMT)



1. Dilatometer blade	4. Control box
2. Push rods (eg.: CPT)	5. Pneumatic cable
3. Pneumatic - electric cable	6. Gas tank
7. Expansion of the membrane	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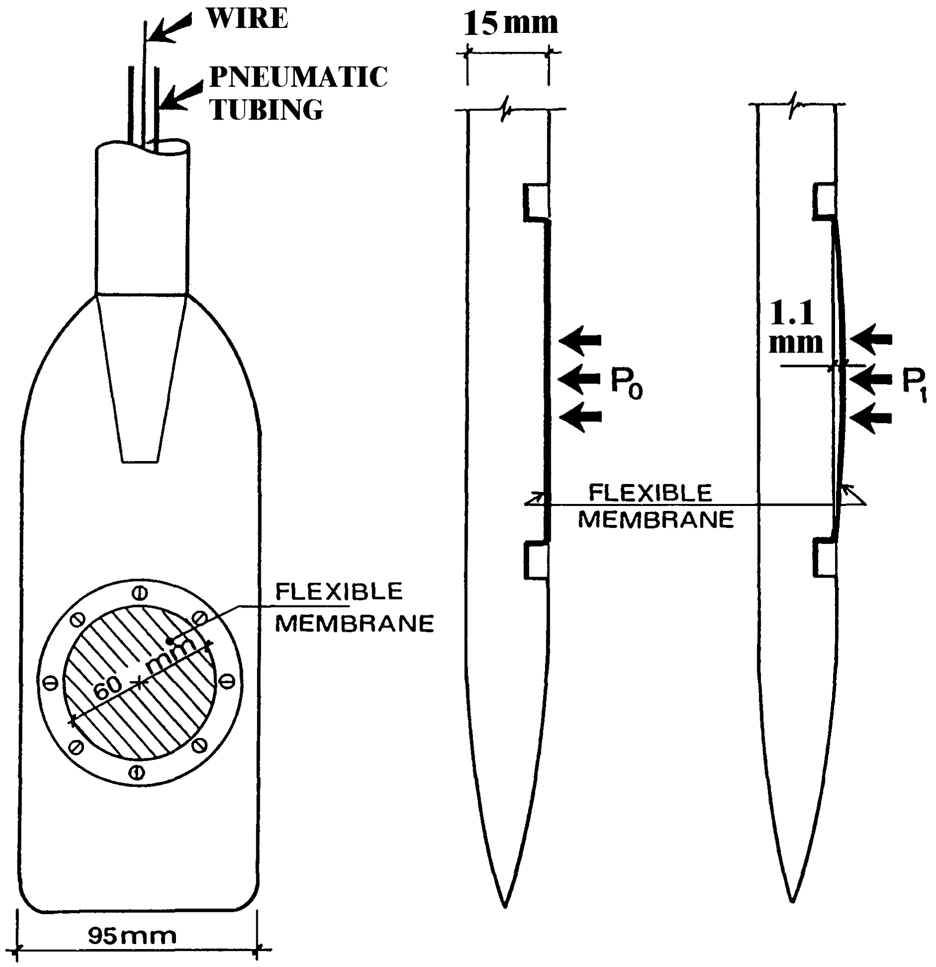
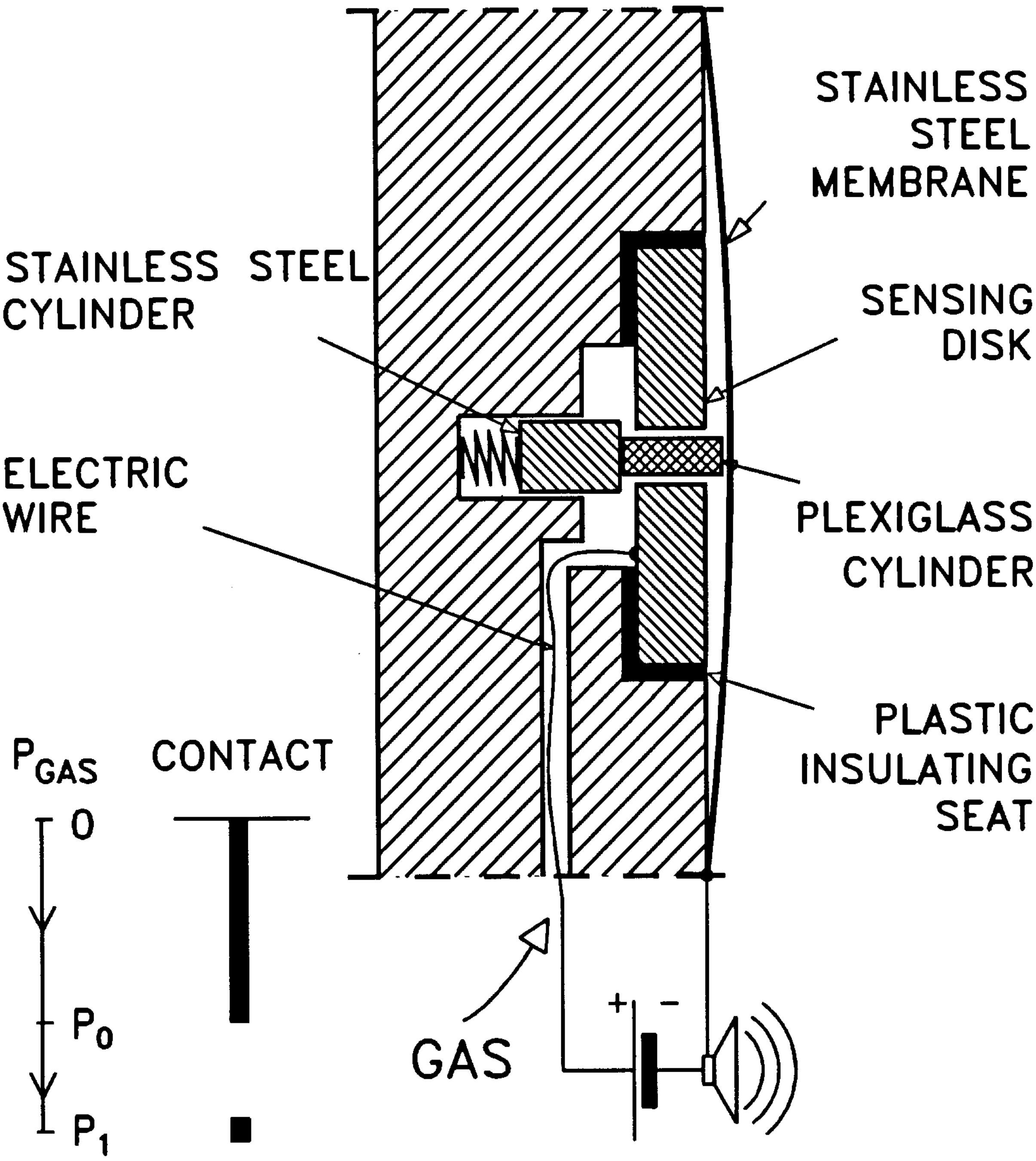
BLADE DETAILS

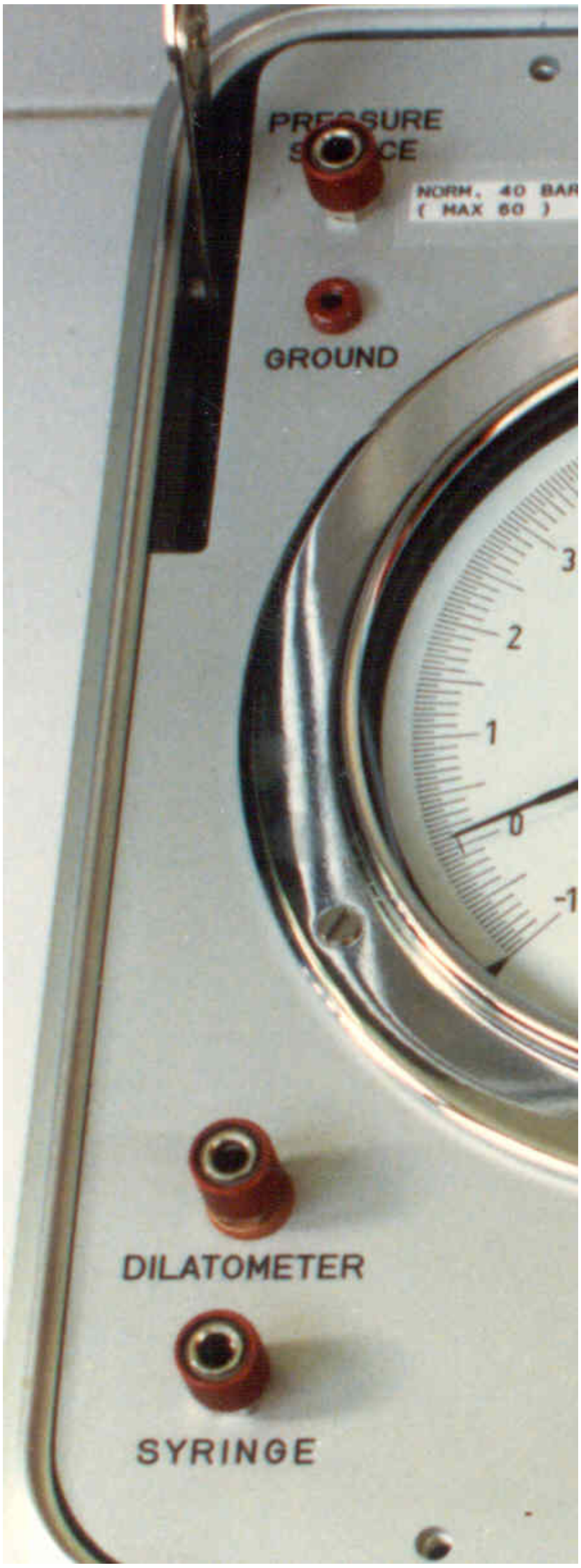


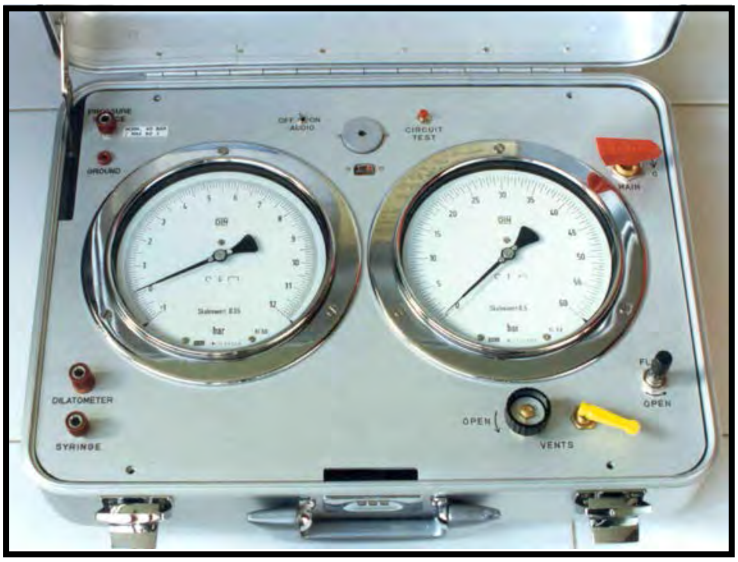
BLADE = ELECTRIC SWITCH (ON/OFF)
non electronic

WORKING PRINCIPLE



CONTROL BOX

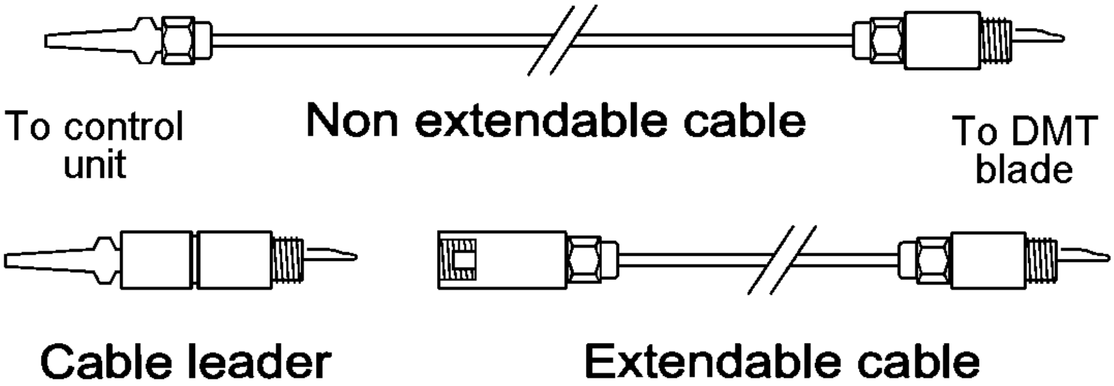

GROUND
DILATOMETER
SYRINGE

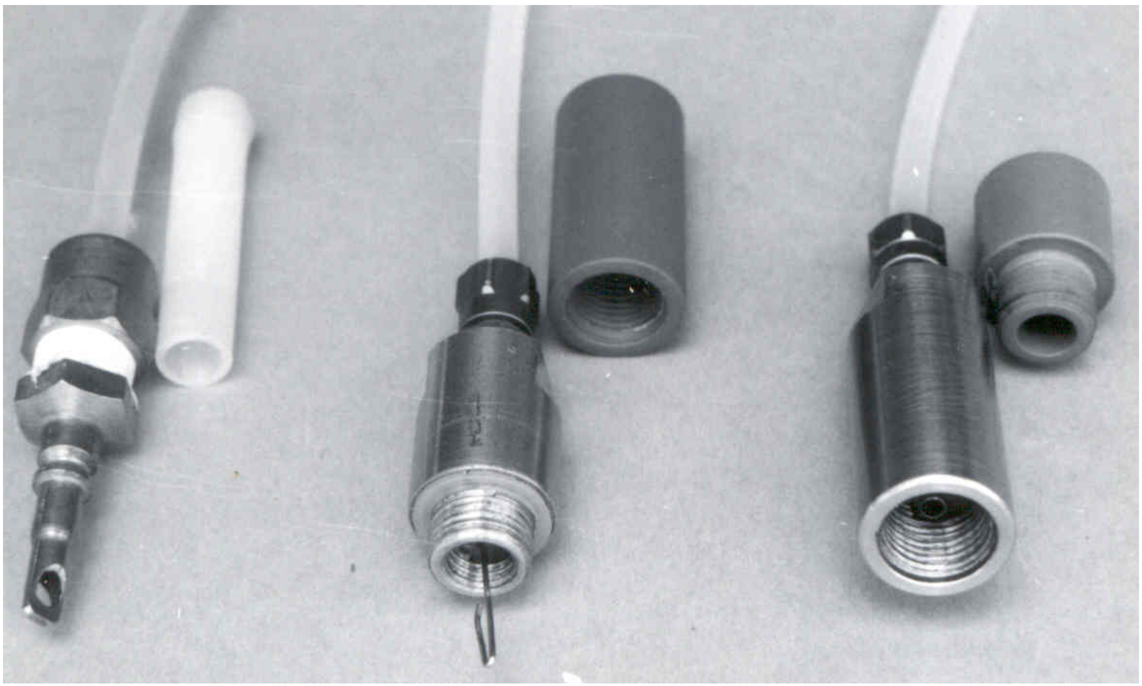



OFF ON
AUDIO
CIRCUIT
TEST

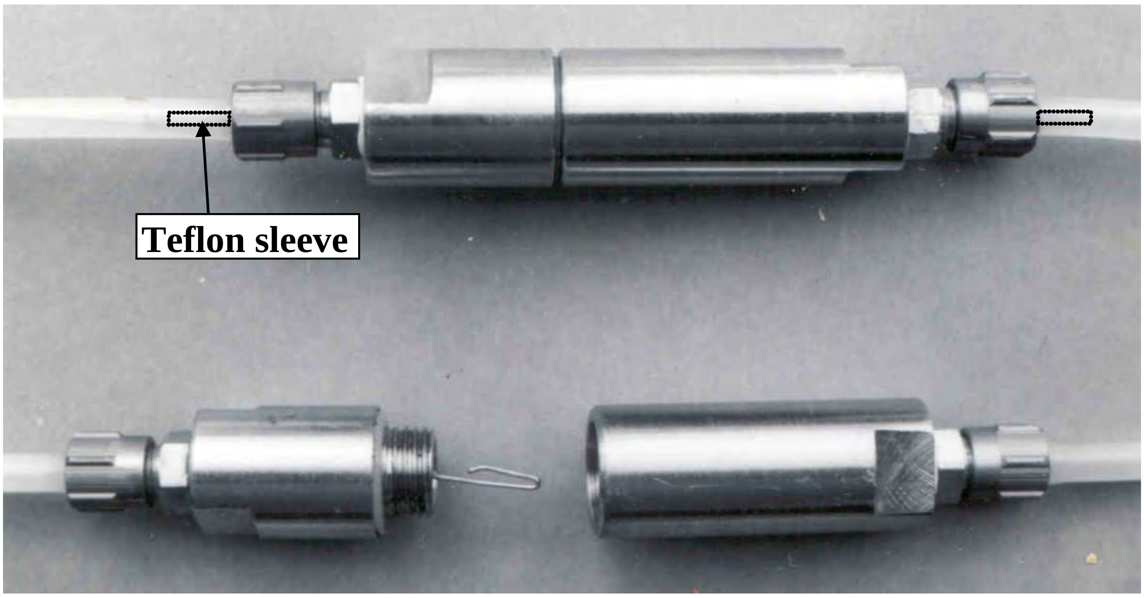

MAIN
DIN
Skalenwert 0,5
bar
OPEN
OPEN
VENTS

PNEUMATIC-ELECTRICAL CABLES

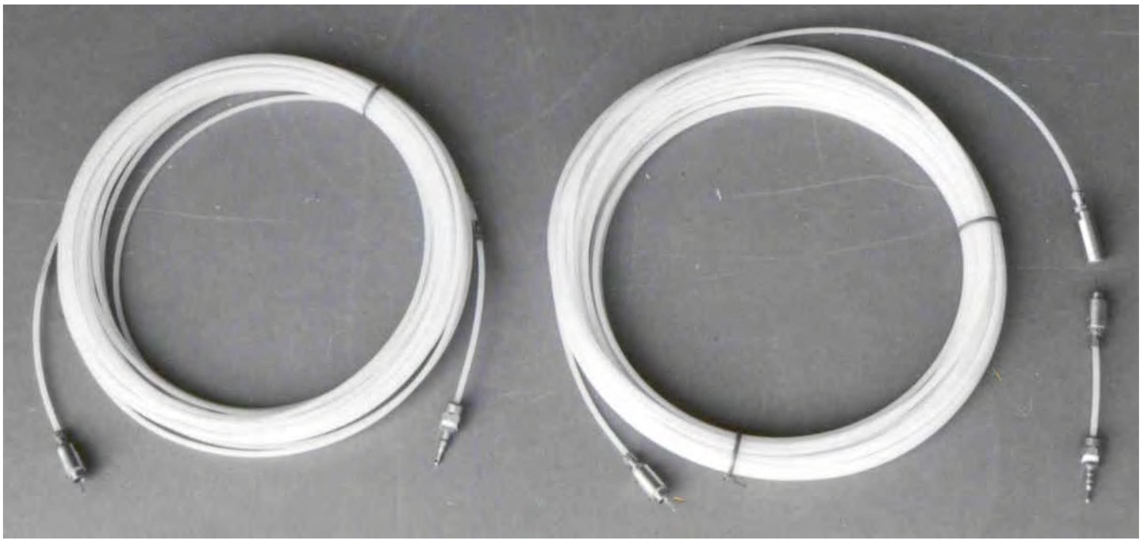




CABLE JOINTS



Note: in the terminals zone, the inner wire is insulated by a teflon sleeve

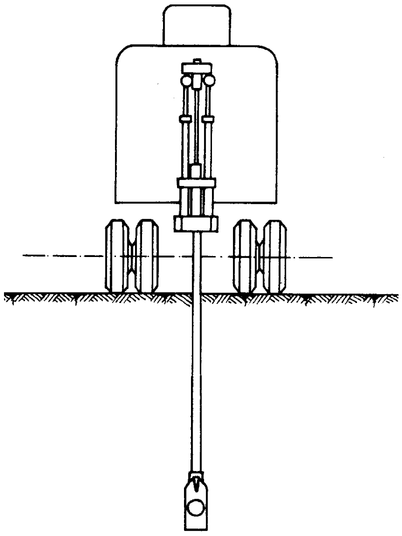


MAIN COMPONENTS of the MALE & FEMALE INSULATED TERMINALS

Metal connectors: electrically insulated from inner wire and airtight (80 bar).

