Universidade de Coimbra

Universidade do Minho

Guimarães, Coimbra October 16th and 17th 2015

THE MENARD PRESSUREMETER : history, equipment, new developments, installation procedures, design rules and methods

Menard matériels

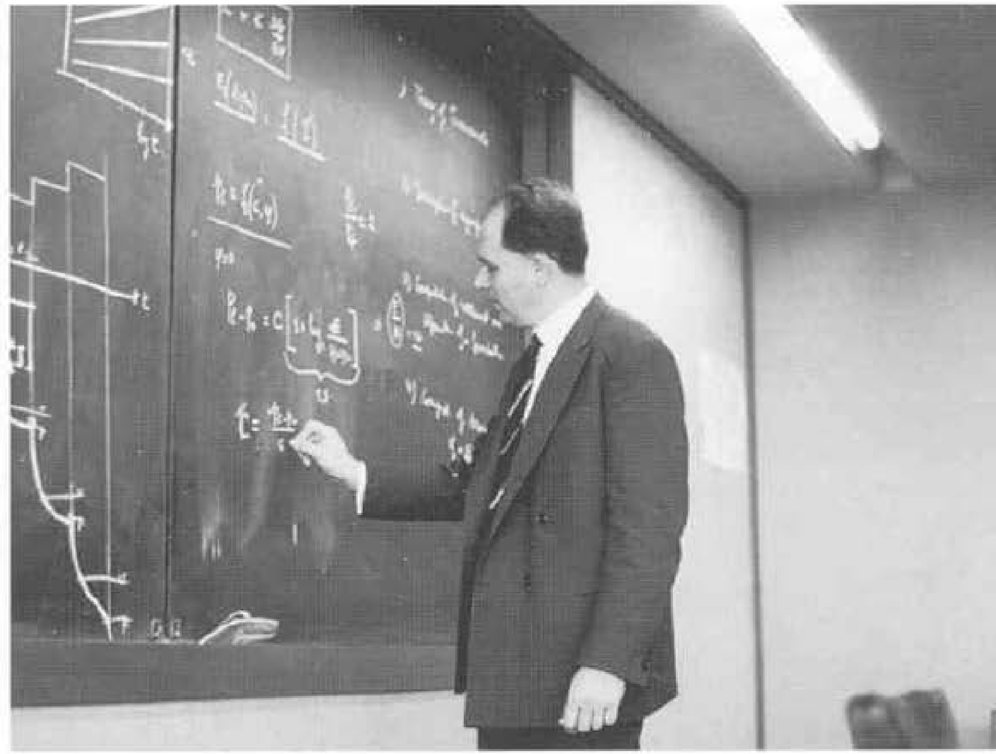
By Serge Varaksin,
Vice Chairman TC211
Scientific Advisor

ISSMGE – TC 211

APAGEO

Louis MENARD (1933-1978)

Courtesy of Michel Gambin



当社でプレシオメーターの講義をするメナール氏（昭和35〈1960〉年）

Courtesy of Kenji Mori

ENGINEER, INNOVATOR

SOME HISTORY

- First pressuremeter idea:

1933 : first expansion test of cylindrical probe

1955 : patent by Louis Ménard and first instrument to mesure
« pressure-time »
and
« pressure-deformation »
in cylindrical borehole

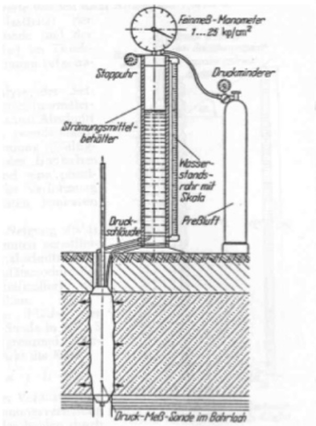
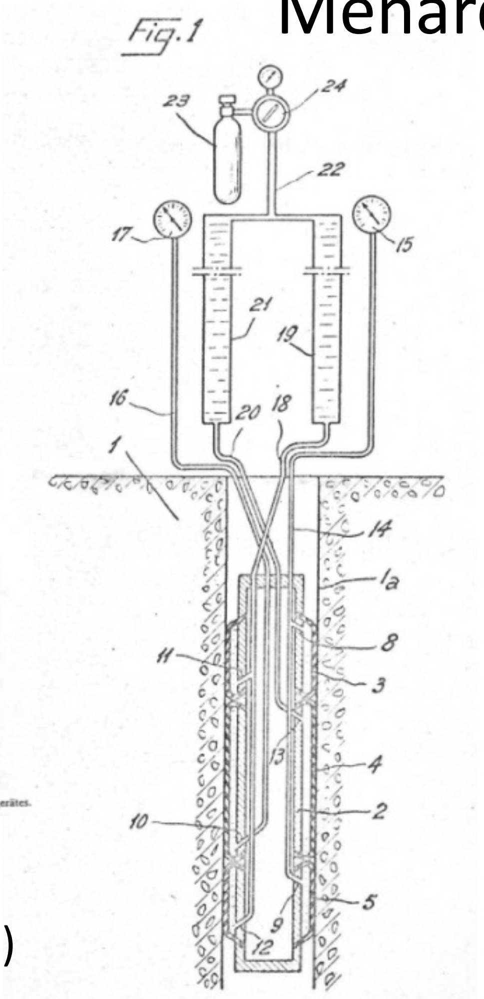


Abb. 2. Schema des verbesserten Kögler-Belastungsgerätes.