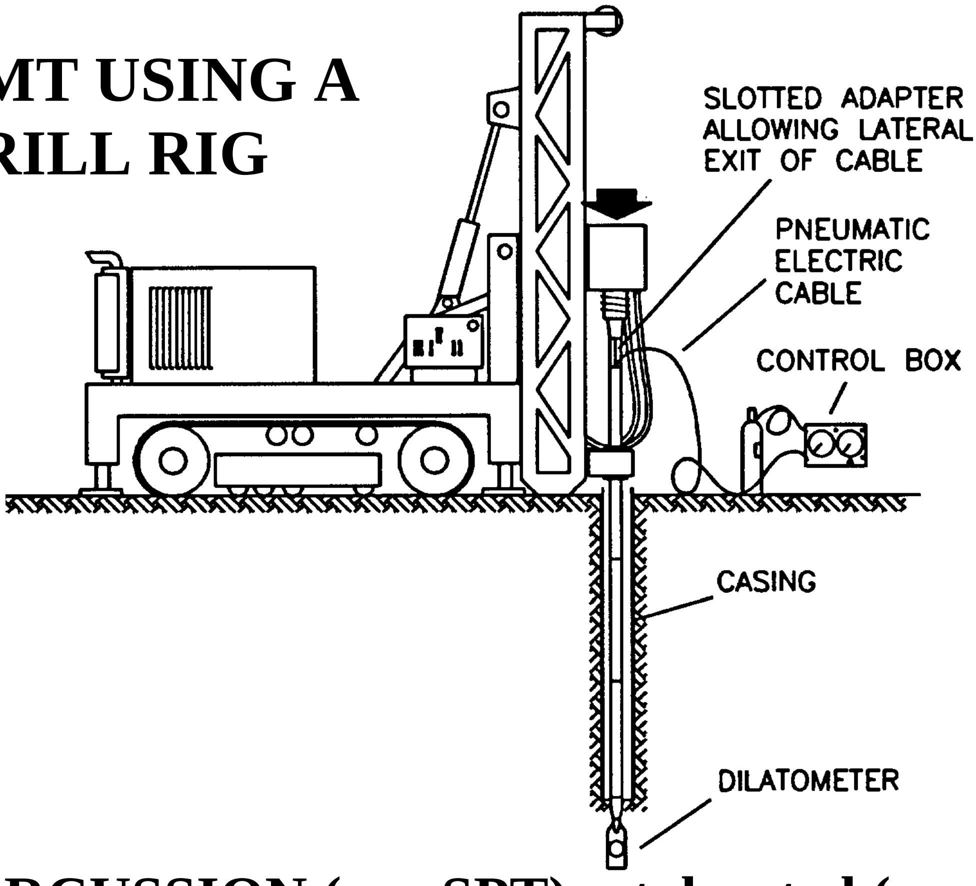
Cables\ terminals not easily repairable in the field.

INSERTION of the DMT BLADE



DMT USING A PENETROMETER

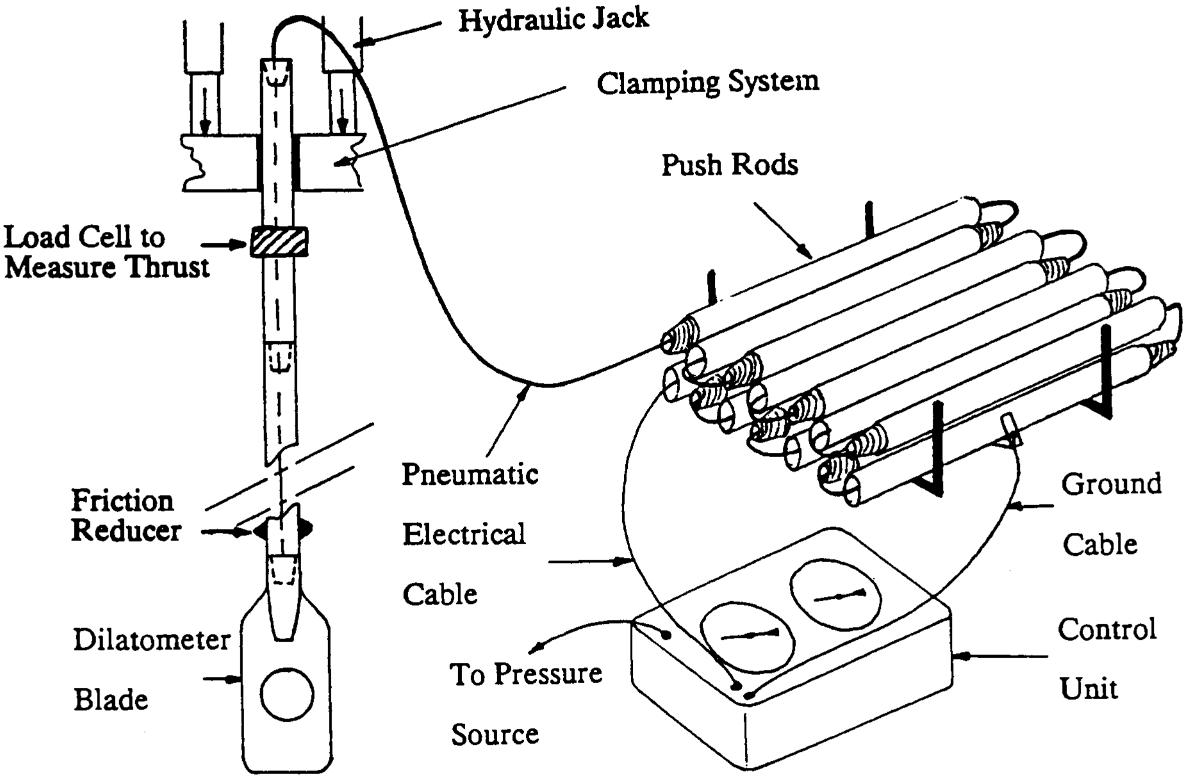
DMT USING A DRILL RIG



PERCUSSION (e.g. **SPT) : tolerated (except v. loose sands and sensitive clays) but not recommended**

PUSH FORCE BY DRILL RIG. CABLE EXITS at SURFACE

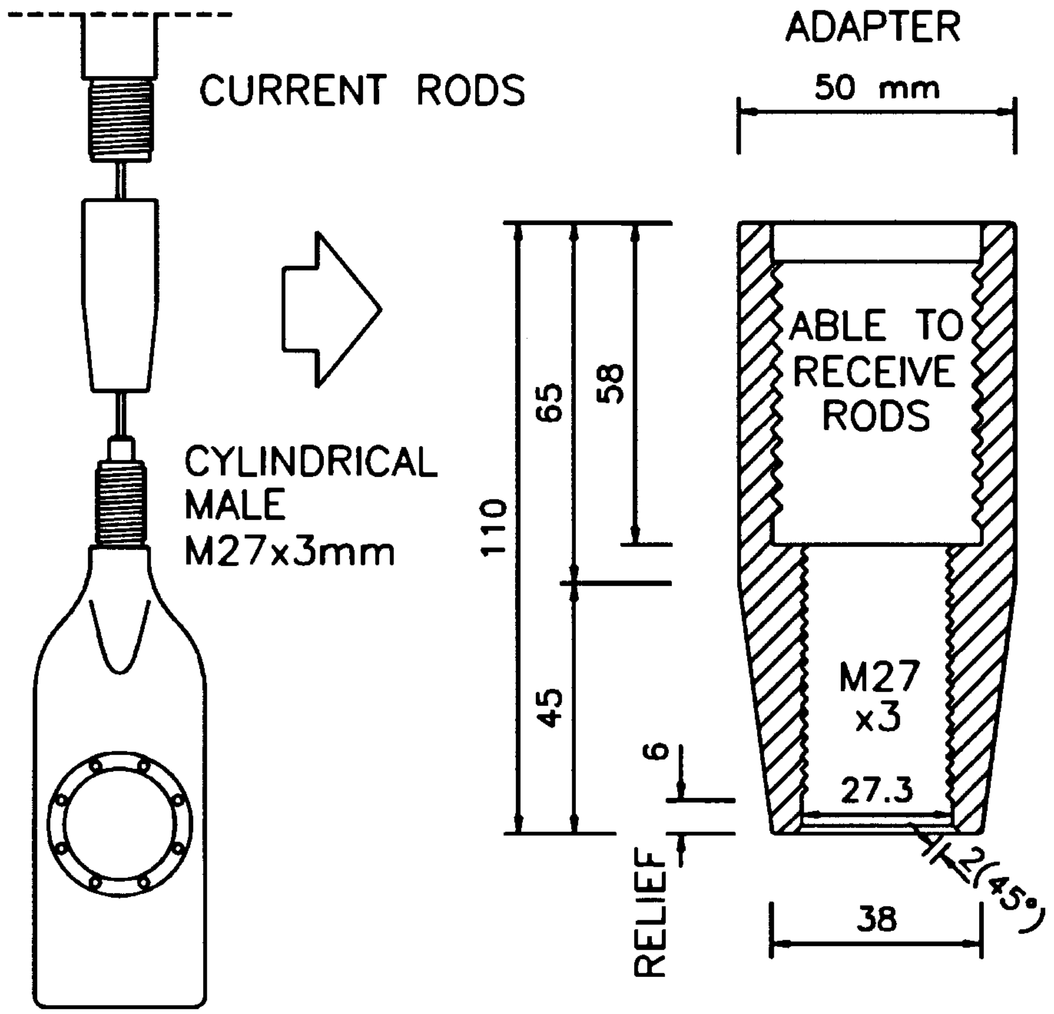
Pre-thread cable through rods (Friction reducer) (Load Cell)



SOILS that can be TESTED by DMT

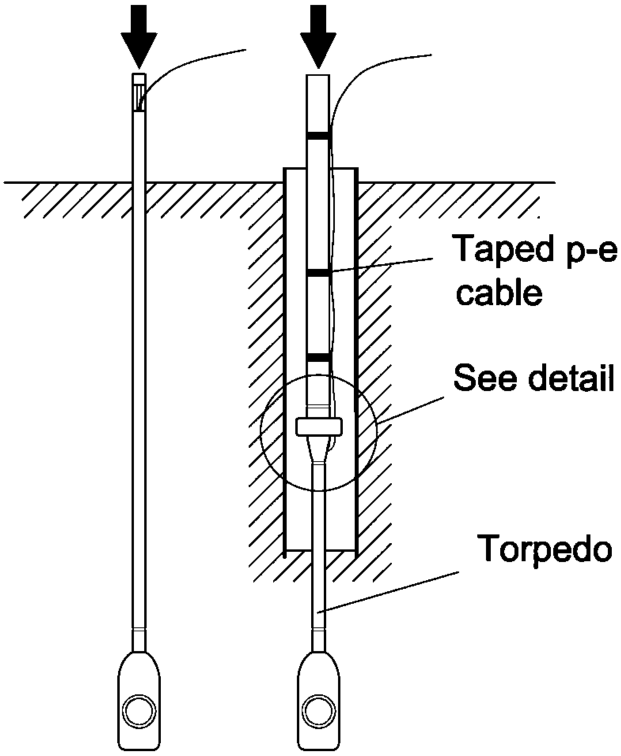
- **Suitable for SANDS, SILTS, CLAY (grains small vs membrane D=60 mm). But can <u>cross</u> through GRAVEL layers ≈ 0.5 m**
- **Very <u>robust</u>, can penetrate soft rocks (safe push on blade 25 ton)**
- **Clays : Cu = 2- 4 KPa to Cu= 10 bar (marls)**
- **Moduli : 5 to 4000 bar (0.5 to 400 MPa)**
- **Penetrates fast and easily in hard soils PROVIDED <u>sufficient</u> pushing capacity (e.g. 20 ton trucks).**

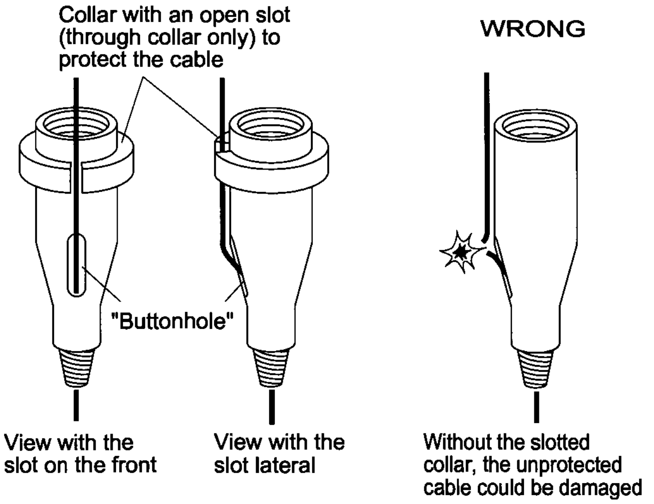
ADAPTORS : RODS to DMT BLADE



"LOWER" ADAPTORS

EXIT of CABLE from RODS. "TORPEDO"





Using stronger RODS (for 15 cm^2 cones)

Commerc. available D=44 mm, same steel as CPT.

Often rods "weakest element in the chain" (20 ton trucks, high strength 25 ton blades). Hence <u>stronger</u> rods.

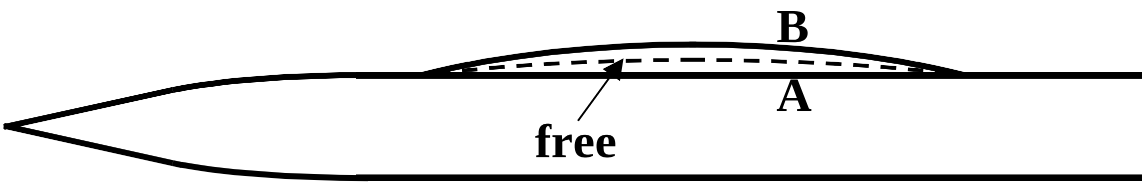
<u>Advantages</u>

-Can penetrate through cemented layers/obstacles.
-Lateral stability agai nst buckling in the first few meters in soft soils or in empty borehole.
-Use completely the push capacity of the truck.
-Less risk of deviation from verticality.
-Risk of loosing the rods $\approx$ 0 (wall = 22 mm).

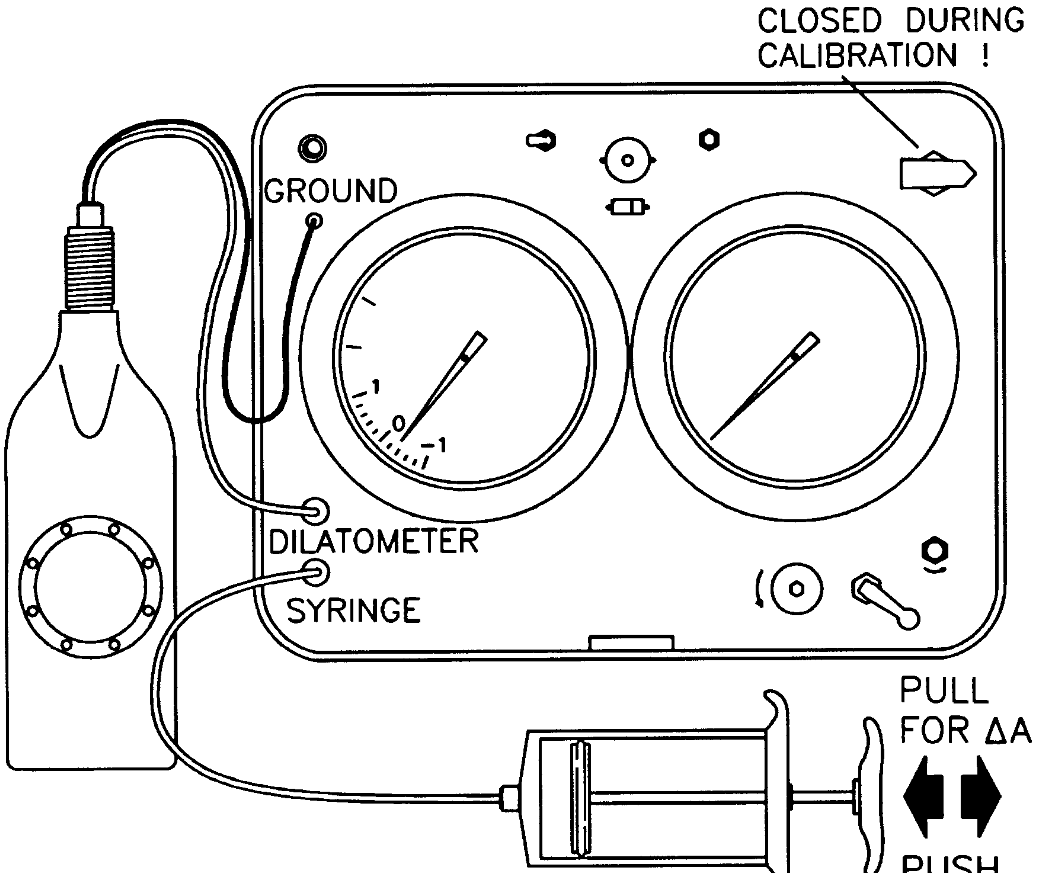
<u>Drawbacks</u>

(Initial cost) and heavier (9 Kg/m, rather than the 6.4 of CPT rods 36 mm, +40%).
No big advant in OC clay (+ skin friction).

CALIBRATION OF MEMBRANE (ΔA & ΔB) - Layout of connections



Positions of the membrane (free, *A* and B)



DEFINITIONS OF Δ*A* & Δ*B*

Δ*A* = external pressure which must be applied to the membrane <u>in free air</u> to collapse it against its seating (i.e. *A*-position)

Δ*B* = internal pressure which <u>in free air</u> lifts the membrane center 1.1 mm from its seating (i.e. *B*-position)

- **Δ*A* & Δ*B* are used to <u>correct the *A* & *B* readings</u> into p_0 & p_1 (≈ *TARES* to be detracted)**
- **Δ*A* & Δ*B* must be measured <u>before</u> and <u>after</u> each sounding**
- **The calibration is a good indicator of <u>equipment condition</u> and expected quality of data**
- **A large difference between before/after Δ*A* & Δ*B* values should prompt a membrane change (usually apparent)**

DETERMINATION OF ΔA & ΔB

To obtain Δ*A*

- **Apply vacuum by pulling back the syringe piston (vacuum causes an inward deflection of the membrane similar to that due to external soil pressure at the start of the test) - buzzer becomes active.**
- **Slowly release the piston and read Δ*A* on the low-range gage when buzzer stops.**
- **Note this negative pressure as a positive Δ*A* value, e.g. Δ*A* = 15 kPa for a vacuum of 15 kPa (the correction formula for p_0 takes into account that a positive Δ*A* is a vacuum).**

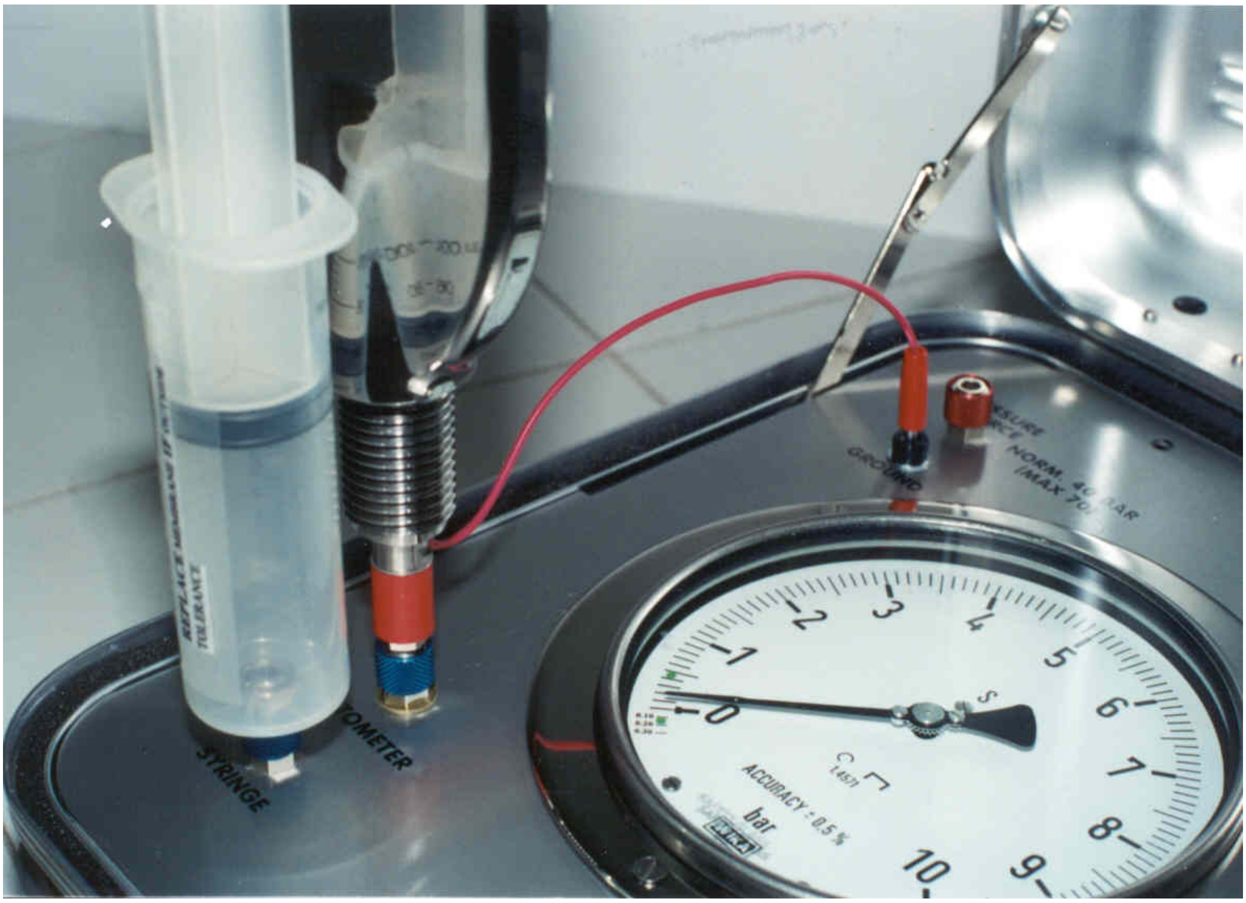
To obtain Δ*B*

- **Push slowly the piston into the syringe and read Δ*B* on the low-range gage when buzzer reactivates.**