Germany
(not pursued)

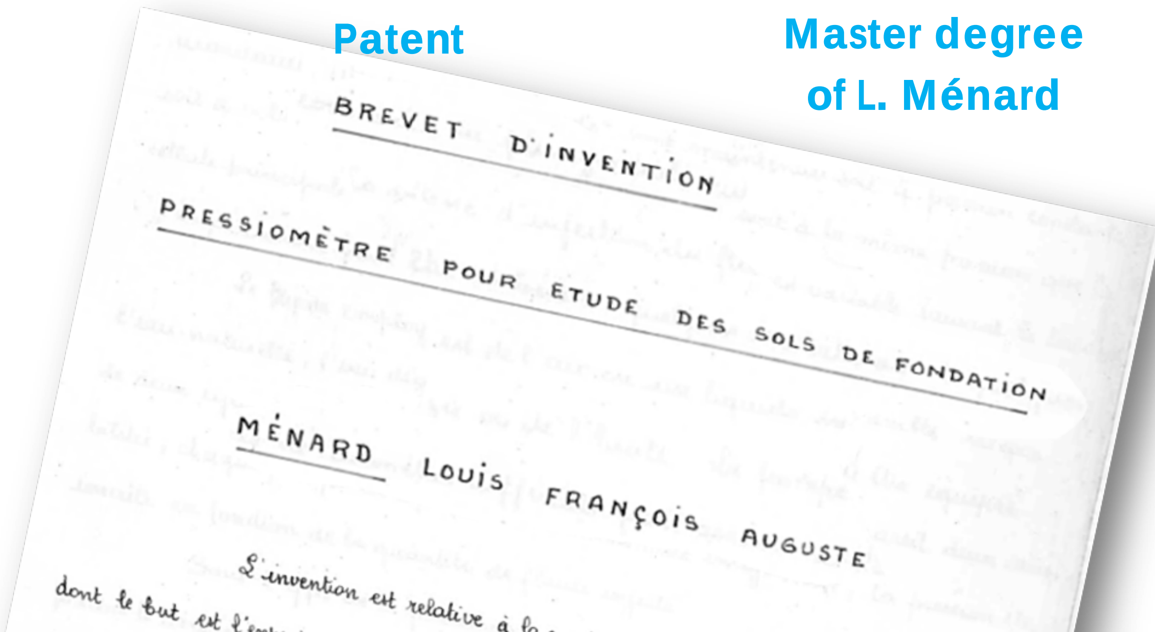
Ménard



KEY DATES OF ORIGINS

Louis Ménard, civil engineer
and inventor of the pressuremeter

1955	1956	1958
Patent	**Master degree of L. Ménard**	**First Company** **Michel Gambin (Mike) joins**



BREVET D'INVENTION

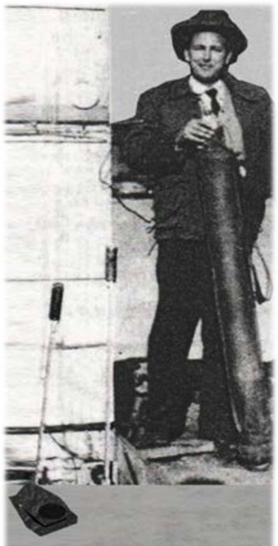
PRESSIOMÈTRE POUR ETUDE DES SOLS DE FONDATION

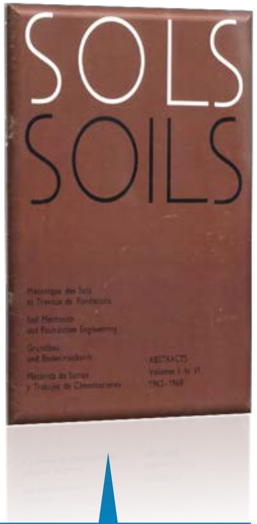
MÉNARD LOUIS FRANÇOIS AUGUSTE

L'invention est relative à la

dont le but est l'

PRESSUREMETERS IMPROVEMENTS WITHIN THE FIRST DECADE





1955 — **The second PMT prototype**

1967 — **D-9000**
Versatile drill

1971-1975 — **G-type and GC-type Pressuremeter**

1975 — **Soil-soils**
edited by Mike Gambin

WHY PRESSUREMETER?

- Performed in previously drilled hole to any depth
- Performed in submerged sand or gravel, directly driven slotted casing or STAF® method
- Performed in fills even landfills (only possible technique)
- Provides its own reaction
- Large volume tested up to several tens of tons
- Average soil response
- Two stress-strain parameters
- Creep information
- Automatic data recording and test perfomance available
- Pressuremeter modulus (E_M) (independent from porepressure)
- Limit pressure (P_{LM}), close to failure of plate, footing or pile tip

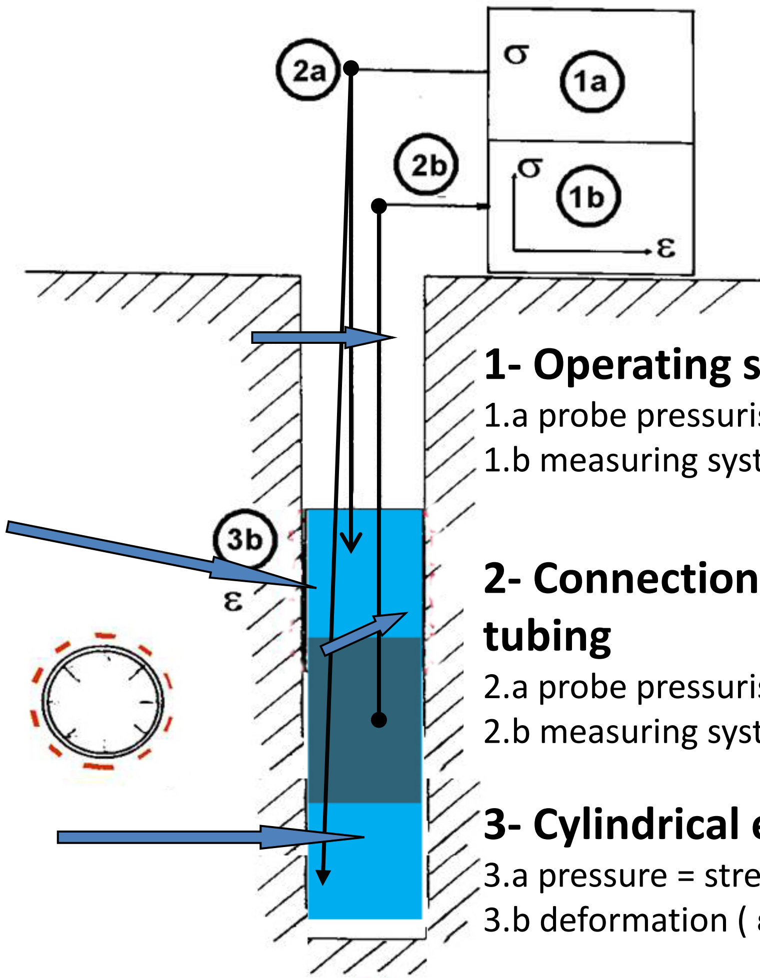
WHY STRESS CONTROLLED TESTS ?