REPEAT SEVERAL TIMES

CONFIGURATION during CALIBRATION

Note the short calibration connector



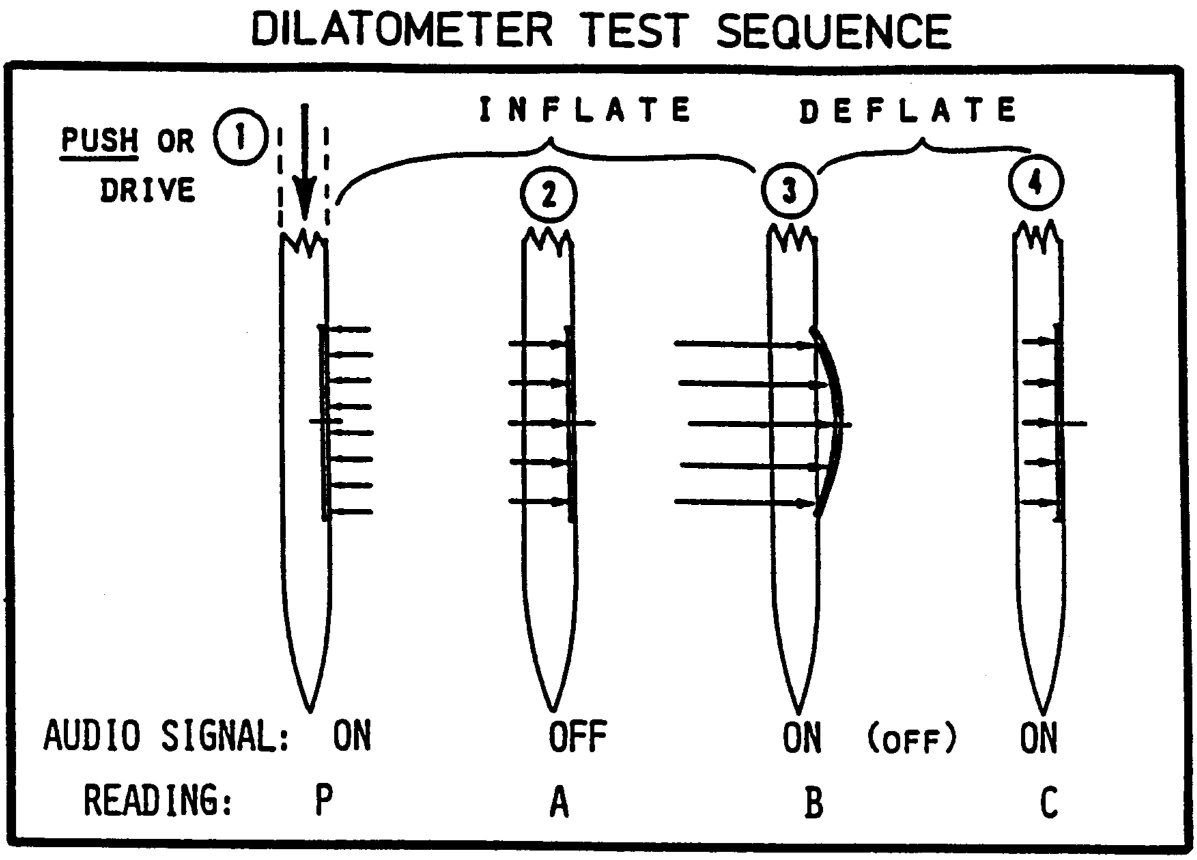
CALIBRATION (with BLADE inaccessible)

At the beginning of a sounding, the blade is in the hands of operator: 1st configuration OK.

Later, when the blade is inaccessible (under the truck) a 2nd configuration is used.

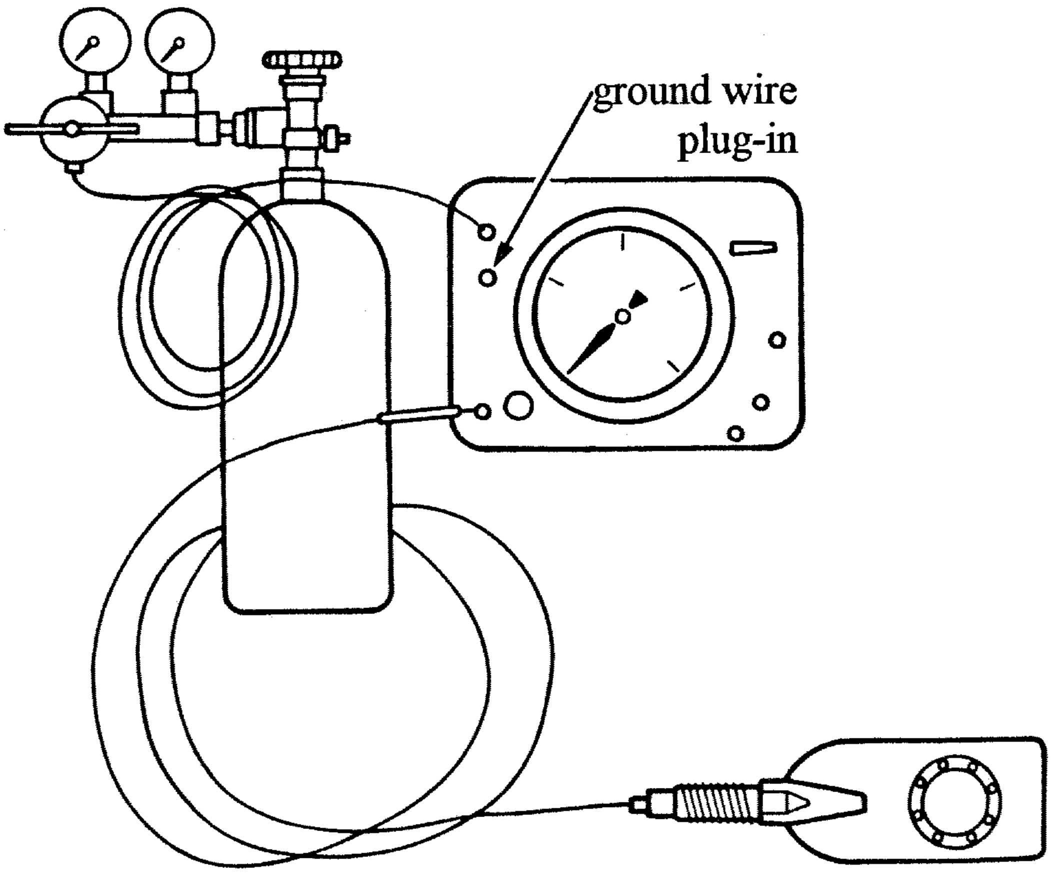
The config. is the same as during current testing, with cables of normal length (20-30 m).

Procedure is identical. However in 2nd case, due to the length of the DMT tubings, there is some time lag (easily recognizable by the slow response of the pressure gages to the syringe). Therefore, in that configuration, DA, DB must be taken slowly (15 sec OK).

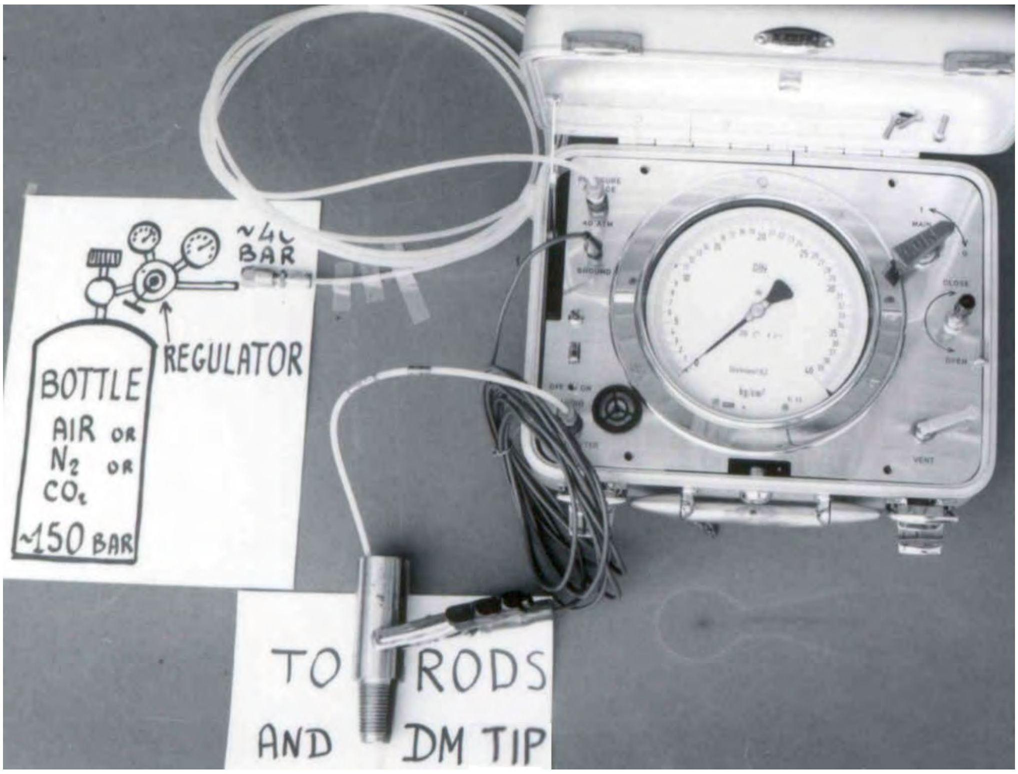

DILATOMETER TEST SEQUENCE
PUSH OR DRIVE
1
INFLATE
DEFLATE
2
3
4
AUDIO SIGNAL: ON
OFF
ON
(OFF)
ON
READING: P
A
B
C

CONNECTIONS DURING CURRENT TESTING

- **PRESSURE SOURCE to "PRESSURE SOURCE" SOCKET**
- **CABLE FROM BLADE to "DILATOMETER" SOCKET**



CONNECTION GROUND CABLE - BLADE



STEP-by-STEP PROCEDURE. A, B (C)

As soon as rig operator reaches test depth, he signals go-ahead to <u>DMT operator, who:</u>

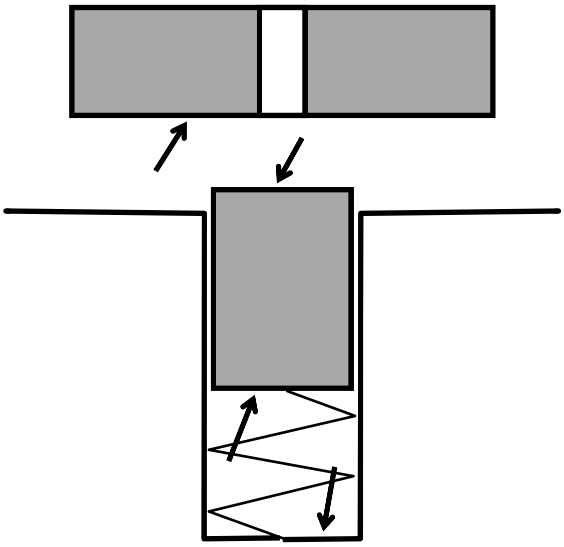
- **(Closes vent valve). Slowly <u>opens</u> micrometer valve (signal on). When sound stops, <u>reads</u> A.**
- **<u>Continues</u> to inflate (signal off). When sound reactivates (1.1 mm) <u>reads</u> B. Immediately after B <u>4 operations</u>:**

1. **Open vent valve : depressurize membrane.**
2. **Close micrometer (pressure supply)**
3. **Gives Go-ahead to rig operator to advance Stepz**
4. **Write A and B.**

AVOID OVERINFLATING MEMBRANE

- **<u>TRIVIAL REASON</u> : *FORGET DEFLATING AFTER B-signal.* MAY happen to BEGINNER.**
- **<u>SERIOUS REASON</u> *ABSENCE of B* (due to <u>DIRT</u>)**

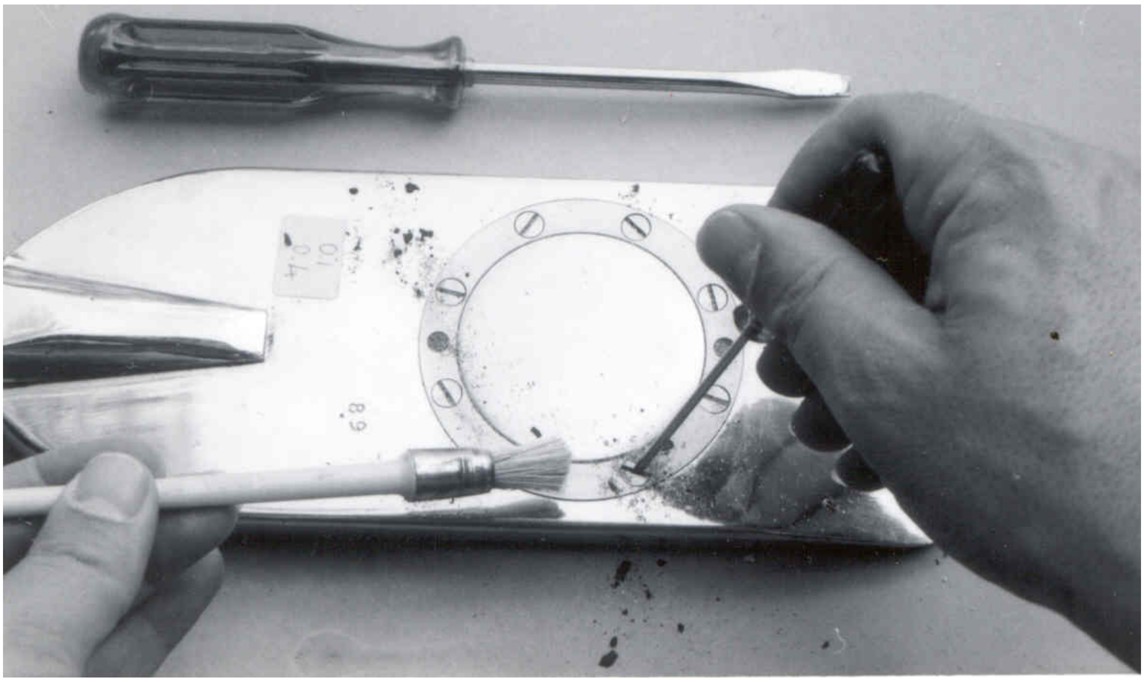
CLEAN 4 POINTS BELOW DIRT, GRAINS, CLOTH... NO CONTACT - NO B-signal. KEEPS INFLATING......

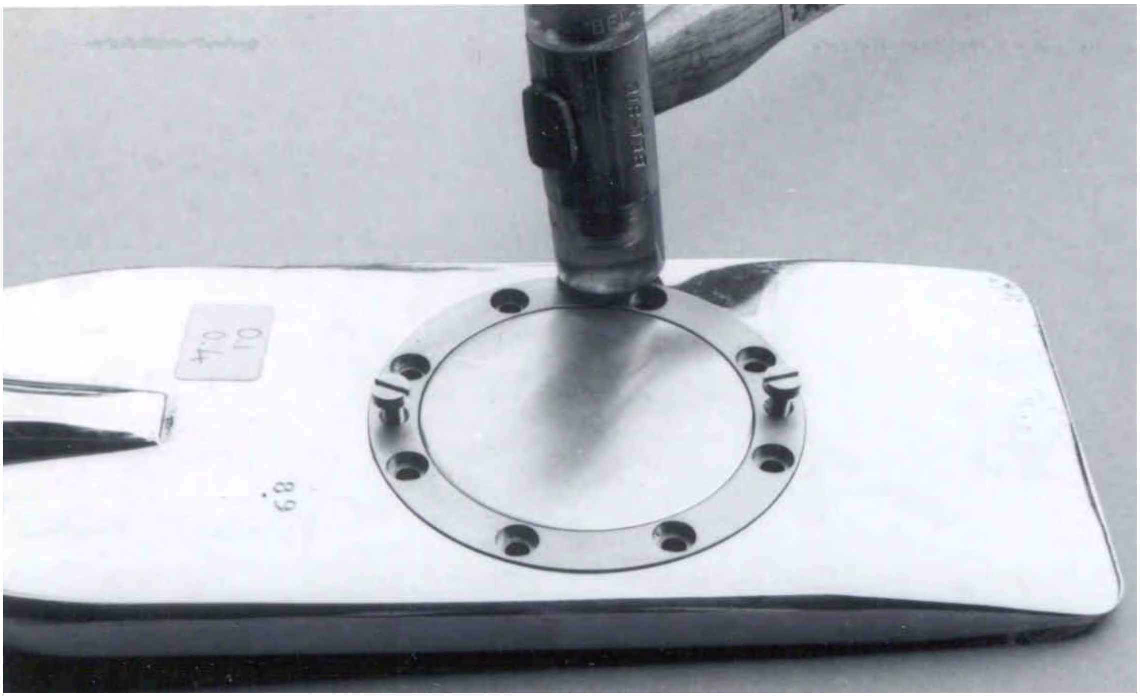


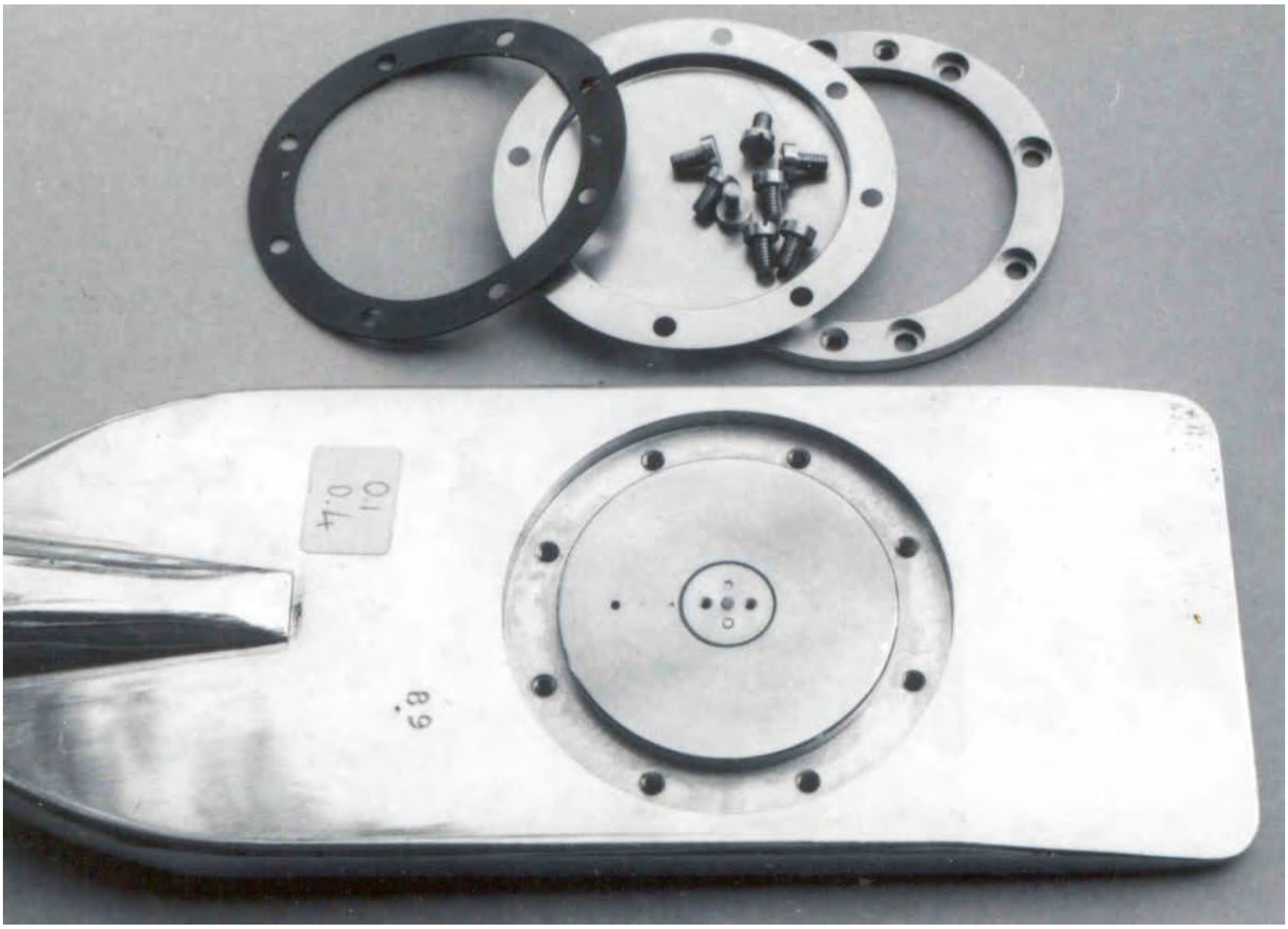
NO NEED TO CLEAN periodically (day, week...) but ONLY after DAMAGE (DIRT inside)