- Strain is only consequence of stress and not its action
- Creep is available
- In construction, loading is stress controlled

General principle of the pressuremeter

Cylindrical drilled hole

Objective :
measurement of radial expansion of the drilled hole by application of a cylindrical stress through an expandable cylindrical probe

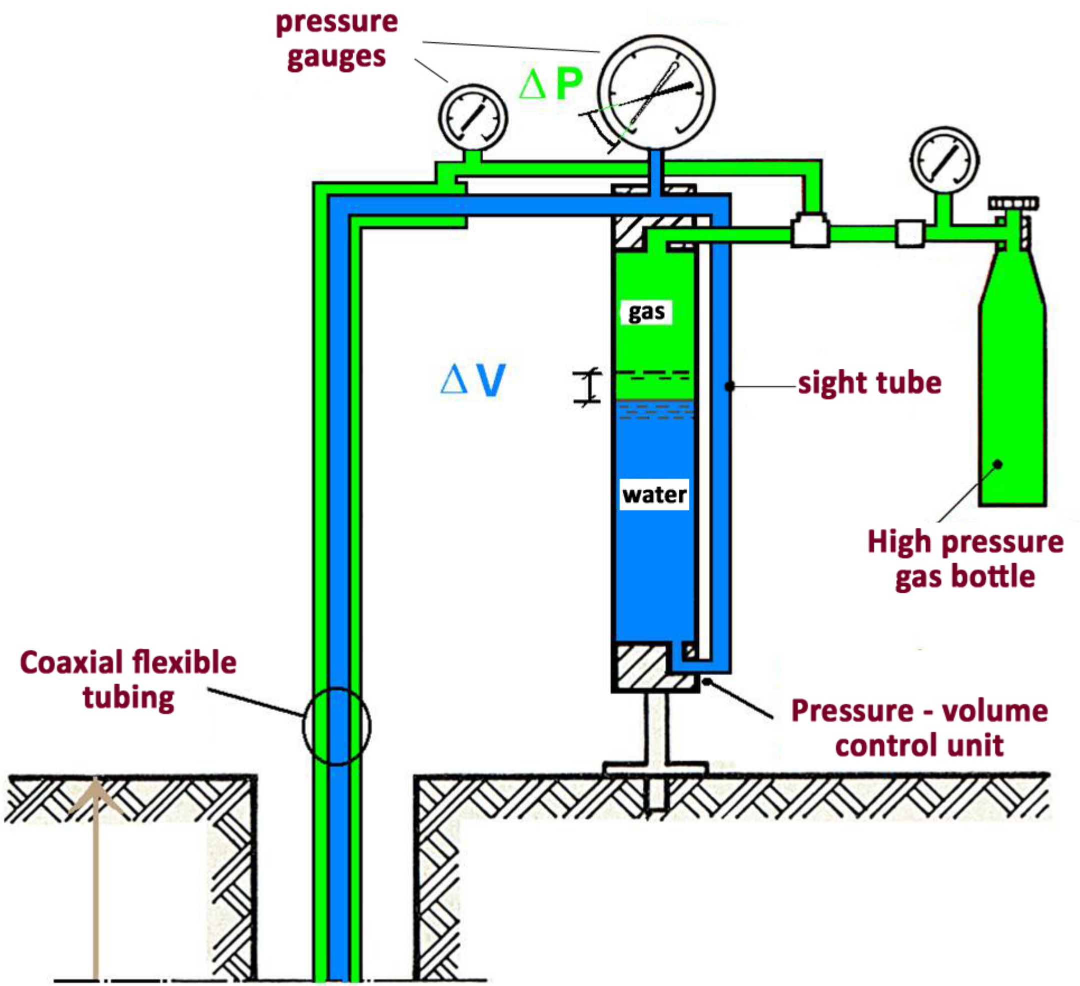


1- Operating system
1.a probe pressurising system
1.b measuring system of pressure and strain

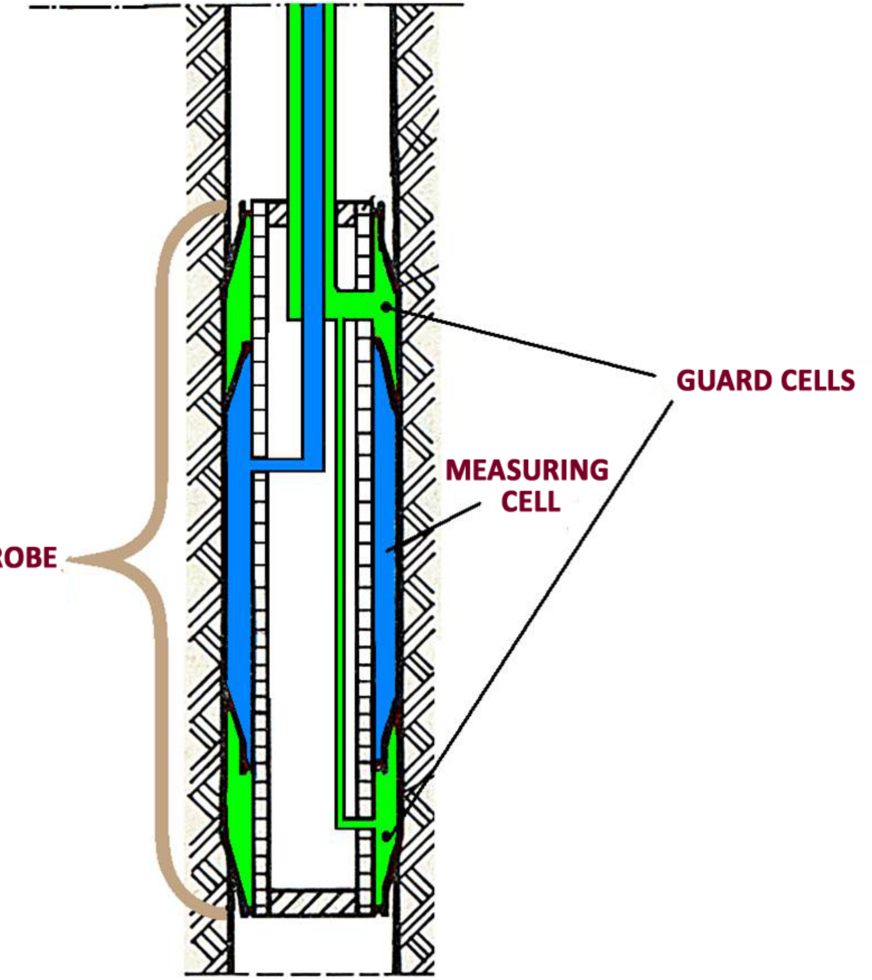
2- Connections by coaxial flexible tubing
2.a probe pressurising system
2.b measuring system of pressure and strain

3- Cylindrical expandable probe
3.a pressure = stress applied on the soil
3.b deformation (ε)

General scheme of a Ménard pressuremeter

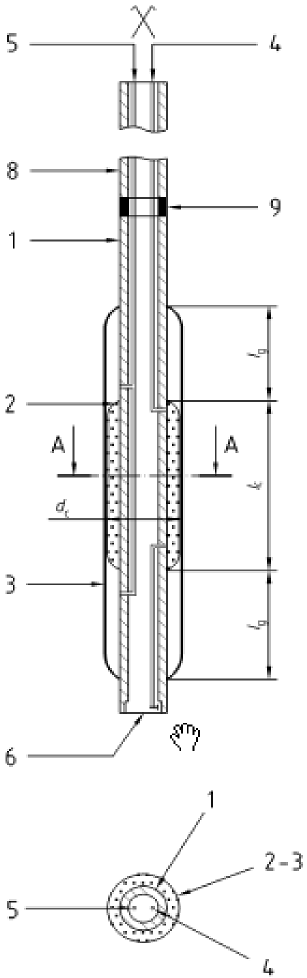


General scheme of a Ménard pressuremeter



Evolution of the pressuremeter

Detail of Ménard pressuremeter probe



<u>Type G probe :</u>

Central Cell + Flexible Cover to form 2 Guard Cells.
Central Cell Pressure is higher than in Guard Cells to balance cell membrane resistance.
Pressure lag between the Central Cell and the Guard Cells is kept constant at a given Depth

1 Hollow probe body
2 measuring cell membrane
3 external sleeve or flexible cover
4 water inlet to the measuring cell
5 gas inlet to the guard cells
6 measuring cell drain outlet
7 slotted tube
8 rods
9 probe/rod coupling

Latest state of the art

- GeoPAC® + GeoBOX

⇒ High precision and high pressure measuring tool.

⇒ Automatic piloting of the test, automatic recording and log presentation transmitted from GeoPAC® to GeoBOX® by Wifi and to the office by GPRS

⇒ Stress-controlled test (possibilities of cyclic program)

⇒ Ranges 0,1 cc to 100 Mpa

Evolution of drilling

- **Drilling methods from European norm**

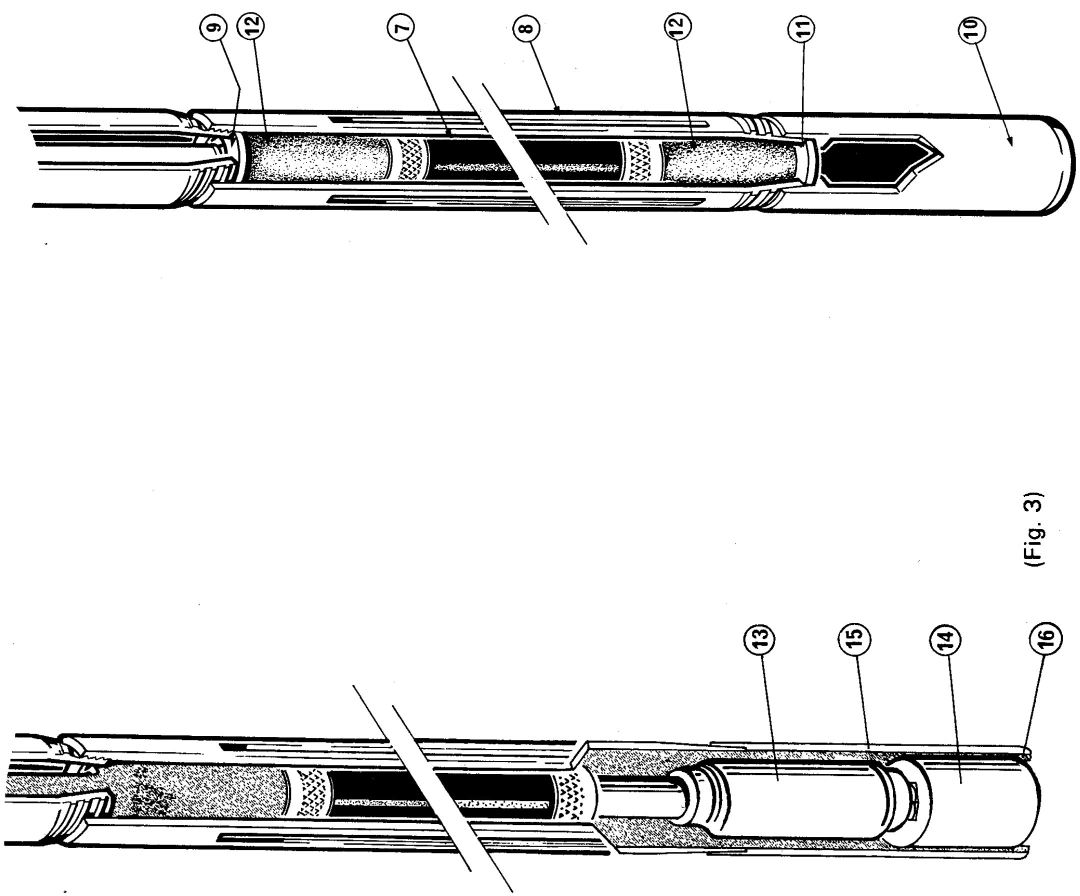
- Hand auger
- Power auger
- Rotary drilling bit with bentonite injection
- Shelby tube sampler
- Slotted casing driving method
- Roto percussion
- Open slotted casing
- Recent STAF® Method (Self bored tube system)
- Self-boring pressuremeter probe under development