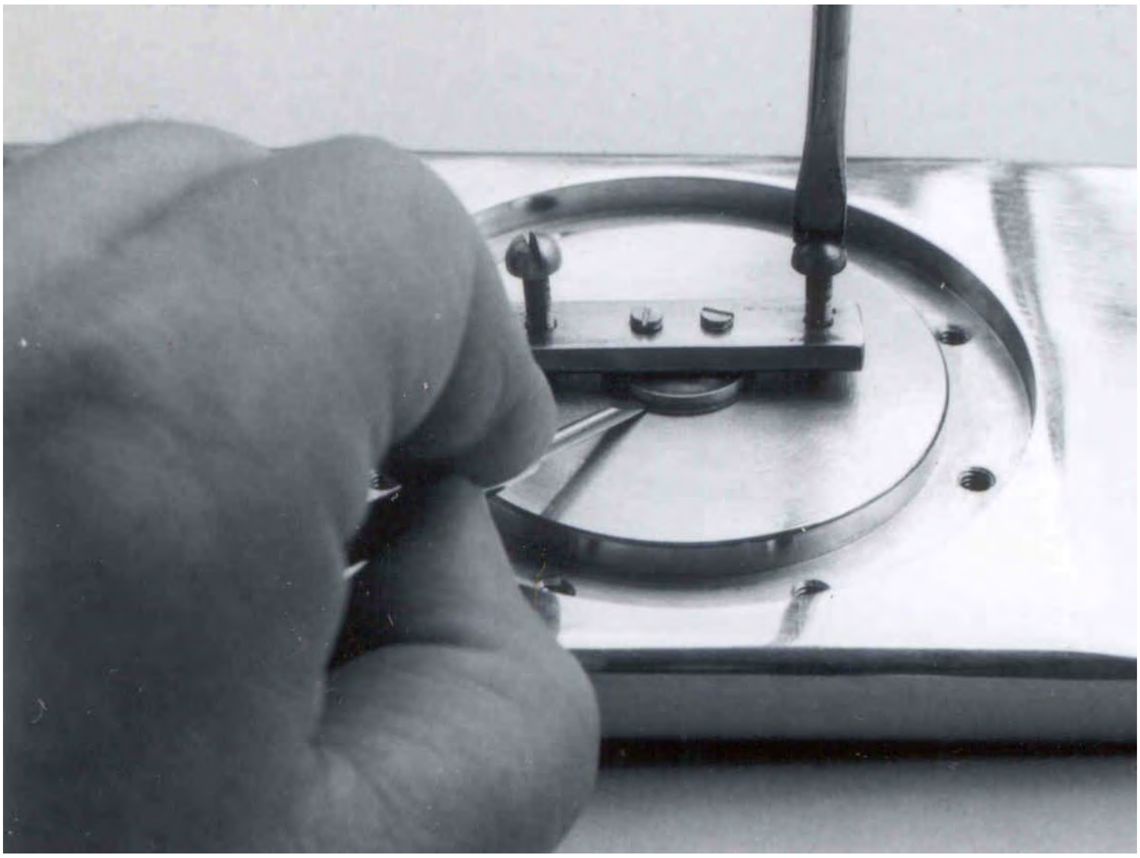
ALL SIGNAL INVERSIONS MUST BE SHARP (checked during Calibration)

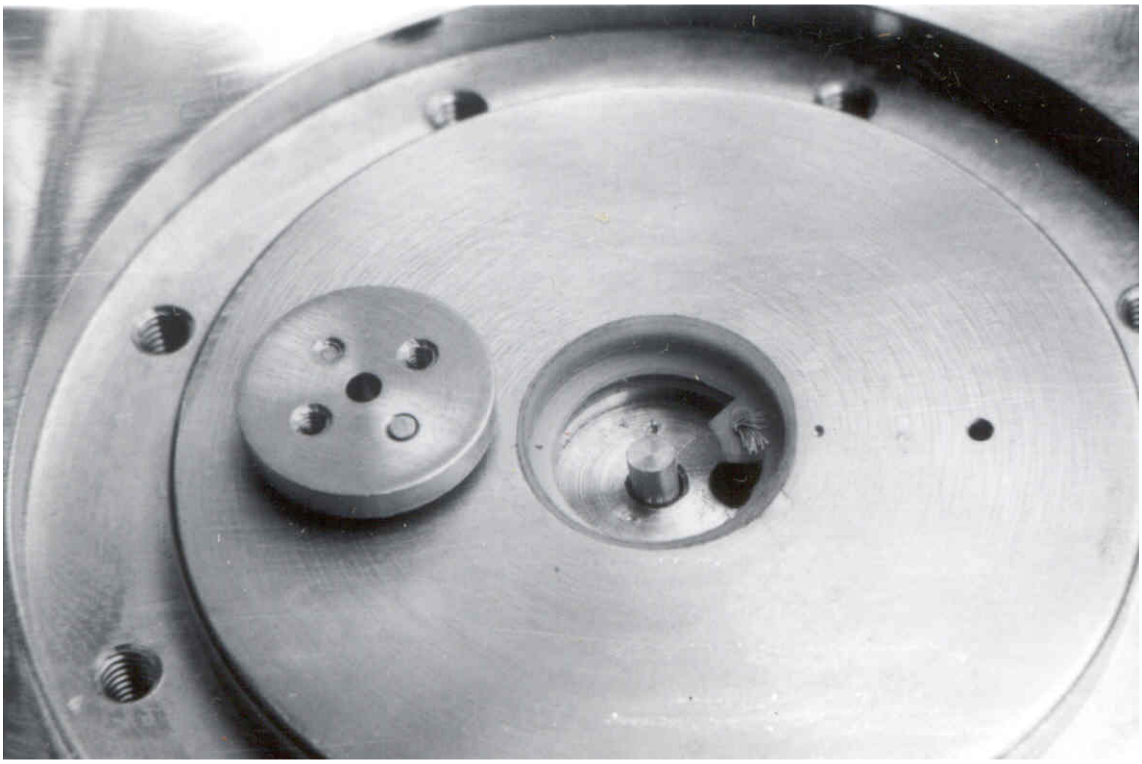
- **CLEANING INSIDE THE BLADE**
- **REPLACING A MEMBRANE**

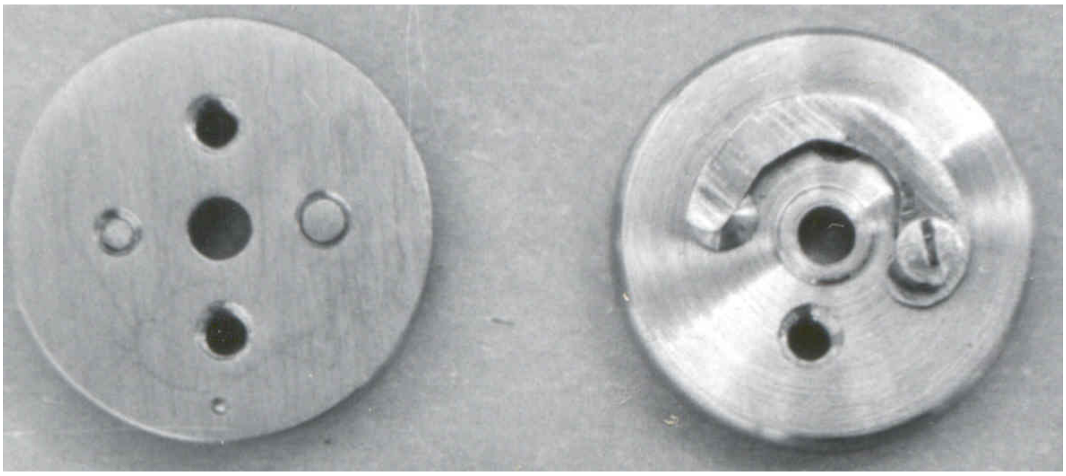


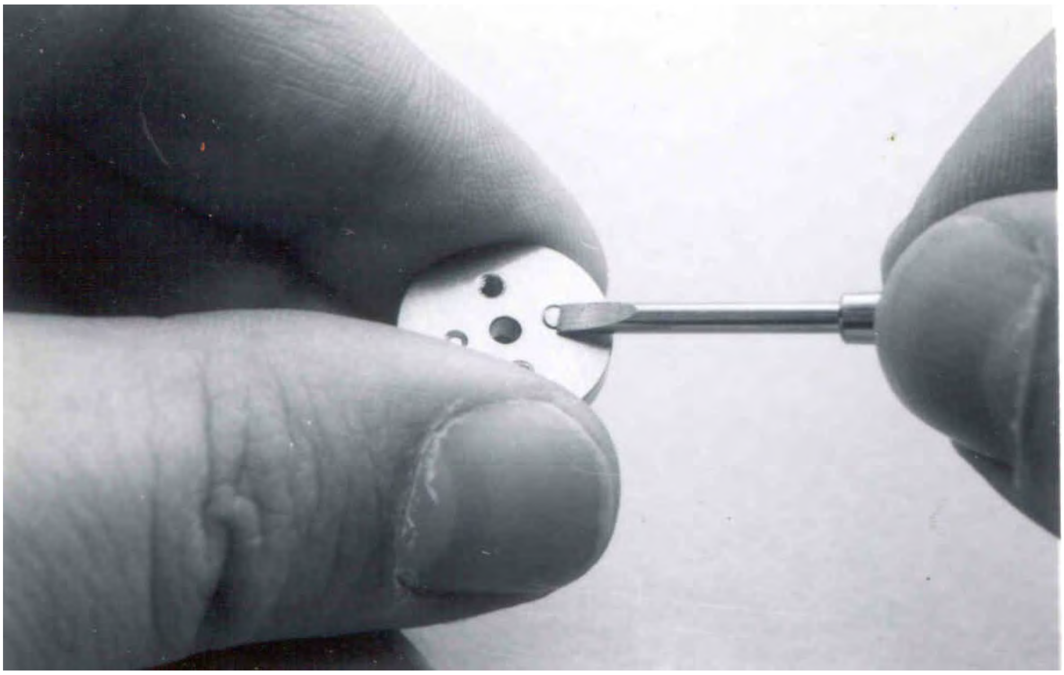




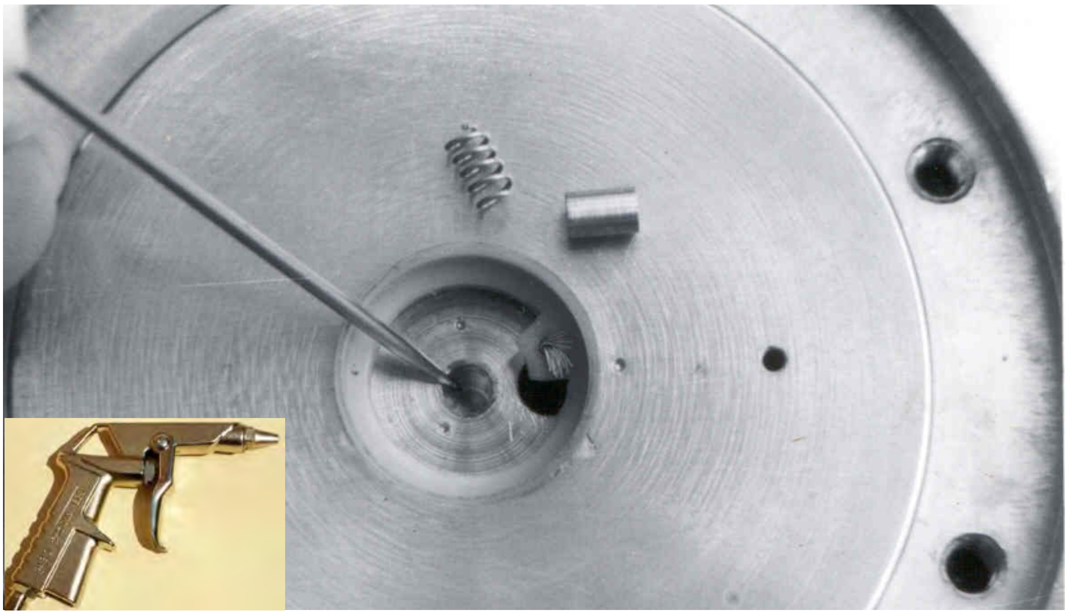


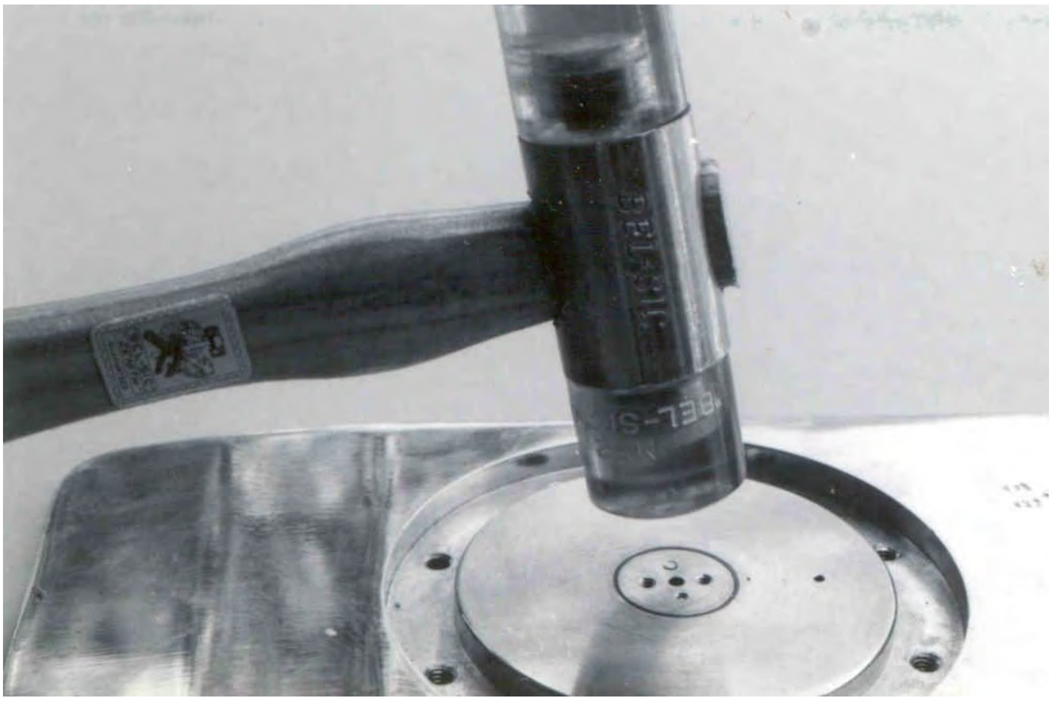






CLEANING THE CENTRAL HOLE





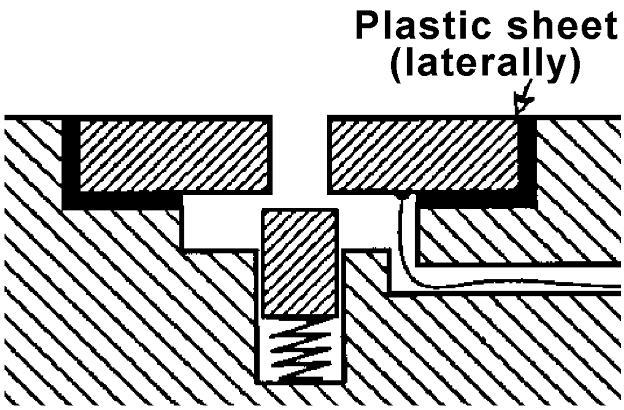
DISC STATIONARY: must fit TIGHTLY

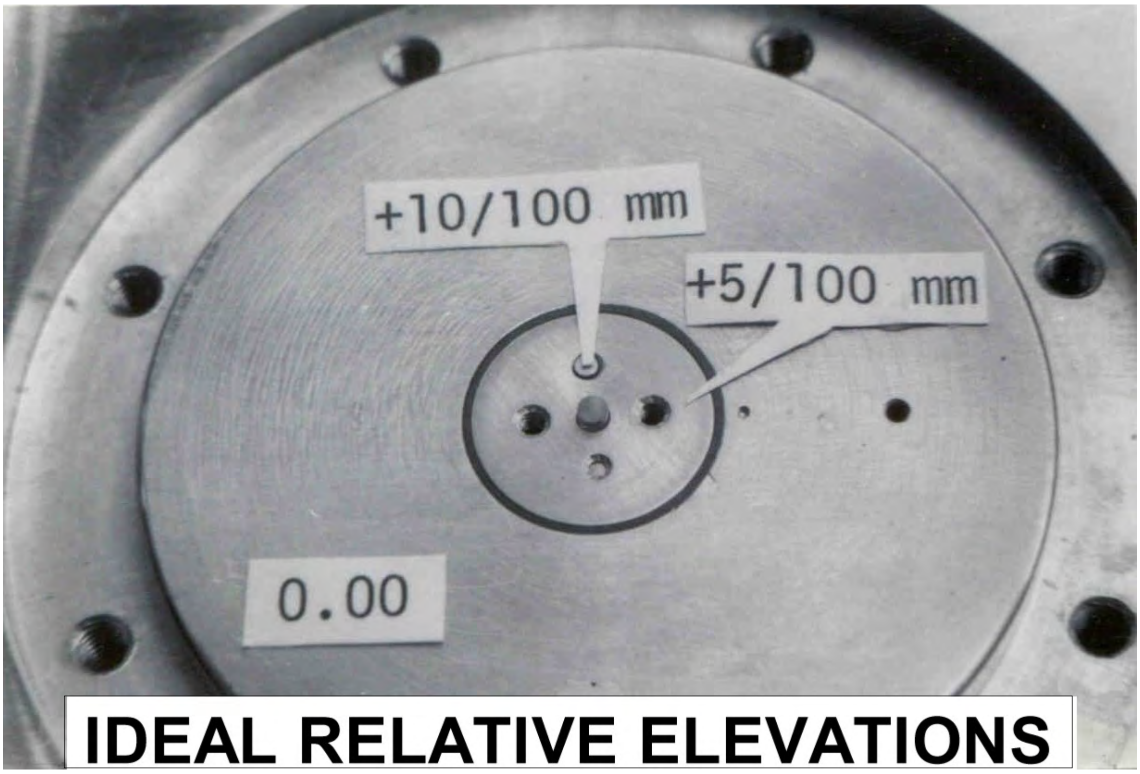
Disc must get forced inside the insulating seat, thanks to lateral gripping force.

Extraction force > weight of blade. If sensing disc is lifted (using puller), blade is lifted too.

If coupling becomes loose (e.g. damage) and disc free to move, increase gripping force.

A quick fix: insert a small piece of plastic sheet (lateral to disc, not on bottom). Then trim.





TOLERANCES:
<u>Sensing Disc</u> : 0.04 to 0.07 mm above surrounding plane

<u>Feeler</u> : 0.04 to 0.07 mm above Sensing Disc

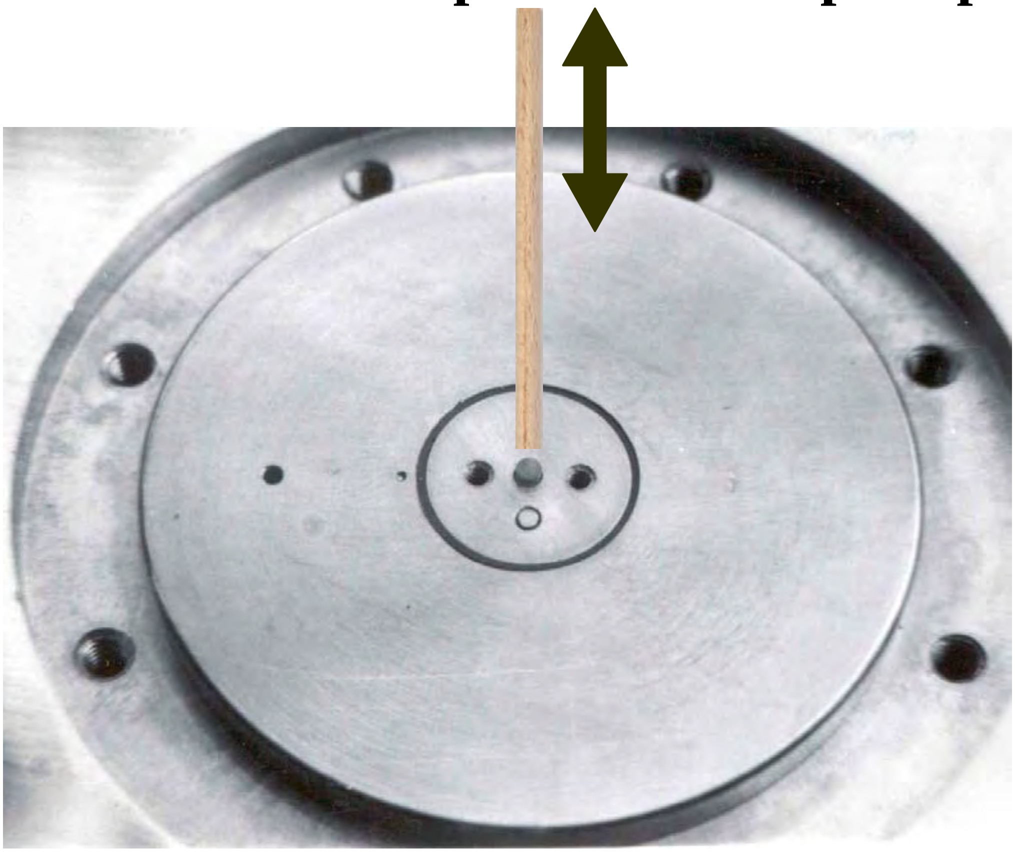
TRIPOD & DIAL GAGE

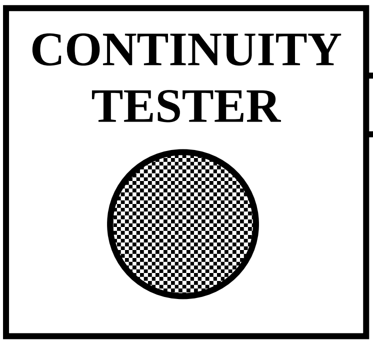
Electrical SHARPNESS of B-reading

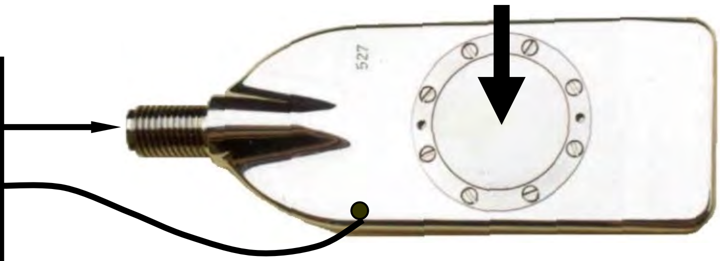
Just before closing the blade:

- **Apply "continuity tester" to blade.**
- **Push up/down the quartz cylinder 10 times.**

B-CONTACT : sharp and **prompt.**



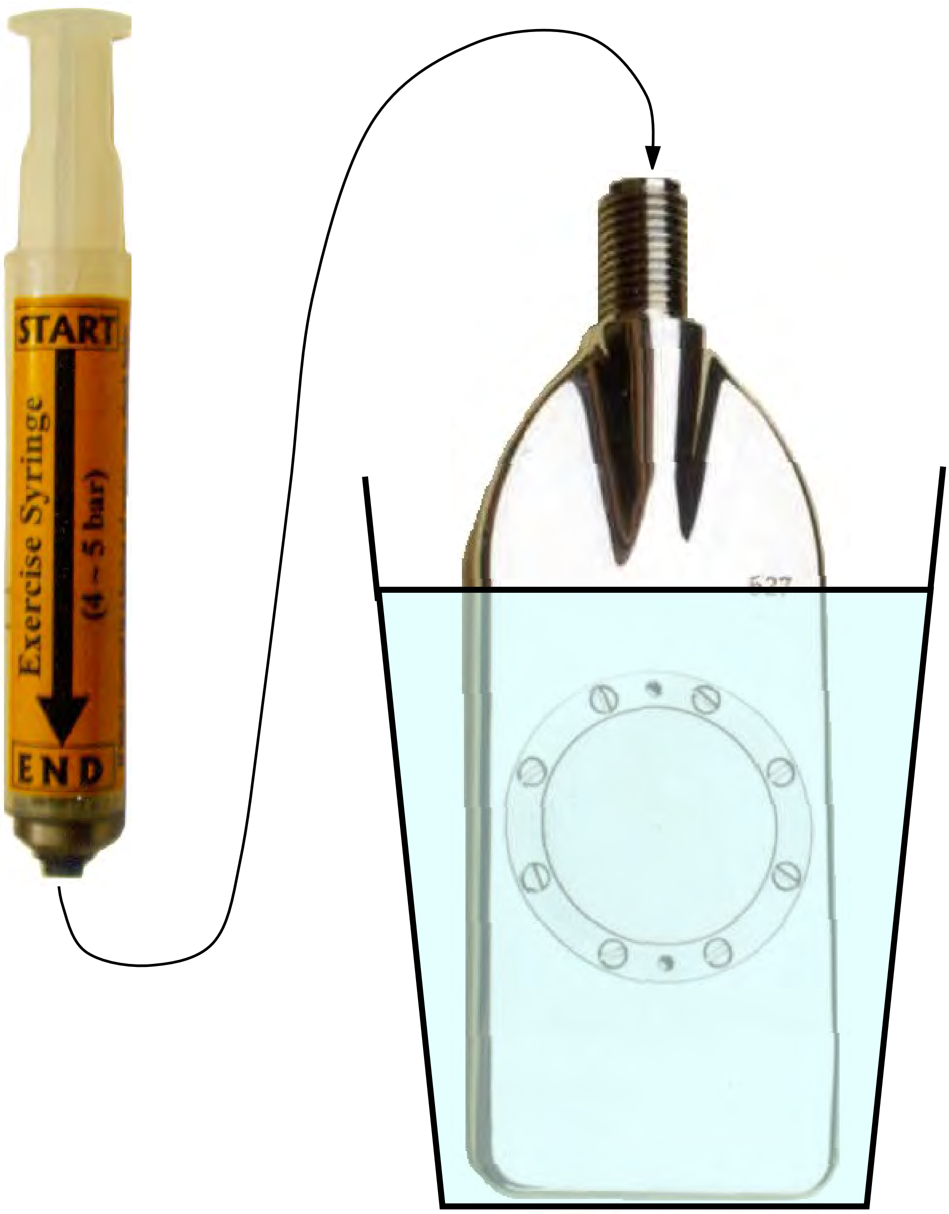




When the blade is closed, push center of membrane. Buzzer should sound.

1. EXERCISE a NEW MEMBRANE
2. CHECK AIRTIGHTNESS

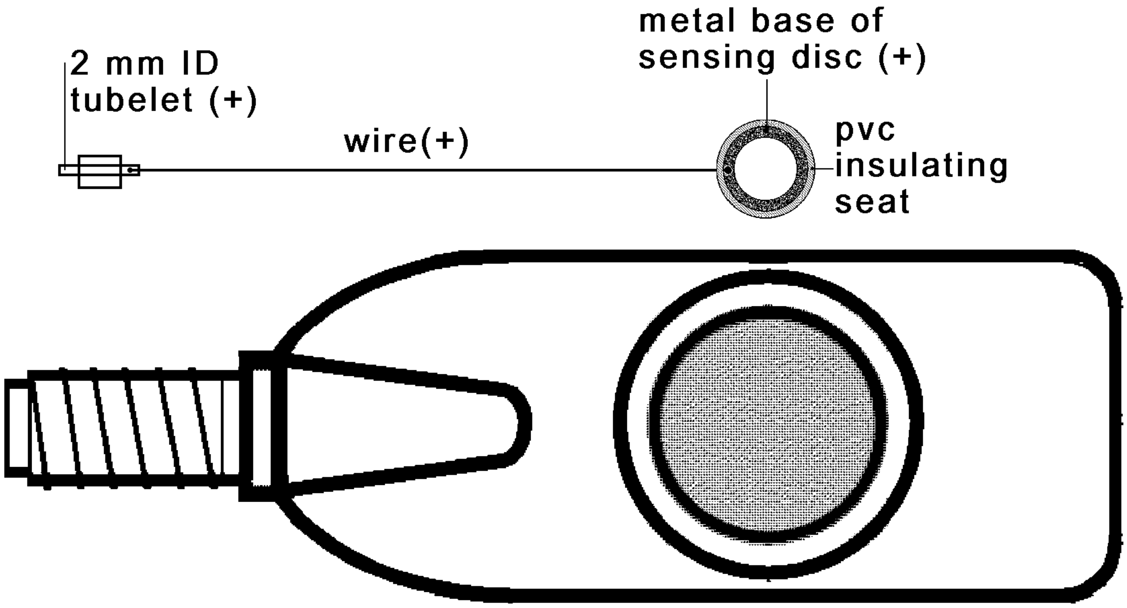
Apply Syringe to back of blade
Push piston from start to end : <u>5 bar</u>
Achieves both functions



LONGITUDINAL WIRE

Note longitudinal wire running inside blade. It is the "live" (+) electrical pole.

Such (+) is <u>insulated</u> from body of the blade. It is the same pole as the steel wire in plastic tube.

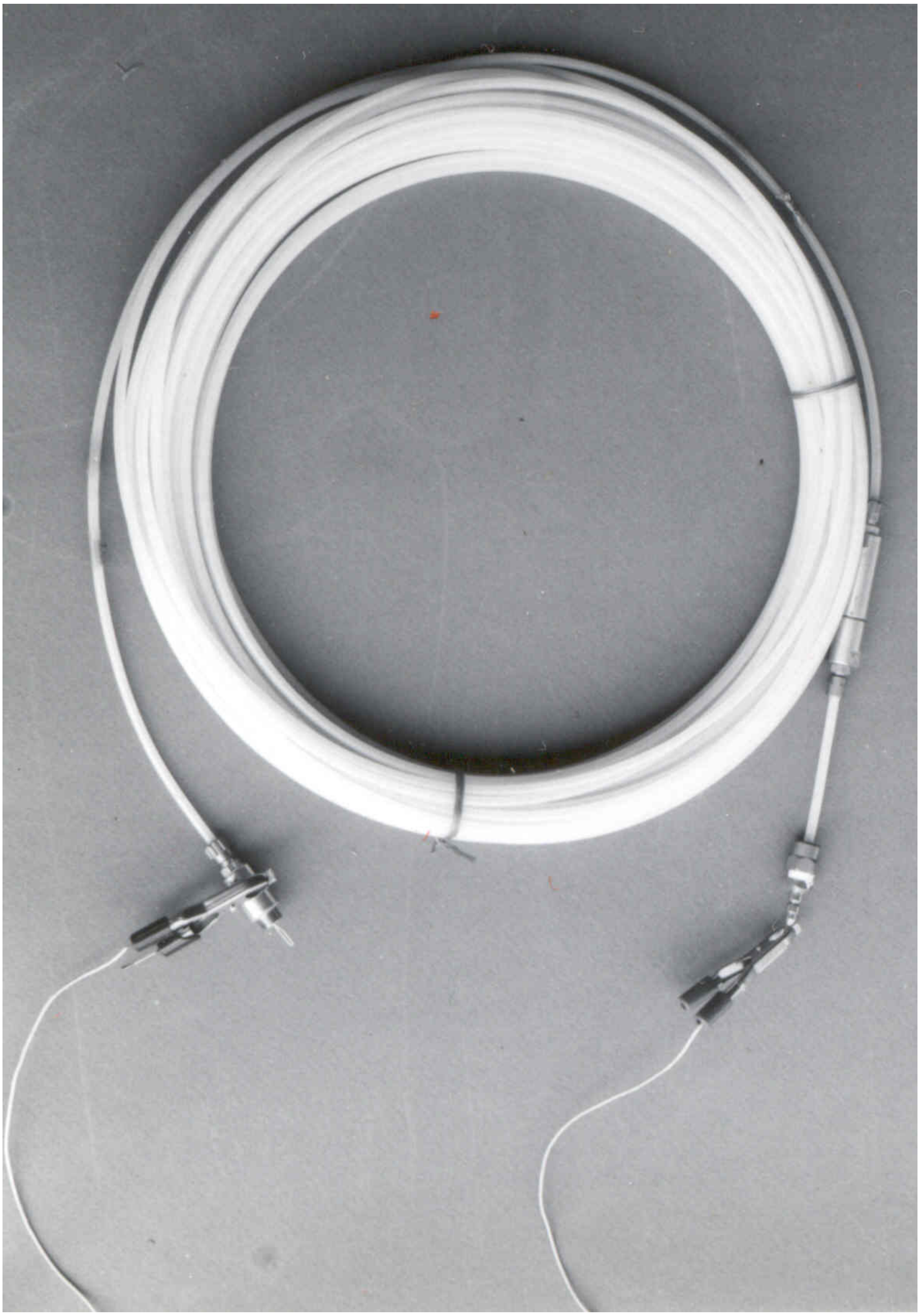


The wire cannot be disassembled, being welded to the "metal base of sensing disc".

To clean : use compressed air inside conduit.

Use contin. tester to check contact / no contact (tubelet & metal base not in contact with body).

CABLES : ELECTRICAL CHECKS



CHECK AIRTIGHTNESS OF CABLES

PRESSURIZE at 40-70 BAR

CLOSED ENDED TERMINAL

SUBMERGE IN WATER

QUALITY CONTROL

CHECKING TOOLS that must be available at the site :

1. **EXERCISE SYRINGE (5 bar) for exercising new membranes and check airtightness.**
2. **CONTINUITY TESTER**
3. **L-SQUARE to check blade coaxiality.**
4. **FEELER GAGE 0.5 mm thick and RULER 15 mm long to check blade planarity.**
5. **TRIPOD with dial gage.**
6. **STOPWATCH for checking time to A and B, and for the dissipation tests.**

MAIN CHECKS

Checks on hardware

The main checks concern essentially the blade. Problems in cables and control box are generally self apparent.

1. **Verify that all blades at the site have ΔA , ΔB in tolerance :**

   ΔA = 0.05 to 0.30;   ΔB = 0.05 to 0.80 bar

2. **In the calibration configuration : Apply 10 cycles of push-pull to the syringe piston to verify sharpness of signal inversion (off-to-on and viceversa).**
3. **Using the 5 bar syringe verify airtightness in a bucket of water.**
4. **Using the tripod, verify proper elevation of sensing disc (0.04 to 0.07 mm above surrounding plane) and feeler (0.04 to 0.07 mm above disc).**

Checks during test execution

1. **Initial ΔA = 0.05 to 0.30 Initial ΔB = 0.05 to 0.80 bar (Note : ΔA, ΔB must be read at the lower gage of the control box).**
2. **A should be reached in 15-20 sec. B within 15-20 sec after A.**
3. **The change of ΔA or ΔB before-after a sounding must be $<$ 0.25 bar, otherwise the test must be discarded.**
4. **The C reading should be reached within 30 to 60 sec after starting the deflation.**

ACCEPTANCE VALUES OF Δ*A* & Δ*B*

(Eurocode 7, 1997)

<u>INITIAL Δ*A*, Δ*B*</u> (before inserting the blade) must be in the ranges :

- **Δ*A* = 5 to 30 kPa**
- **Δ*B* = 5 to 80 kPa**

If not, replace the membrane before testing.

<u>FINAL Δ*A*, Δ*B*</u> :

- **The change of Δ*A* or Δ*B* at the end of the sounding must be ≤ 25 kPa**

In not, test results must be discarded.

<u>TYPICAL VALUES OF Δ*A*, Δ*B*</u> :

- **Δ*A* = 15 kPa**
- **Δ*B* = 40 kPa**

IMPORTANCE OF ACCURATE Δ*A* & Δ*B*

- **Inaccurate Δ*A*, Δ*B* are virtually the <u>only potential source</u> of DMT instrumental error**
- **Any inaccuracy in Δ*A*, Δ*B* would propagate to all *A*, *B* of a sounding**
- **Accurate Δ*A*, Δ*B* are <u>necessary</u> in soft soils (≈ liquid clays or liquefiable sands) where *A*, *B* are just a bit higher than Δ*A*, Δ*B* (correction ≈ difference between similar numbers)**
- **Small inaccuracies in Δ*A*, Δ*B* are negligible in medium to stiff soils (Δ*A*, Δ*B* are a small part of *A*, *B*)**

<u>How Δ*A*, Δ*B* can go out of tolerance</u> :

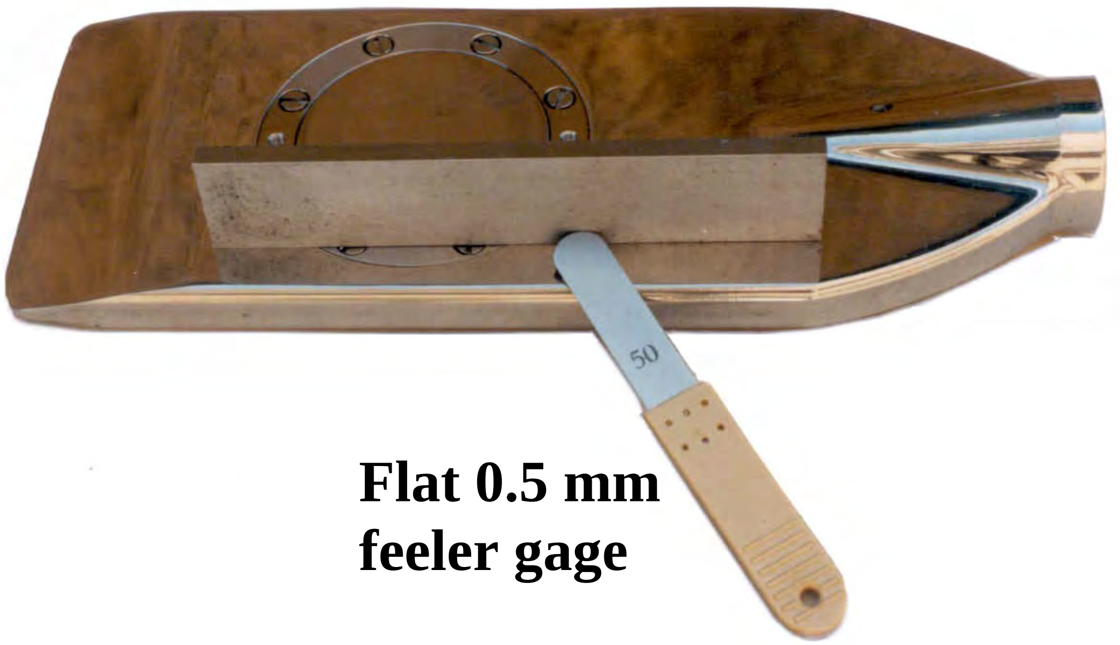
- ***<u>overinflating the membrane</u>* far beyond the *B*-position**

  (once overinflated a membrane requires excessive suction to close - Δ*A* > 30 kPa - even Δ*B* may be a suction)

PLANARITY CHECK

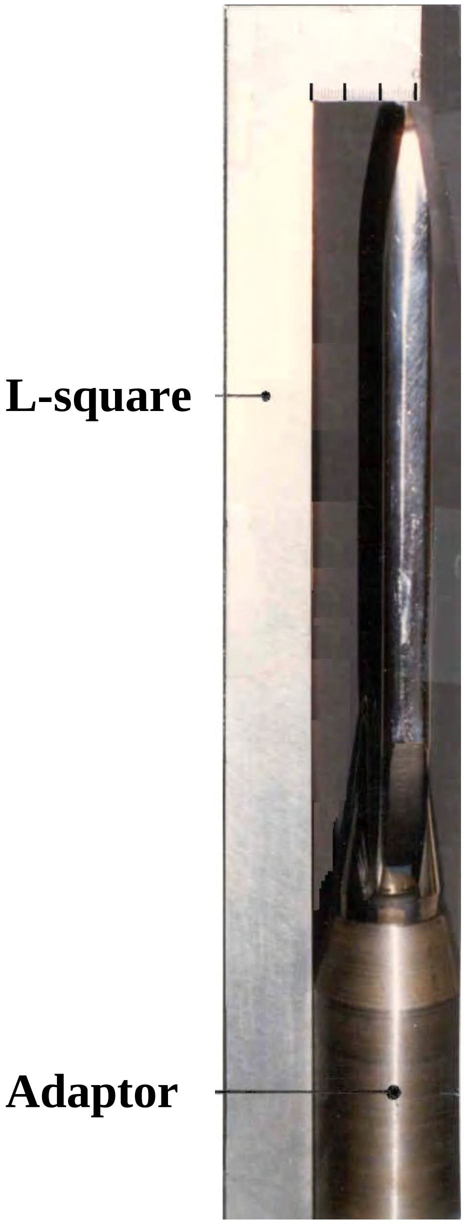
Place a 15 cm ruler against the face of the blade parallel to its long side.

The "sag" between the ruler and blade should not exceed 0.5 mm.



Flat 0.5 mm feeler gage

COAXIALITY CHECK
between blade and axis of the rods



With the *lower adaptor* mounted on the blade, place the inside edge of an L-square against the side of the adaptor.

Note the distance from the penetration edge of the blade to the side of the L-square.

Turn the blade 180° and repeat the measurement.

The difference between the two distances should not exceed 3 mm (corresponding to a coaxiality error of 1.5 mm).