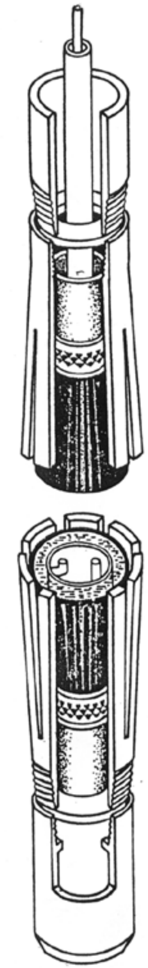
Guidelines for pressuremeter probe placement techniques

		SOIL TYPE										
		CLAYEY SOILS			SILTY SOILS		SANDY SOIL			COARSE SOILS	ROCKS	
BORING TECHNIQUES		SLUDGE AND SOFT	SOFT TO MEDIUM STIFF	STIFF	ABOVE WATER TABLE	BELOW WATER TABLE	LOOSE ABOVE WATER TABLE	LOOSE BELOW WATER TABLE	MEDIUM DENSE AND DENSE	GRAVELS, COBBLES	WEATHERED ROCK, SOFT ROCK	HARD
OPEN HOLE DRILLING	HA hand auger	***	***	*	***	**	**	*	***	-	-	-
	HAM hand auger and mud	***	***	**	***	***	***	***	***	-	-	-
	CFA Continuous flight auger	-	**	***	**	-	**	-	**	*	*	*
	STDTM Slotted tube with inside rotary tool and mud circulation	*	***	***	**	*	**	*	***	**	***	**
	CD Core drilling	-	**	***	**	*	*	-	*	-	**	***
	RP Rotary percussion	-	*	**	*	*	*	*	**	***	**	***
	PT Pushed tube	***	*	-	*	-	-	-	-	-	*	-
	VDT Vibro driven tube	-	-	-	*	-	-	-	*	*	*	-
FULL DISPLA-CEMENT	DST Driven slotted tube	-	*	*	*	*	*	*	**	**	-	-
SELF BORING	VIBRO-STAF®	-	**	**	***	***	***	***	***	***	*	-
	ROTO-STAF®	-	**	**	***	***	***	***	***	***	*	-
	SAF® self-bored probe	***	-	-	***	***	***	***	-	-	-	-

*** Recommended ** Suited * Acceptable - Not suited

Slotted casing method





Cross section of a probe inside a slotted casing

The Menard Pressuremeter : typical loading tests

Typical ***load tests*** conducted on foundations :

(i) PBT; and

(ii) PMT

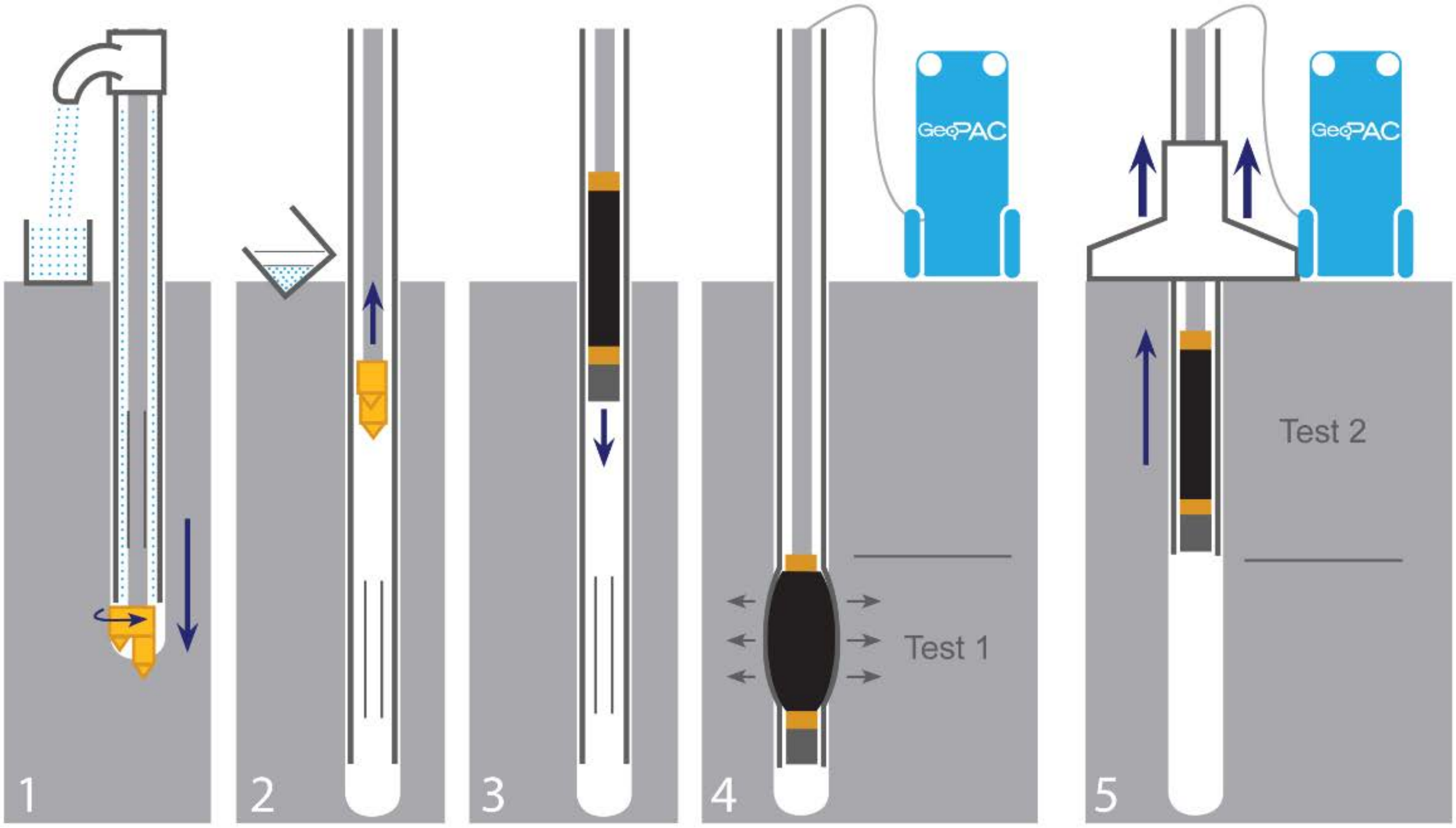
(*not CPT or SPT*)