DMT DATA FIELD FORM

Typical: 0.15 0.40

FIRM (max characters no.=32)	BLADE No. ↓		ΔA (bar) 0.05-0.20	ΔB (bar) 0.20-0.80	(1) Δmm	Membrane Aspect (2)
CUSTOMER (32)		Start				
JOB (32)		Z_E= (3)				
SITE (32)		Z_E=				
REMARK (32)		Z_E=				

TEST NAME (12) DATE (20)

Absol. elev.(optional) ______ m Z_{water} **(necess.)** ____ m or ☐ > Z_{final}

Zero of gauge ____________ bar γ_{top} ______ t/m³ (default 1.75)

(1) Coaxiality error (L square)
(2) Elastic, overinflated, wrinkled, snapping, scratched, etc.
(3) Depth reached from extracted blade

☐ Rig ☐ Penetrometer

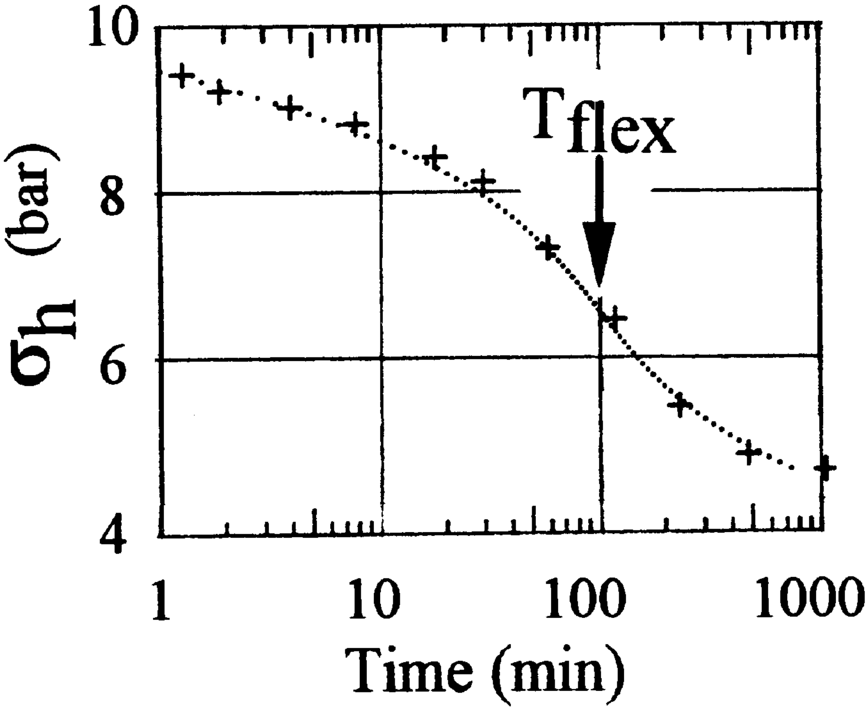
Diameter of rod behind the blade _______

TEST STOPPED BECAUSE → REFUSAL ☐ MEMBRANE † ☐ Z =Z prefixed ☐

OPERATOR ___________

0	A	B	C	6				12				18				24			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			
1				7				13				19				25			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			
2				8				14				20				26			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			
3				9				15				21				27			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			
4				10				16				22				28			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			
5				11				17				23				29			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8				8				8				8				8			

DISSIPATION TESTS



<u>DMT DISSIPATION (by all methods)</u> :

- **Stop the blade at a given depth**
- **Monitor the decay of the total contact horizontal stress σ_h with time**
- **Infer the coeff. of consolidation / permeability (c_h , k_h) from the rate of decay of σ_h**

IN CLAYS AND SILTS (not feasible in sandy silt, sand and gravel)

DMT-A DISSIPATION METHOD

RECOMMENDED METHOD

Timed sequence of *A*-readings (only *A* is taken, avoiding expansion to *B*)

(for other methods see TC16 2001)

DMT-A PROCEDURE

1) **Stop the blade at a given depth and start a stopwatch ($t = 0$ when pushing is stopped). Slowly inflate the membrane to take the *A*-reading. Vent the blade soon after *A*. Record *A*-value and stopwatch time at the instant of *A*-reading.**

2) **Continue to take additional *A*-readings e.g. by a factor 2 increase in time (0.5, 1, 2, 4, 8, 15, 30 etc. minutes after stopping the blade).**

3) **Plot in the field a preliminary *A–log t* diagram (usually S-shaped). Stop the dissipation when the *A–log t* curve has flattened sufficiently to clearly identify the time at contraflexure point t_{flex} (used for the interpretation).**

"DMT-A" FIELD DATA FORM

REG. ______

FIRM ____________________

JOB ____________________

SITE ____________________

DMT SOUNDING ________

DISSIPATION DEPTH Z_D ________ m

DATE ____________________

ZERO OF GAUGE _____ bar Z_w ________ m

PRE ΔA __________ bar ΔB ________ bar

POST ΔA __________ bar ΔB ________ bar

	Z (m)	A	B
Z_D−0.40			
Z_D−0.20			
Z_D			//////
Z_D+0.20			
Z_D+0.40			

DO NOT WRITE HERE

No. of readings ________

I_D _____ OCR _____ σ'_v ________ bar

F_{scale} ____________ bar

$Z_D - Z_W$ ________ m U_o ________ bar

TIME (hh:mm:ss)	Δt (min) suggested	real	DO NOT WRITE HERE	A (bar)
START __:__:__	0	0		DEFLATE IMMEDIAT. AFTER A
	0.5			
	1			
	2			
	4			
	8			
	15			
	30			
	1^h			
	2^h			
	4^h			
	8^h			
	16^h			
	t_f ______			A_f ____
	B_f ______			◁ Do not forget it !

NOTES

ACCURACY : Read A with maximum accuracy. Inflate very slowly approaching A.

ZERO TIME : Start stopwatch at the instant blade reaches Z_D

SEQUENCE : Suggested times need not to be followed strictly. If not, write actual times.

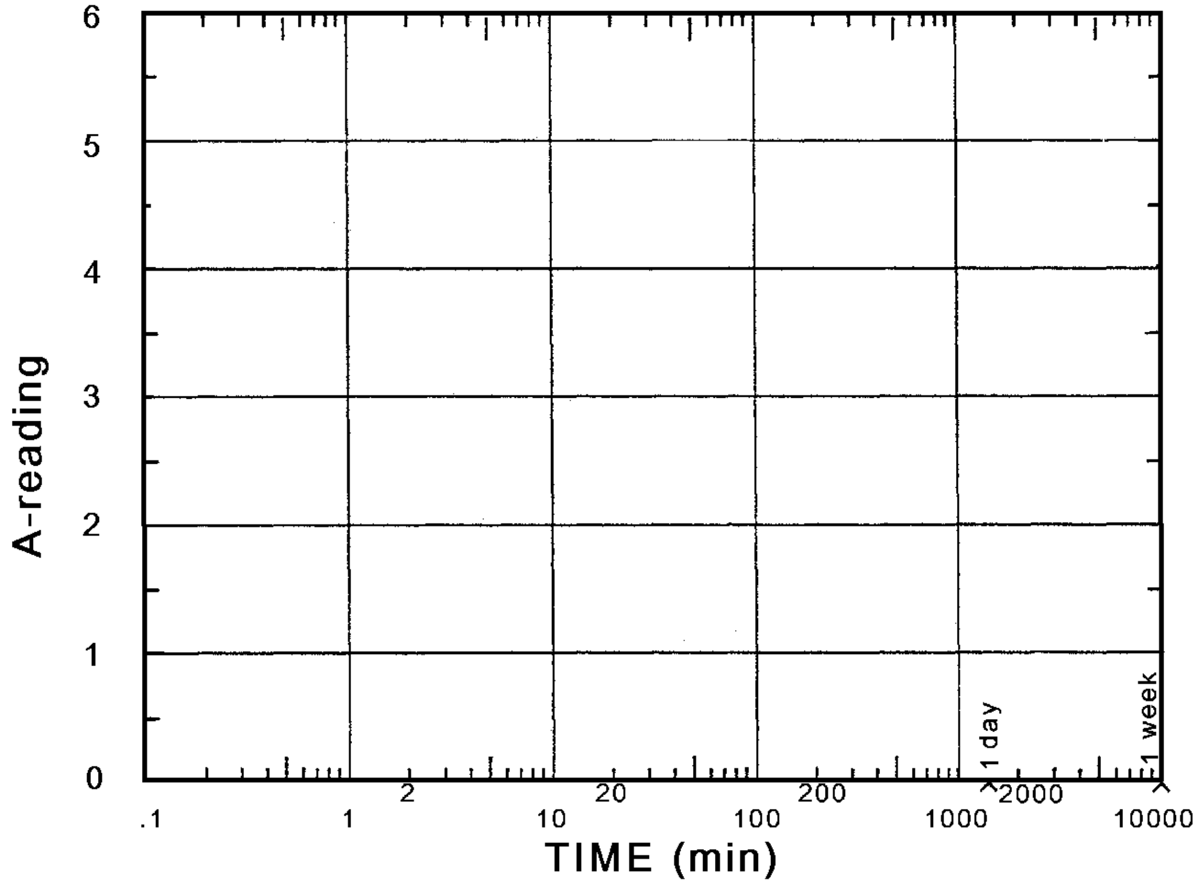
END : The test may be concluded a couple of readings after the inflection point of the A−log(t) curve has been identified.

FORM used in the FIELD to find out if INFLECTION POINT has been reached

DISSIPATION "DMTA"

SOUNDING ______ Z_D = _____m Date ________

Note : Adjust numbers of the vertical scale as required



C-READINGS IN SANDS

- **Besides "normal" *A* & *B* readings, a third reading *C* - *closing pressure* - can also optionally be taken by slowly deflating the membrane soon after *B* is reached.**
- **If the *C*-reading is to be taken, there is only one difference in the normal test sequence :**
  - **After *B*, open the *slow vent valve* instead of the fast *toggle vent valve* and wait ≈ 1 min until the pressure drops approaching the zero of the gage. At the instant the signal *returns* take the *C*-reading.**
- **Note that, in sands, the value to be expected for *C* is a low number (usually < 100 - 200 kPa, i.e. 10 or 20 m of water).**

Corrected *C*-reading

$$p_2 = C - Z_M + \Delta A$$

FREQUENT MISTAKE IN C-READINGS

- **After *B*, i.e. when the slow deflation starts, the signal is *on*. After some time the signal stops (from *on* to *off*). The mistake is to take the pressure at this inversion as *C*, which is incorrect (at this time the membrane is the *B*-position).**
- **The correct instant for taking *C* is some time later (≈ 1 min), when, completed the deflation, <u>the membrane returns to the "closed" *A*-position</u>, thereby contacting the supporting pedestal and reactivating the signal.**

FREQUENCE OF C-READINGS

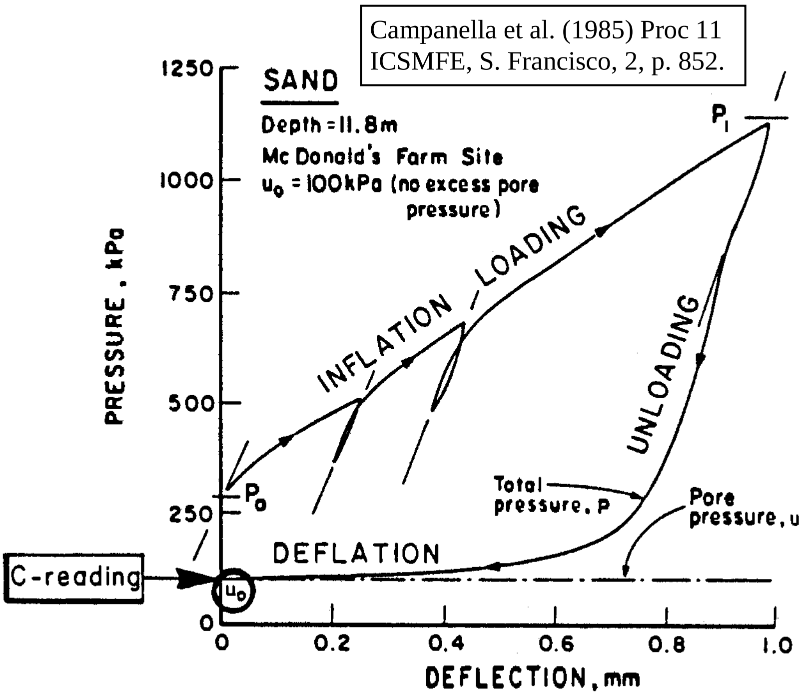
(a) SANDY SITES

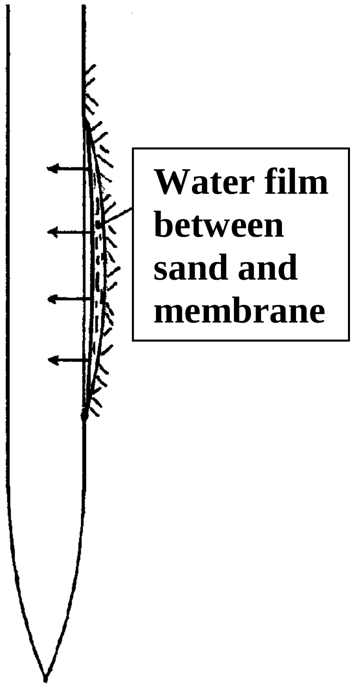
- **In sands ($B \geq 2.5\ A$) *C*-readings may be taken <u>sporadically</u>, say every 1 or 2 m, and are used to evaluate u_0 (equilibrium pore pressure) as $u_0 \approx p_2$**
- **Repeat the *A-B-C* cycle several times to insure that all cycles provide similar *C*-readings.**

(b) INTERBEDDED SANDS AND CLAYS

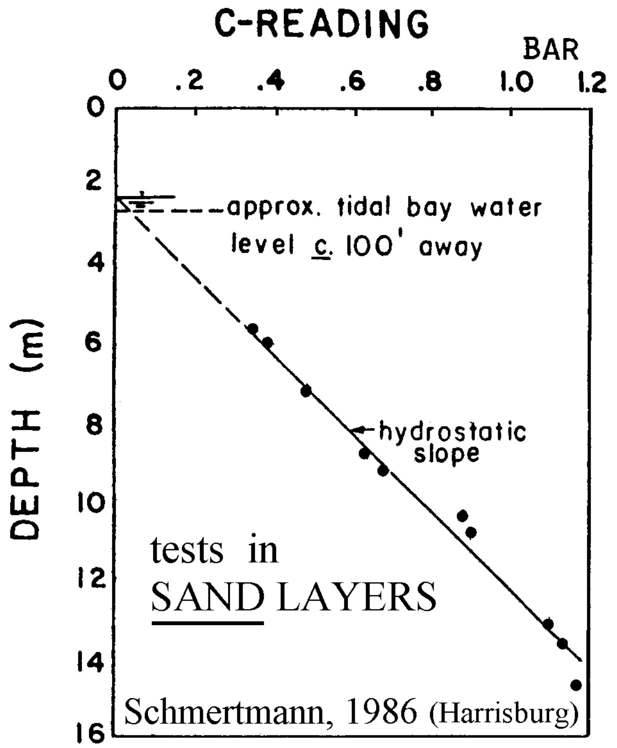
- **If the interest is limited to finding the u_0 profile, then *C*-readings are taken <u>in the sandy layers</u> ($B \geq 2.5\ A$), say every 1 or 2 m.**
- **When the interest, besides u_0, is to discern free-draining layers from non free-draining layers, then *C*-readings are taken <u>at each test depth</u>.**

C-READING (pressure on membrane at "membrane closure") in SAND = Uo





$\approx$ no contact Sand/Membrane $\Rightarrow$ $\sigma = \cancel{\sigma'} + Uo$



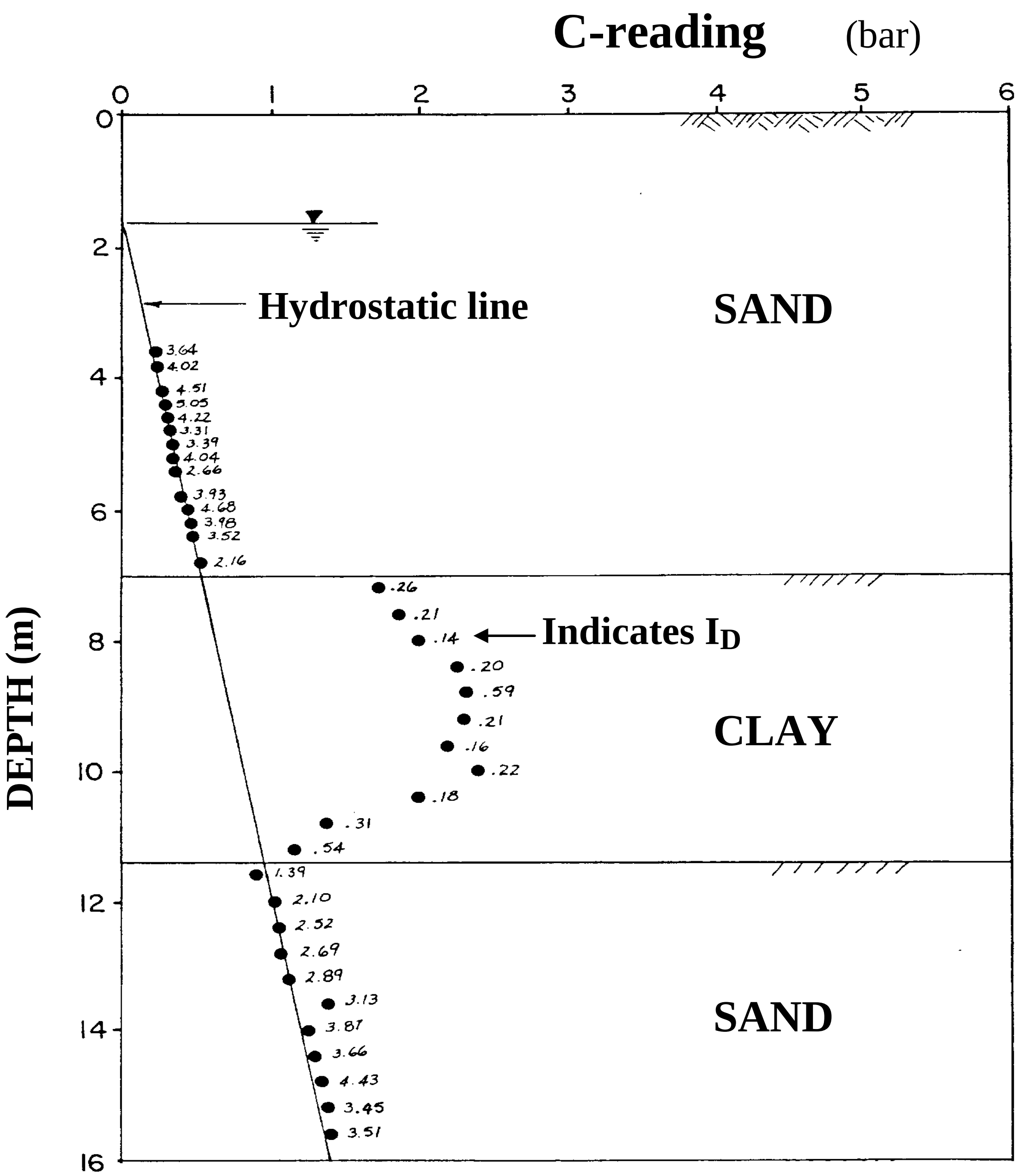
Same Uo as from a piezometer, without problems of :

- **Filter clog**
- **Smearing**
- **Saturation**

Schmertmann, J.H.S.(1986). Some 1985-86 Development in Dilatometer Testing and Analysis. Proc. PennDOT and ASCE Conf. on Geotechnical Engineering Practice, Harrisburg, PA.

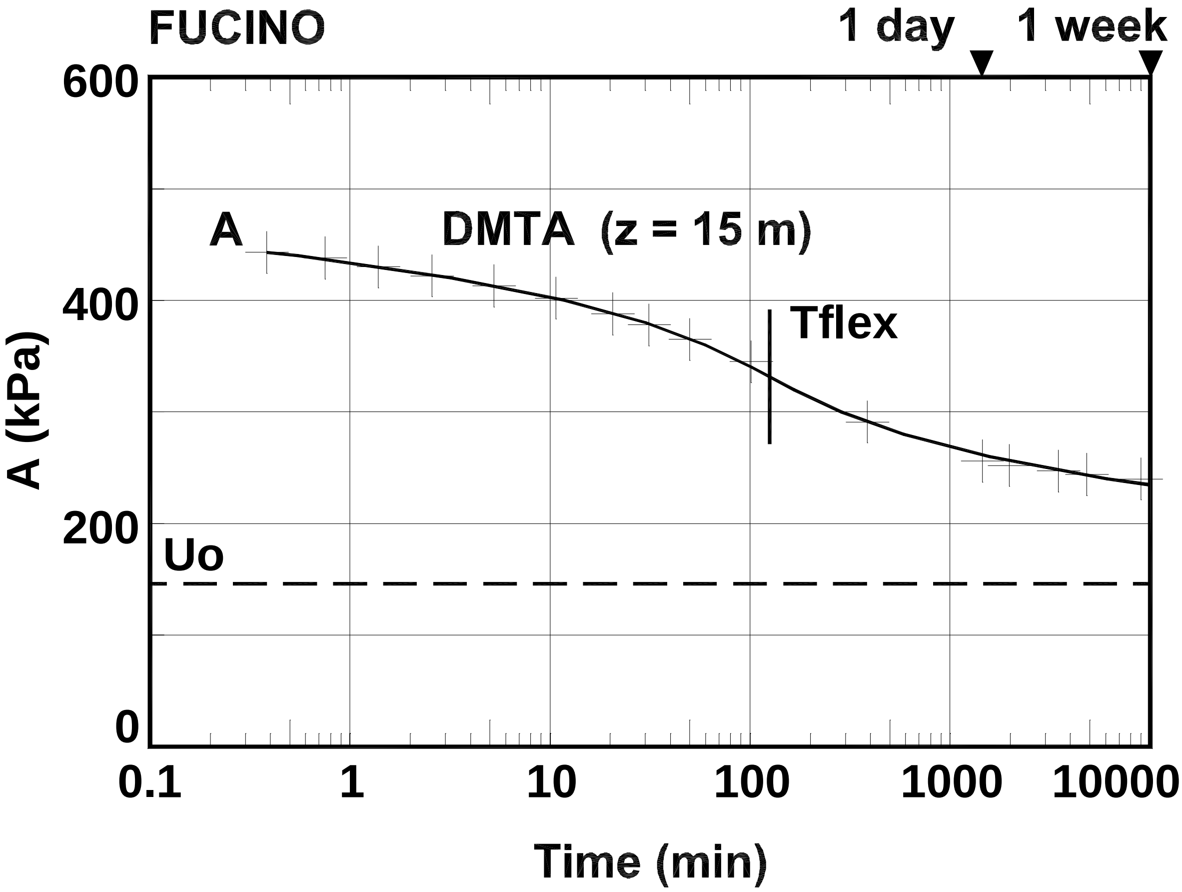
C-reading (P2)

- **in SANDS measures Uo (≈ piezometer)**
- **in CLAYS evidences Δu (i.e. non freely draining)**



Schmertmann, 1988 **(DMT Digest No. 10, May 1988, Fig.3)**

EXAMPLE OF DMT-A DECAY CURVE



$$C_h \cong \frac{7cm^2}{T_{flex}} \qquad k = \frac{C \cdot \gamma_w}{M}$$

ADVANTAGES of "DMT-A" DISSIPATION

- **Similarity to the well-established "<u>holding test</u>" by pressuremeter**
  - ***theory* for the DMT σ_h vs time decay curve not available yet (but expected similar)**
  - ***fixity* inherently insured for the DMT blade (solid object)**

- **No problems of filter smearing / clogging / loss of saturation**
  - **DMT membrane = non-draining boundary**
  - **what is monitored is a <u>*total* contact stress</u>**

- **Straightforward interpretation (no need to know u_o**
  - **Plot *A–log t* curve**
  - **Identify t_{flex}**
  - **Calculate $c_h \approx 7\ \text{cm}^2 / t_{flex}$**

BASIC DMT REDUCTION FORMULAE

p_0 and p_1	p_0	Corrected First Reading	$p_0 = 1.05(A - Z_M + \Delta A) - 0.05(B - Z_M - \Delta B)$
	p_1	Corrected Second Reading	$p_1 = B - Z_M - \Delta B$
Inter-mediate parameters	I_D	Material Index	$I_D = (p_1 - p_0) / (p_0 - u_0)$
	K_D	Horizontal Stress Index	$K_D = (p_0 - u_0) / \sigma'_{vo}$
	E_D	Dilatometer Modulus	$E_D = 34.7\,(p_1 - p_0)$
Interpreted parameters	K_0	Coeff. Earth Pressure in Situ	$K_{0,DMT} = (K_D / 1.5)^{0.47} - 0.6$
	OCR	Overconsolidation Ratio	$OCR_{DMT} = (0.5\,K_D)^{1.56}$
	c_u	Undrained Shear Strength	$c_{u,DMT} = 0.22\,\sigma'_{vo}\,(0.5\,K_D)^{1.25}$
	φ	Friction Angle	$\varphi_{safe,DMT} = 28 + 14.6 \log K_D - 2.1 \log^2 K_D$
	c_h	Coefficient of Consolidation	$c_{h,DMTA} \approx 7\,cm^2 / T_{flex}$
	k_h	Coefficient of permeability	$k_h = c_h\,\gamma_w / M_h$ $(M_h \approx K_0\,M_{DMT})$
	γ	Unit Weight and Description	(see chart)
	M	Vertical Drained Constrained Modulus	$M_{DMT} = R_M\,E_D$ if $I_D \le 0.6$ $R_M = 0.14 + 2.36 \log K_D$ if $I_D \ge 3$ $R_M = 0.5 + 2 \log K_D$ if $0.6 < I_D < 3$ $R_M = R_{M,0} + (2.5 - R_{M,0}) \log K_D$ where $R_{M,0} = 0.14 + 0.15(I_D - 0.6)$ If $K_D > 10$ $R_M = 0.32 + 2.18 \log K_D$ If $R_M < 0.85$ set $R_M = 0.85$
	U_0	Equilibrium pore pressure	$U_0 = p_2 \approx C - Z_M + \Delta A$

The complete set of formulae (+ chart) to run the computations : given as Table 1 and Fig. 16 in the TC16 reports (referenced above)

By such formulae, every user can write a relatively simple computer program, or use available ones.

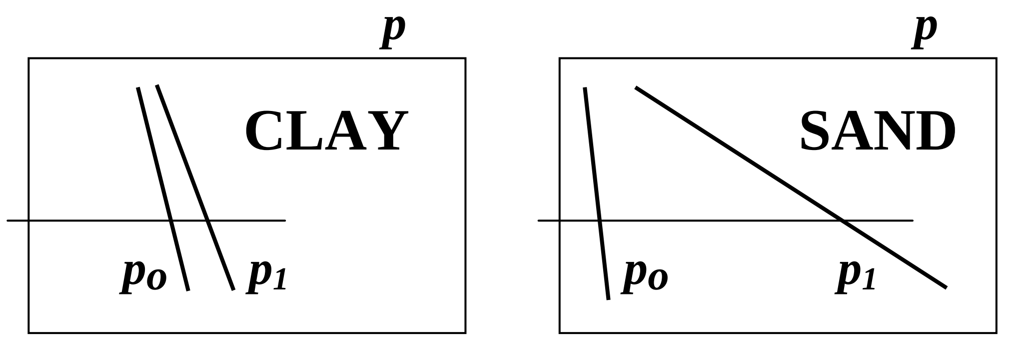
HOW TO USE A,B (Po ,P1

			STEP 1			**STEP 2**				
			CALCULATE INTERMEDIATE (OBJECTIVE)			**Convert Id Kd Ed to COMMON PARAMETERS (via CORRELATIONS)**				
Z	**Po**	**P1**	**Id**	**Kd**	**Ed**	**Ko**	**OCR**	**M**	**Cu**	**ϕ**
m	Bar	bar			bar			bar	bar	
1.0	1.1	3.3	1.87	6.3	73			151		38.3
1.2	1.3	1.8	.33	6.6	15	1.4	6.5	31	.19	
1.4	1.2	1.7	.37	5.7	15	1.3	5.1	29	.17	
1.6	1.2	1.6	.28	5.3	11	1.2	4.6	21	.16	
1.8	1.1	1.4	.21	4.6	8	1.1	3.6	13	.14	

- **Basic philosophy : evaluate familiar <u>parameters</u> (users can check vs other tests). Design via parameters.**
- **No correlations to *bearing capacity, foundations* etc.**
- **It is just mentioned here that M and Cu are generally the most useful and accurate parameters by DMT.**

Id - Material Index (soil type)

Whoever does DMT 1st time notes :



∴ came natural (apart theory) define Id as a "vicinity ratio"

$$I_d = (P_1 - P_o)/(P_o - U_o)$$

Experience has shown

- **Id v. sensitive, 0.1 to 10 (2 log cycles)**

0.1 — 0.6 — 1.8 — 10

CLAY	SILT	SAND
0.1 – 0.6	0.6 – 1.8	1.8 – 10

- **Like FR in CPT <u>but</u> : amplified, highly reproducible**
- **Not primary scope, but a nice extra - generally reliable**
- **I_D not result of sieve analysis, but from mechanical response (≈ *rigidity index*)**
- **Eg clay + sand described by I_D as *silt* ⇒ behaves mechanically as... (incorrect for grain size, + relevant mechanical behavior)**
- **If interest in permeability, (besides I_D) other index U_D**

AUTOMATIC ACQUISITION for DMT

Little stimulus. Numbers are few, 1 every ≈ 30 sec. Operator can easily write in dead time between operations (in CPT-U is a necessity, huge quantity. of data)

Speed (productivity) not improved by acquisition, nor quality.

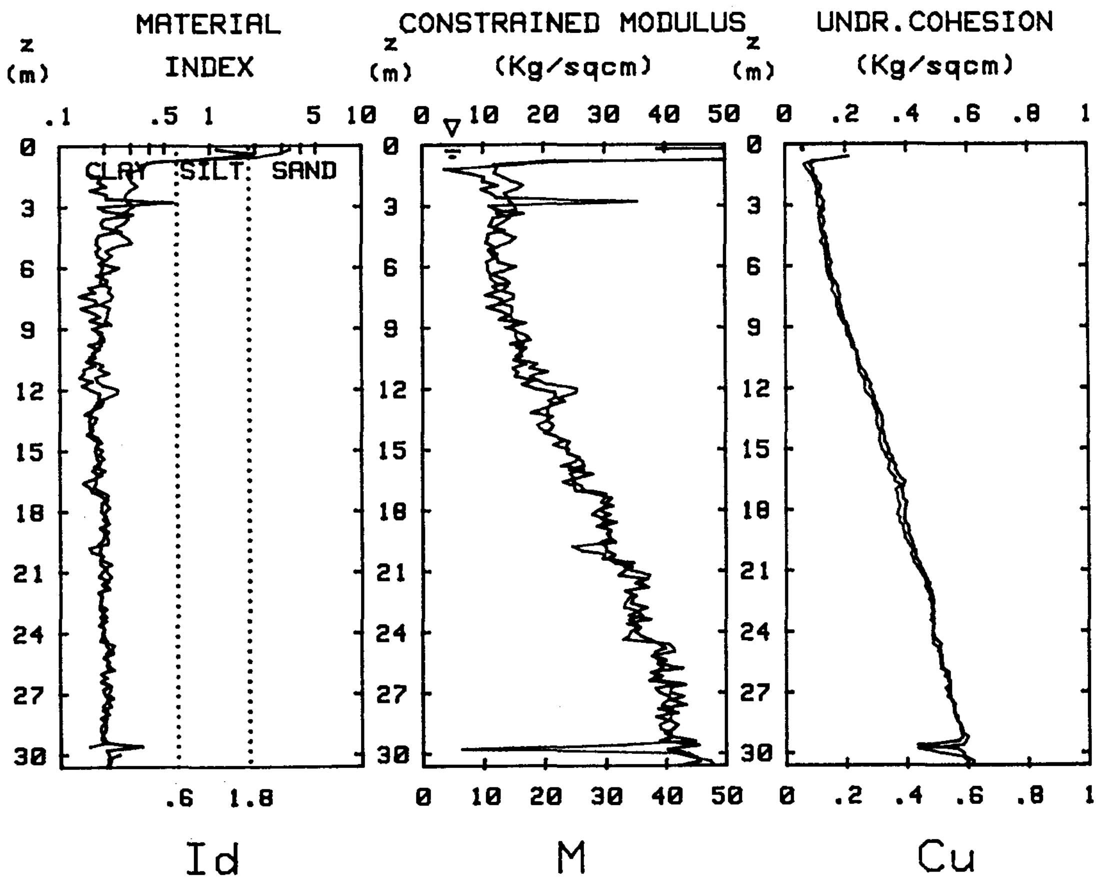
Little problem re-type in office, "few" numbers. Any secretary.

Is requested nowadays mostly for quality control checks, easier when everything is recorded.

Various users have developed automatic systems. Cost/weight dropping every day

REPRODUCIBILITY of DMT

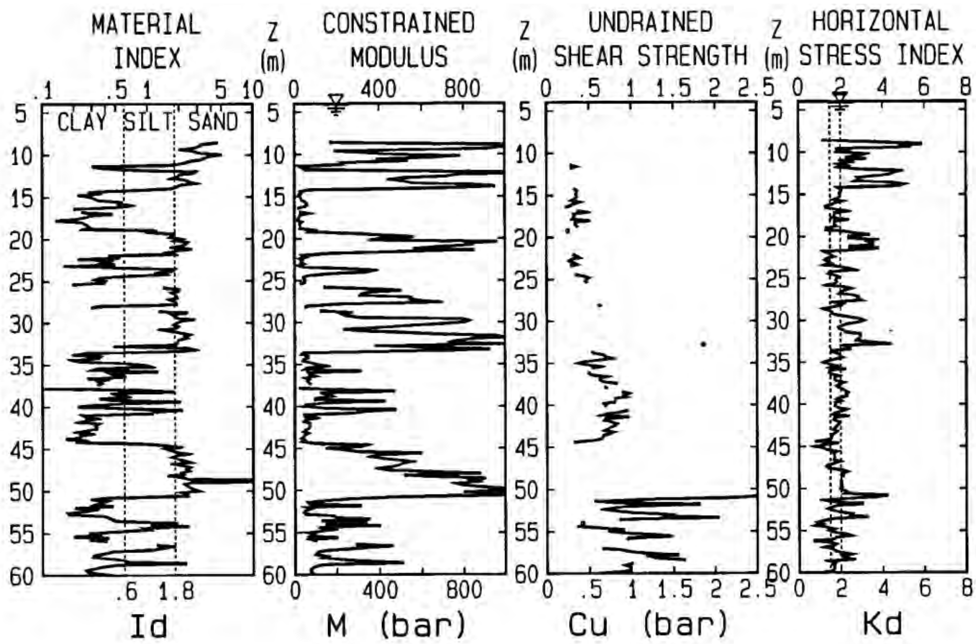
Performed by 4 alternating operators: Cestari (SGI), Lacasse (NGI), Lunne (NGI), Marchetti (Aq)



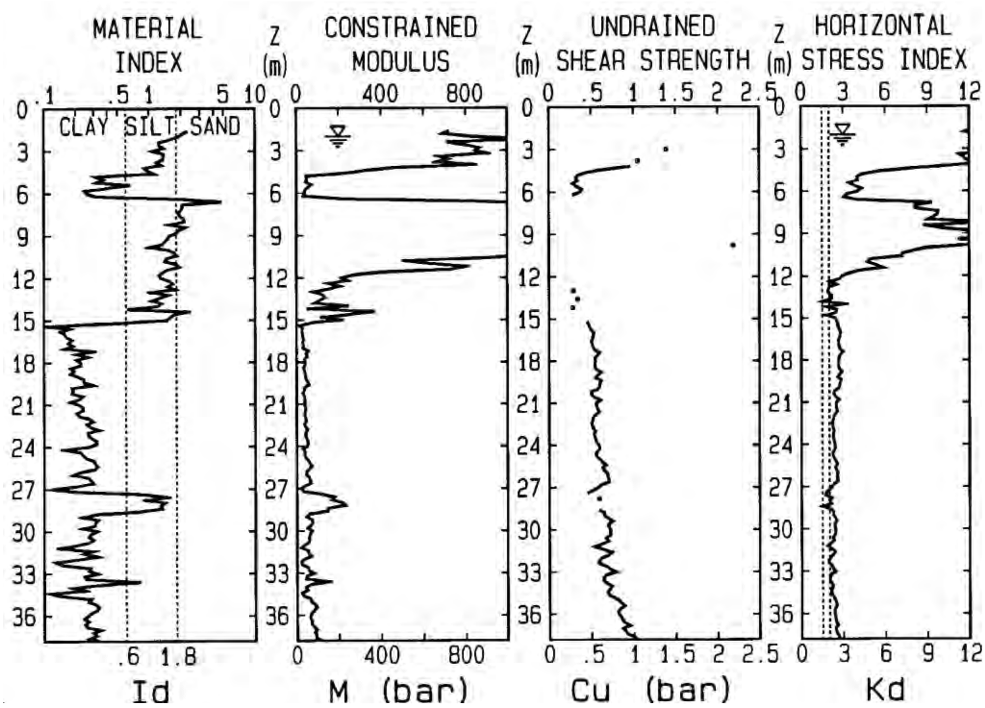
Marine NC sensitive clay
(Onsoy, Norway)

Examples of DMT results in NC sites ($K_D \approx 2$)

VENEZIA LIDO

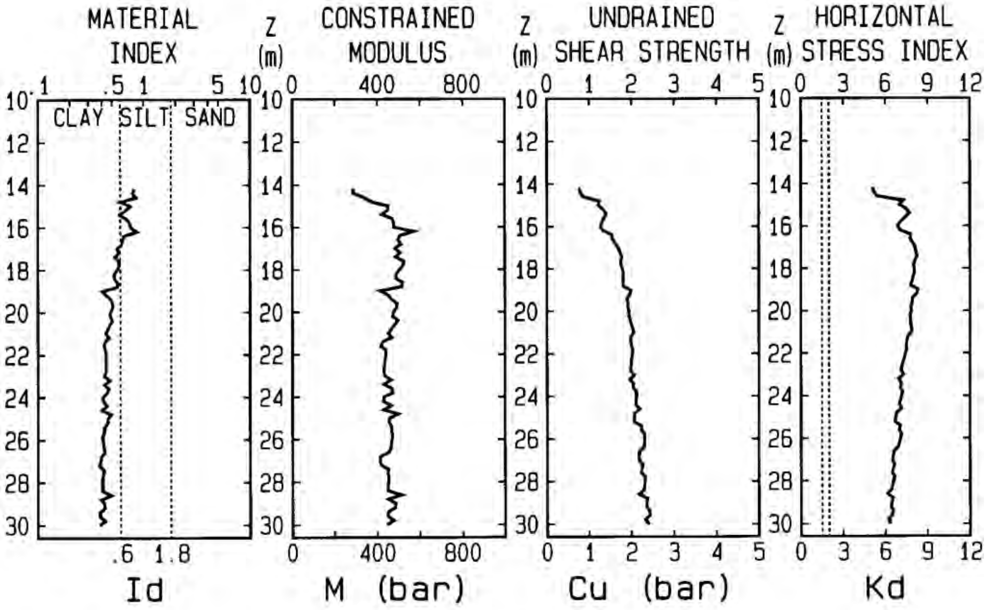


STAGNO LIVORNO

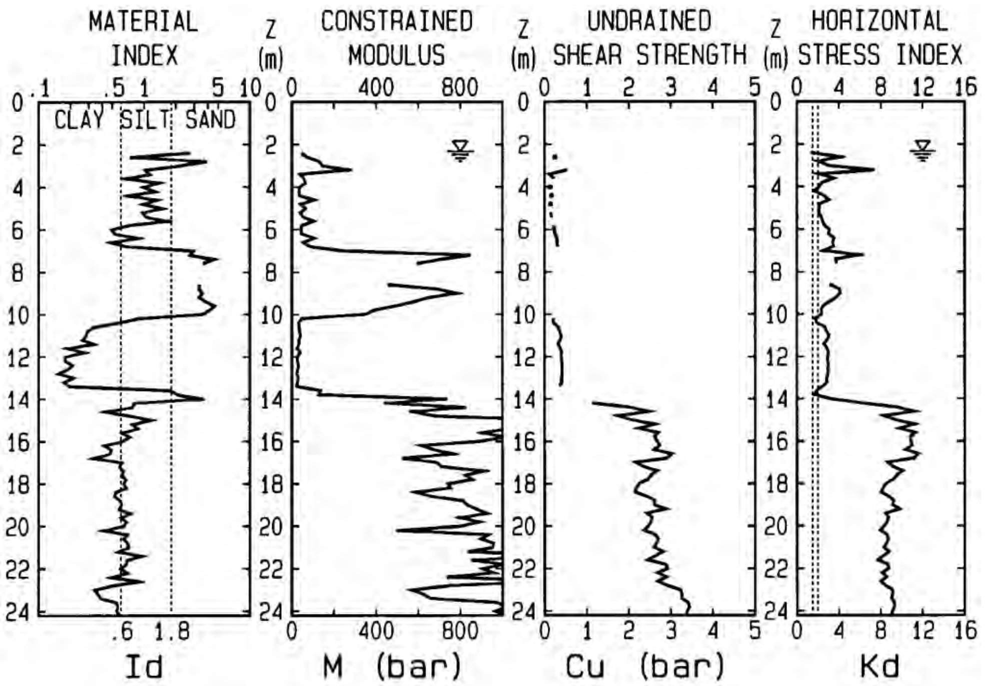


Examples of DMT results in OC sites (K_D >> 2)

AUGUSTA



TARANTO



INPUT DATA - REDUCTION BY COMPUTER

DATA SHEET WITH RESULTS

REG 9334 Typical: 0.15 0.40

			ΔA (bar) 0.05-0.20	ΔB (bar) 0.20-0.80	Δmm [(1)]	Membrane Aspect [(2)]
FIRM (max characters no.=32)	GEOTEST	BLADE No. ↓				
CUSTOMER (32)	NEW HARBOUR	Start	0.20	0.67		
JOB (32)	LIVORNO	Z_E= (3)	0.24	0.63		
SITE (32)	WEST QUAY	Z_E=				
REMARK (32)	/	Selected	.22	.65		

TEST NAME (12) D1 DATE (20) 8 AUG 1998

Absol. elev.(optional) 0 m Z_{water} (necess.) 1 m or ☐ > Z_{final}

Zero of gauge 0 bar γ_{top} 1.75 t/m³ (default 1.75)

(1) Coaxiality error (L square)
(2) Elastic, overinflated, wrinkled, snapping, scratched, etc.
(3) Depth reached from extracted blade

☐ Rig ☐ Penetrometer

Diameter of rod behind the blade ______

TEST STOPPED BECAUSE ➔ REFUSAL ☐ MEMBRANE † ☐ Z = Z prefixed ☐

OPERATOR ______

0	A	B	C	6				12				18				24			
2				2				2				2				2			
4				4				4				4				4			
6				6				6				6				6			
8	7.4	22.1		8				8				8				8			
1	4.65	15.7		7				13				19				25			
2	3.45	13.1		2				2				2				2			
4	2.82	10.7		4				4				4				4			
6	2.08	8.8		6				6				6				6			
8	1.45	5.45		8				8				8				8			
2	1.15	4.08		8				14				20				26			
2	1	2.15		2				2				2				2			
4	1.1	2.65		4				4				4				4			
6	3.18	15.1		6				6				6				6			
8	4.22	15.3		8				8				8				8			
3	4.4	14.8		9				15				21				27			
2	3.61	11.4		2				2				2				2			
4	2.55	11.1		4				4				4				4			
6	3.31	12.1		6				6				6				6			
8	1.45	6.05		8				8				8				8			
4	2.1	7.15		10				16				22				28			
2	4.08	12.2		2				2				2				2			
4	2.58	9.1		4				4				4				4			
6	2.35	5.45		6				6				6				6			
8	1.45	6.75		8				8				8				8			
5	1.65	2.75		11				17				23				29			
2	—	—		2				2				2				2			

PROGRAM FOR DATA REGISTRATION

The program initially prompts for the headings

```
FILE  NUMBER   9334

A1$       = GEOTEST                   ZW     =
A2$       = NEW HARBOUR               ZI     =
A3$       =                           ZF     =
A4$       =                           ZABS   =
A5$       =                           GAMTOP =
NAMETEST$ =                           ZM     =
DAY$      =                           DELTAA =
STEPZ     =                           DELTAB =
                                      N      =

A2$?            (MAX 32 CHAR,UPPER RIGHT)
NEW HARBOUR    (enter)                           MENU
```