PBT – vertical load test

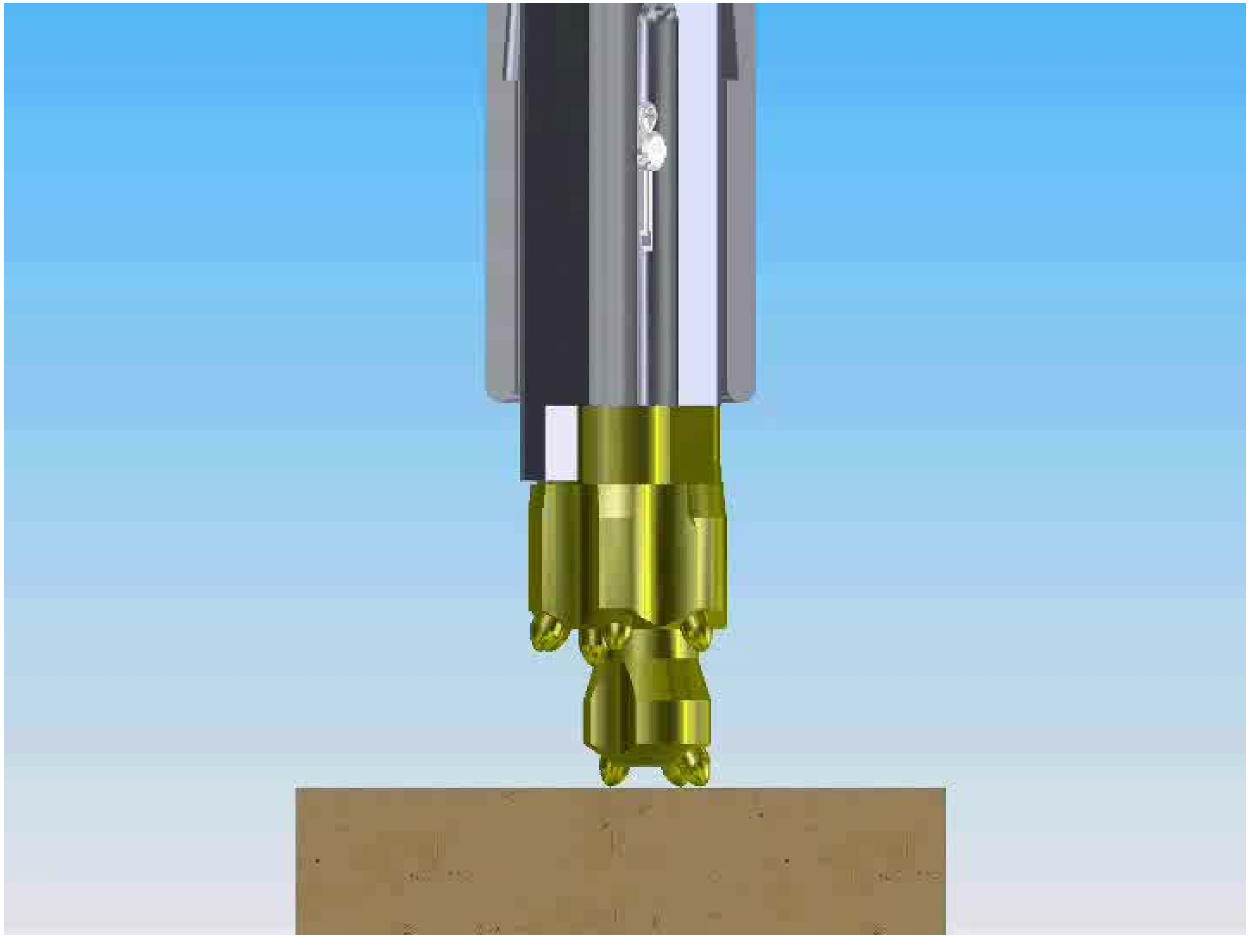
PMT – shear loading test

Self bored tube system STAF®

STAF® technique : Ménard Pressuremeter Tests inside a self-bored slotted tube

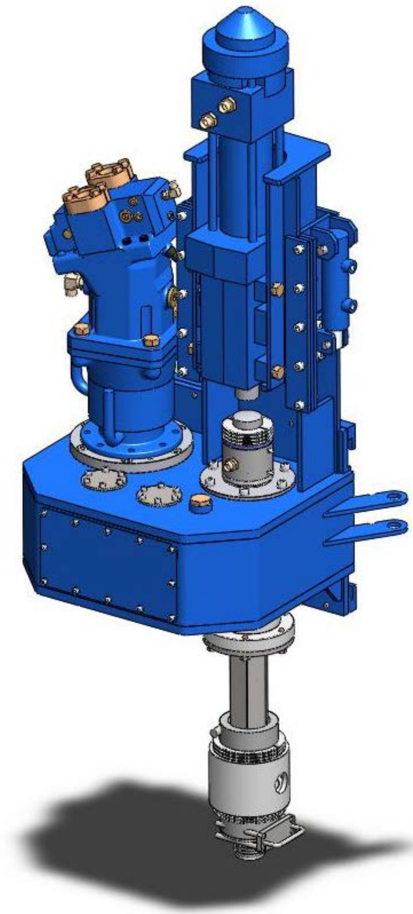


Self bored tube system STAF®



Roto percussion drilling

to reduce casing friction



Research pressuremeter: PAF and K0 meter

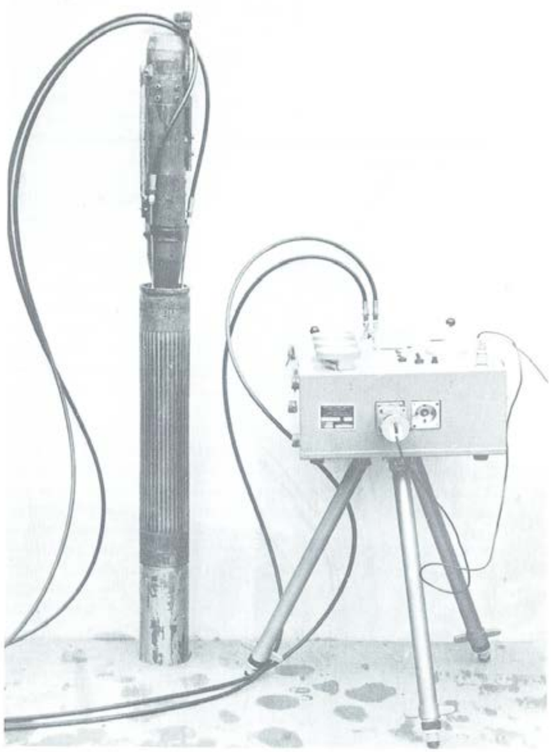


Fig. 6-39: Probe and control unit for a self-boring pressuremeter for hard soil (PAFSOR or PAF–72).

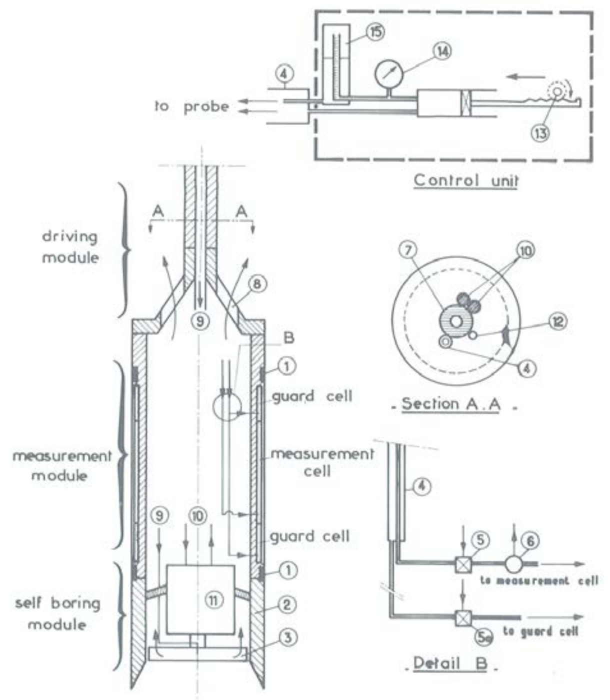


Fig. 6-41: Principles of PAF–76: The probe, the control unit and the leads (not to scale).

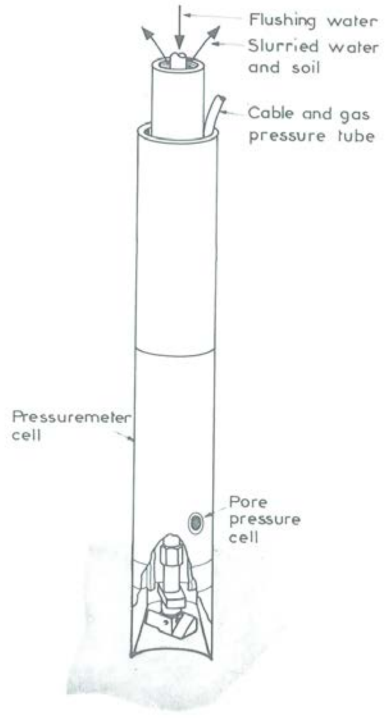


Fig. 6-37: Principles of the Camkometer.