Once the headings are entered, the program prompts for the readings A,B at each depth

```
FILE  NUMBER   9334

A1$       = GEOTEST                    ZW     =  1.00
A2$       = NEW HARBOUR                ZI     =  0.80
A3$       = LIVORNO                    ZF     =  5.00
A4$       = WEST QUAY                  ZABS   =  0.00
A5$       =                            GAMTOP =  1.75
NAMETEST$ = D1                         ZM     =  0.00
DAY$      = 8 AUG 1998                 DELTAA =  0.22
STEPZ     =  .2                        DELTAB =  0.65
                                       N      = 21.00

  Z          A         B
0.80        7.40      22.10
1.00        4.65      15.70
1.20        3.45      13.10

A (bar)  at    1.40 m ?
2.82   (enter)                      MENU      Z
```

FILE 09334.DAT OPENED by NOTEPAD and printed DIRECTLY

```
.8,5,21,.22,.65,34.7,0,1,0,1.75,.2
"GEOTEST","NEW HARBOUR"
"LIVORNO","WEST QUAY",""
"8 AUG 1998","D1"
740,2210
465,1570
345,1310
282,1070
208,880
145,545
115,408
100,215
110,265
318,1510
422,1530
440,1480
361,1140
255,1110
331,1210
145,605
210,715
408,1220
258,910
235,545
145,675
165,275
```

STRUCTURE of FILES .DAT (with example)

(Usually generated by the program **REG** , but can be written directly as text)

	FILE 09334.DAT	MEANING	COMMENTS
11 numbers	.8	1. Zinitial (m)	**Item 3 (N)**
	5	2. Zfinal (m)	N = Nrows – 1. In general
	21	3. N (integer)	N=(Zfinal – Zinitial)/Stepz.
	.22	4. DeltaA (bar)	If Stepz=0.2 then
	.65	5. DeltaB (bar)	N=5x(Zfinal – Zinitial)
	34.7	6. Factored (34.7 for s=1.1 mm)	In this case N=5x(5-0.8)=21
	0	7. Zm (zero offset of gage, bar)	
	1	8. Zw (m) (waterdepth below GL)	**Item 7 (Zm)**
	0	9. Zabs (m)	Usually zero
	1.75	10. Gamtop (Gamnat/Gamwater)	
	.2	11. Stepz (m) usually 0.2)	**Item 9 (Zabs)**
			Usually zero
7 strings	"GEOTEST"	12. Description1$	
	"NEW Harbour"	13. Description2$	**Item 10 (Gamtop)**
	"LIVORNO"	14. Description3$	Usual in the range 1.5 to 2.4
	"WEST QUAY "	15. Description4$	
	""	16. Description5$	**Items 12-18**
	"8 AUG 1998"	17. Day$	The 7 strings are enclosed in """"
	"D1"	18. Nametest$	
			Item 16 (Description5$**)**
22 rows	740,2210	1. A,B in kPa (1 bar=100 kPa)	Usually left blank
	465,1570	2. A,B	
	345,1310	3. A,B	
	282,1070	4. A,B	**Pairs of A,B**
	208,880	5. A,B	The pairs of A,B are comma separated.
	145,545	6. A,B	
	115,408	7. A,B	Values of A,B start at Zinitial and end at Zfinal, at the interval Stepz (usually 2 m)
	100,215	8. A,B	
	110,265	9. A,B	
	318,1510	10. A,B	Missing values of A and/or B are input as 0.
	422,1530	11. A,B	
	440,1480	12. A,B	As a check, the number of rows of pairs A,B is equal to N+1 (in this case 21+1=22).
	361,1140	13. A,B	
	255,1110	14. A,B	
	331,1210	15. A,B	
	145,605	16. A,B	
	210,715	17. A,B	
	408,1220	18. A,B	
	258,910	19. A,B	
	235,545	20. A,B	
	145,675	21. A,B	
	165,275	22. A,B	

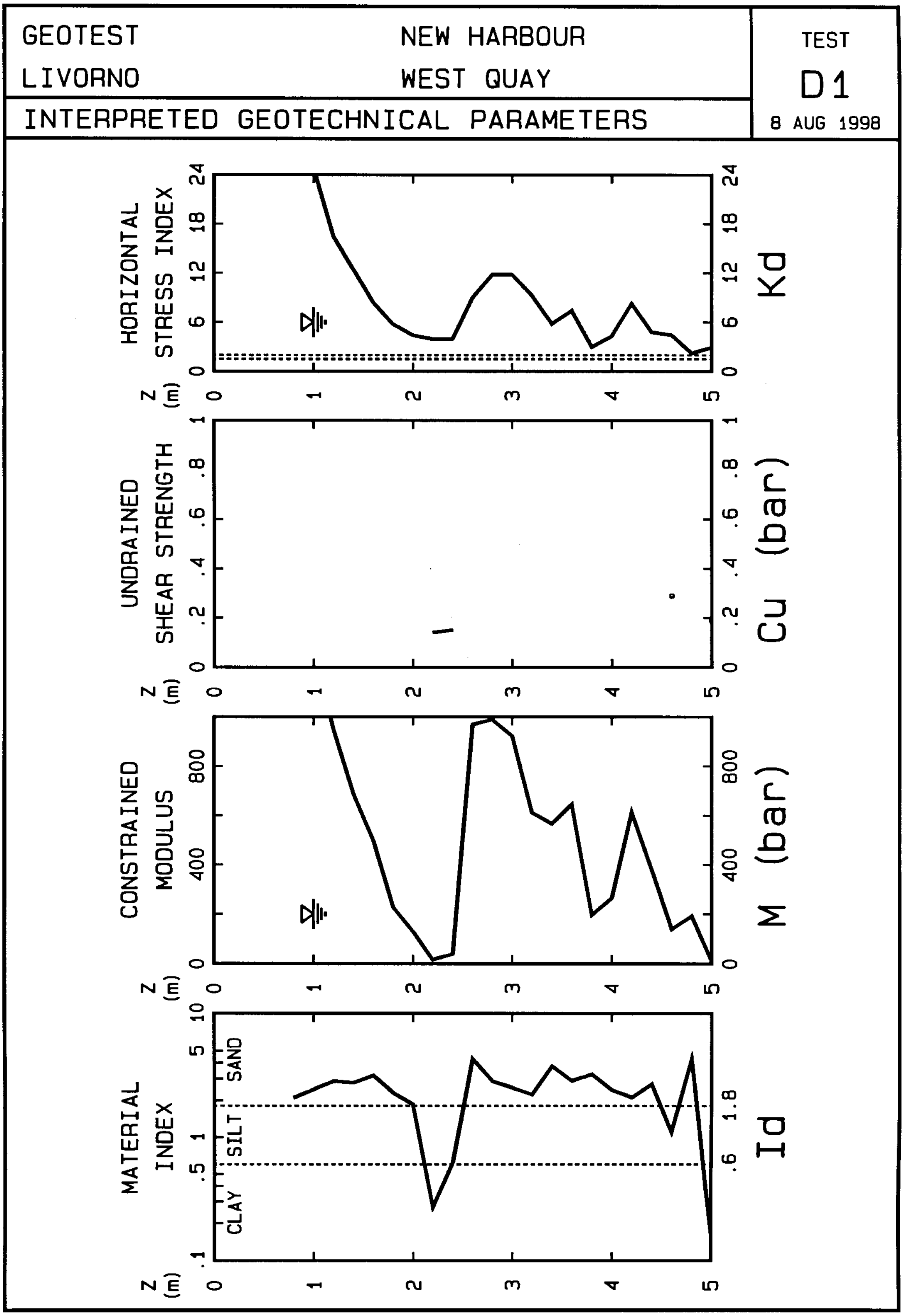
NOTES on STRUCTURE of FILES .DAT

- There are 18 variables (11 numerical + 7 strings), then the pairs of values A and B (A,B in KPa) taken at each depth. See attached example 09334.DAT.
- Normally the file .DAT is generated the program **REG** by answering the questions of the guided input. A file .DAT can alternatively be written directly as a text file using any text editor (e.g. EDIT of DOS or NOTEPAD) following exactly the sequence in the attached example. Variables must be separated by commas or end-of line (LF+CR). The strings must be enclosed in "". The variables can be written one per line or some of them can be grouped in the same line, separated by commas.
- A warning concerning N and Stepz.
  N is not an independent number, but is dependent on the variables alraedy included in the input. It is in fact N = (Zfinal-Zinitial)/Stepz. E.g. in the frequent case Stepz = 0.2, N=5*(Zfinal-Zinitial).
  It should be noted that N is NOT the number (Nrows) of depths at which pairs of A,B have been taken, but it is smaller by 1, i.e. N=Nrows-1 (this difference is due to the fact that N is the final value of the index I of the vectors A(I) and B(I), and I starts from zero). For instance in the attached example the number of lines of pairs A,B is Nrows=22, while N=21.
- In some cases A,B are taken at irregular depth intervals. In this case Stepz must be entered as zero (Stepz=0). Stepz=0 will cause the REG program to ask (and later record), in addition to A and B, also the depth Z (in cm). The resulting file will differ from the attached example for 2 differences : (1) Stepz=0 (2) Each line of readings (after the initial 18 variables) is made of 3 numbers : A,B,Z (Z in cm). Even this type of file can be written directly without using REG. Both programs REG and ELAB handle both types of files, because, once they read the value of Stepz, they know if they are going to read A,B or A,B,Z.
- Since N is not an independent number, if the file .DAT is composed using a text editor, N must be input correctly, otherwise both the program REG and the program ELAB will signal an error. The rules for computing the right N are repeated here :
  -If Stepz>0 (readings at a constant depth interval) then N = (Zfinal-Zinitial)/Stepz
  -If Stepz=0 (irregular intervals) then N=Nrows-1 (where Nz is the number of depths for which A,B,Z are given).
- If the file .DAT is composed using a text editor, it is advisable to cross check that N is correct. To do this, load it with the program REG and print the preliminary output. Such output also permits to insure the absence of negative Ed.
- It is reminded that the names of a file .DAT is a 5-digit number followed by the extension .DAT (example 09334.DAT). However when the programs REG or ELAB ask for the registration number of a test, just input 9334 (leave out leading zeros and extension). The program will add them when assigning the name
- Corrections : A file .DAT can be corrected with ease using the input program. However it can be edited equally well, maybe faster, using e.g. EDIT of DOS or NOTEPAD.

PRELIMINARY OUTPUT to CHECK INPUT DATA (and all E_D POSITIVE)

```
FILE  NUMBER   9334
A1$       = GEOTEST                            ZW       =   1.00
A2$       = NEW HARBOUR                        ZI       =   0.80
A3$       = LIVORNO                            ZF       =   5.00
A4$       = WEST QUAY                          ZABS     =   0.00
A5$       =                                    GAMTOP   =   1.75
NAMETEST$ = D1                                 ZM       =   0.00
DAY$      = 8 AUG 1998                         DELTAA   =   0.22
STEPZ     =  .2                                DELTAB   =   0.65
                                               N        =  21.00

 Z in m       A , B , Ed in bar

Z=  0.80      A(0) =7.400      B(0) = 22.100      Ed= 503.9

Z=  1.00      A(1) =4.650      B(1) = 15.700      Ed= 370.9
Z=  1.20      A(2) =3.450      B(2) = 13.100      Ed= 319.9
Z=  1.40      A(3) =2.820      B(3) = 10.700      Ed= 255.4
Z=  1.60      A(4) =2.080      B(4) =  8.800      Ed= 213.1
Z=  1.80      A(5) =1.450      B(5) =  5.450      Ed= 114.0

Z=  2.00      A(6) =1.150      B(6) =  4.080      Ed=  75.1
Z=  2.20      A(7) =1.000      B(7) =  2.150      Ed=  10.2
Z=  2.40      A(8) =1.100      B(8) =  2.650      Ed=  24.8
Z=  2.60      A(9) =3.180      B(9) = 15.100      Ed= 402.6
Z=  2.80      A(10)=4.220      B(10)= 15.300      Ed= 372.0

Z=  3.00      A(11)=4.400      B(11)= 14.800      Ed= 347.2
Z=  3.20      A(12)=3.610      B(12)= 11.400      Ed= 252.1
Z=  3.40      A(13)=2.550      B(13)= 11.100      Ed= 279.8
Z=  3.60      A(14)=3.310      B(14)= 12.100      Ed= 288.6
Z=  3.80      A(15)=1.450      B(15)=  6.050      Ed= 135.9

Z=  4.00      A(16)=2.100      B(16)=  7.150      Ed= 152.3
Z=  4.20      A(17)=4.080      B(17)= 12.200      Ed= 264.2
Z=  4.40      A(18)=2.580      B(18)=  9.100      Ed= 205.9
Z=  4.60      A(19)=2.350      B(19)=  5.450      Ed=  81.3
Z=  4.80      A(20)=1.450      B(20)=  6.750      Ed= 161.4

Z=  5.00      A(21)=1.650      B(21)=  2.750      Ed=   8.4


Edmin =   8.38 (aZ=  500 m)  (POSITIVE , OK)
```

GRAPHICAL OUTPUT



TABULAR OUTPUT

GEOTEST　　　D M T : D1 - 8 AUG 1998　　　Reg 9334

NEW HARBOUR　　　LIVORNO
WEST QUAY

WATERTABLE m 1

Reduction formulae according to ASCE Geot.Jnl.,Mar. 1980, Vol.109, 299-321
NOTE : OCR = ''relative OCR''. OCR below often reasonable. Accuracy can be improved if precise OCR values are available. Then factorize all OCR below by the ratio OCRreference/OCR

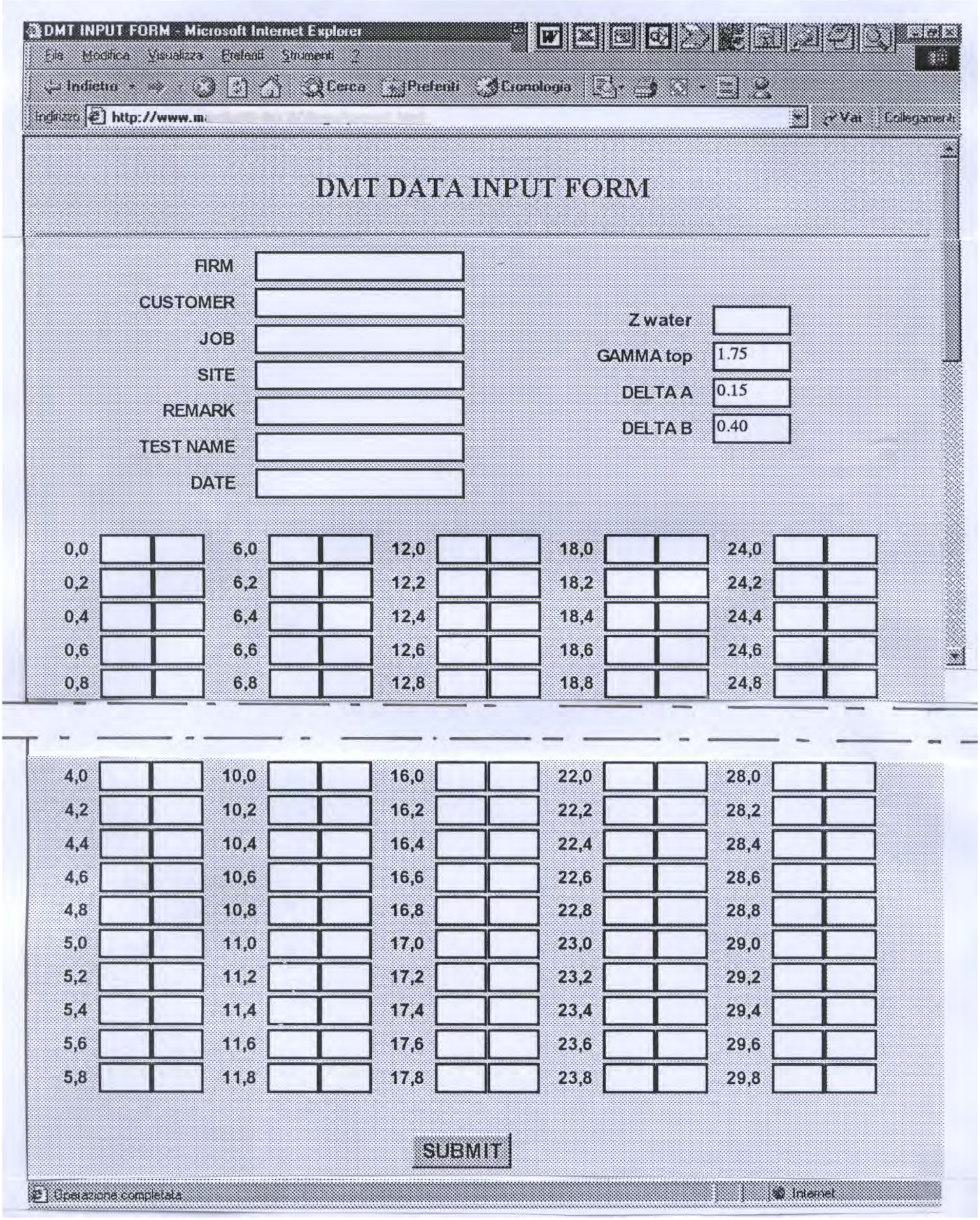
Po	= Corrected A reading	bar
P1	= Corrected B reading	bar
Gamma	= Bulk unit weight/GammaH2O	(-)
Sigma'	= Effective overb. stress	bar
U	= Pore pressure	bar
Id	= Material Index	(-)
Kd	= Horizontal stress index	(-)
Ed	= Dilatometer modulus	bar

INTERPRETED GEOTECHNICAL PARAMETERS

Ko	= In situ earth press. coeff.	(-)
Ocr	= Overconsolidation ratio	(-)
Phi	= Safe floor value of friction angle	(-)
M	= Constrained modulus (at Sigma')	bar
Cu	= Undrained shear strength	bar

Z (m)	Po	P1	Gamma	Sigma'	U	Id	Kd	Ed	Ko	Ocr	Phi	M	Cu	DESCRIPTION
0.80	6.9	21.4	2.00	0.14	0.00	2.10	50.4	504			47	2032		SILTY SAND
1.00	4.4	15.0	2.00	0.18	0.00	2.45	24.7	371			44	1245		SILTY SAND
1.20	3.2	12.4	1.90	0.20	0.02	2.87	16.4	320			43	949		SILTY SAND
1.40	2.7	10.1	1.90	0.21	0.04	2.78	12.4	255			41	690		SILTY SAND
1.60	2.0	8.1	1.90	0.23	0.06	3.15	8.4	213			40	501		SILTY SAND
1.80	1.5	4.8	1.80	0.25	0.08	2.29	5.8	114			38	228		SILTY SAND
2.00	1.3	3.4	1.70	0.26	0.10	1.85	4.4	75			37	130		SILTY SAND
2.20	1.2	1.5	1.50	0.28	0.12	0.27	3.9	10	0.97	2.8		16	0.14	MUD
2.40	1.3	2.0	1.60	0.29	0.14	0.62	4.0	25	0.98	2.9		39	0.15	CLAYEY SILT
2.60	2.8	14.4	1.90	0.30	0.16	4.31	9.0	403			40	968		SAND
2.80	3.9	14.6	1.90	0.32	0.18	2.86	11.8	372			41	989		SILTY SAND
3.00	4.1	14.1	1.90	0.34	0.20	2.54	11.8	347			41	922		SILTY SAND
3.20	3.5	10.8	1.90	0.35	0.22	2.22	9.3	252			40	612		SILTY SAND
3.40	2.4	10.4	1.90	0.37	0.24	3.75	5.8	280			38	567		SAND
3.60	3.1	11.4	1.90	0.39	0.26	2.89	7.4	289			39	646		SILTY SAND
3.80	1.5	5.4	1.80	0.41	0.27	3.24	3.0	136			34	197		SILTY SAND
4.00	2.1	6.5	1.80	0.42	0.29	2.42	4.3	152			36	264		SILTY SAND
4.20	3.9	11.6	1.90	0.44	0.31	2.10	8.3	264			40	614		SILTY SAND
4.40	2.5	8.4	1.90	0.46	0.33	2.72	4.8	206			37	381		SILTY SAND
4.60	2.5	4.8	1.70	0.47	0.35	1.11	4.5	81	1.1	3.5		138	0.28	SILT
4.80	1.4	6.1	1.80	0.49	0.37	4.32	2.2	161			33	192		SAND
5.00	1.9	2.1	1.50	0.50	0.39	0.16	2.9	8	0.77	1.8		10	0.18	MUD

Z (m) Po P1 Gamma Sigma' U Id Kd Ed Ko Ocr Phi M Cu DESCRIPTION


DMT INPUT FORM - Microsoft Internet Explorer

File Modifica Visualizza Preferiti Strumenti ?

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Vai Collegamenti

DMT DATA INPUT FORM

FIRM

CUSTOMER

JOB

SITE

REMARK

TEST NAME

DATE

Z water

GAMMA top 1.75

DELTA A 0.15

DELTA B 0.40

0,0	6,0	12,0	18,0	24,0
0,2	6,2	12,2	18,2	24,2
0,4	6,4	12,4	18,4	24,4
0,6	6,6	12,6	18,6	24,6
0,8	6,8	12,8	18,8	24,8
4,0	10,0	16,0	22,0	28,0
4,2	10,2	16,2	22,2	28,2
4,4	10,4	16,4	22,4	28,4
4,6	10,6	16,6	22,6	28,6
4,8	10,8	16,8	22,8	28,8
5,0	11,0	17,0	23,0	29,0
5,2	11,2	17,2	23,2	29,2
5,4	11,4	17,4	23,4	29,4
5,6	11,6	17,6	23,6	29,6
5,8	11,8	17,8	23,8	29,8

SUBMIT

Operazione completata

Internet