The pressuremeter curve

- Typical PMT field record (manual recording)

FEUILLE D'ESSAI PRESSIOMETRIQUE :

CHANTIER de CROSNE
Date : 17/5/97 Heure :
Forage n° F4 Profondeur : 3 m
Type de forage : Taillant ϕ 64 mm
Sonde Ø et mise en œuvre : 44 TF 56 mm

Feuille n° Pression différentielle :

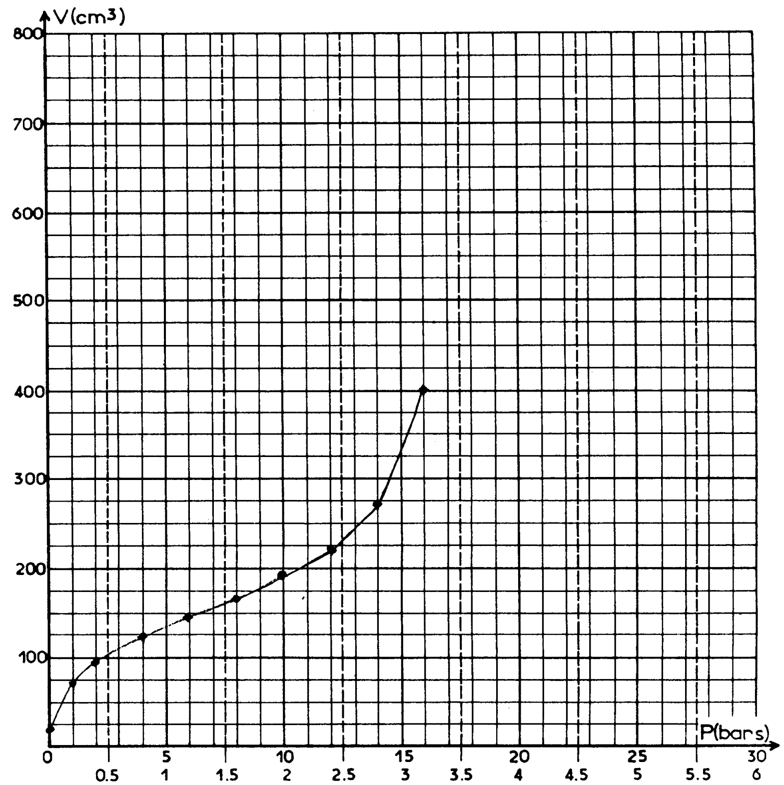
Pression	Volume	Diff.	Pression Report	Volume	Diff.
0	20	52			
1	61 / 72	11 / 20			
2	90 / 92	2 / 28			
4	117 / 120	3 / 24			
6	142 / 144	2 / 20			
8	163 / 164	1 / 24			
10	186 / 188	2 / 31			
12	216 / 219	3 / 52			
14	263 / 271	8 / 69			
16	350 / 400	50			
18	↓				

E | Pl

Inertie : F18

Nom de l'opérateur ELISABETH

COURBE PRESSION VOLUME :



Typical PMT test

- Geobox automatic test piloting and recording

European Pressuremeter Surveys Company
11 avenue Francis de Pressensé 93571 SAINT-DENIS LA PLAINE cedex
Tél. 33 (0)1 41 62 80 00 Fax 33 (0)1 49 17 90 00 catherine.pineau@afnor.fr

MENARD PRESSUREMETER
TESTA DATA
Borehole expansion test conforming to EN ISO 22476-4 procedure B

SITE	
File	2366
Country	France
Job site identification	PARIS
Location plan ref.	IGC 23-15
Borehole number	FP 401

PROBE

CELL PARAMETERS			
Code	44 g.c.t_l		
Length		Cover	
210 mm		Rubber	
370 mm	X	Reinforced mesh	
Type		Metallic mesh	
E		Metallic strips	
G	X	Slotted tube	X

TUBING & FLUID PARAMETERS				
Type	Coaxial X	Liquid	Nature	Eau
	Twin		Unit weight γ_f/γ_w	1,00
Total length (m)		Gas	Nature	Azote
30,00			Compressibility λ_g (m^{-1})	0,00016

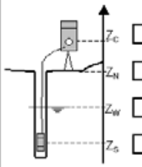
MEMBRANE PARAMETERS	
Supplier type and cote	m4
Pressure loss p_m (MPa)	0,044

PRESSURE LOSS PARAMETERS	
Correction sheet reference	ET10120202
Ultimate pressure loss p_{el} (MPa)	0,272
VOLUME LOSS PARAMETERS	
Correction sheet reference	CA10120201
Calibration cylinder diameter d_i (mm)	65,0
Calibration coefficient a (cm^3/MPa)	2,354
Probe volume V_s (cm^3)	1009,2

TEST	
Test number (or depth)	ES11120202
Test date and time	12 nov 02 - 13:19
Control unit number	-G200E-
Data logger number	201
Operator's name	TL
Differential pressure (MPa)	-0,100
Observations (weather, etc.)	sun 18°C

FIELD DATA									DATA CORRECTED from P&V losses			
Step	PRESSURES pr (MPa)				VOLUMES V(t) (cm^3)				PRESSURE p (MPa)	VOLUME V^{60} (cm^3)	SLOPE m_i $\Delta V^{60/30}/\Delta p$ (cm^3/MPa)	CREEP $\Delta V^{60/30}$ (cm^3)
	1 s	15 s	30 s	60 s	1 s	15 s	30 s	60 s				
0								0,0				
1	0,052	0,052	0,047	0,055	30,6	58,2	77,8	88,3	0,028	87,9		10,4
2	0,101	0,097	0,096	0,096	92,6	97,5	99,3	100,5	0,066	99,8	312	1,2
3	0,138	0,153	0,151	0,155	103,6	109,1	111,6	114,0	0,115	112,9	271	2,5
4	0,198	0,200	0,205	0,203	118,9	123,2	125,7	128,7	0,156	127,2	350	3,1
5	0,247	0,250	0,253	0,251	133,6	138,5	141,6	144,7	0,195	142,8	397	3,1
6	0,300	0,303	0,305	0,310	149,6	156,3	160,6	166,7	0,236	164,5	528	6,1
7	0,348	0,347	0,350	0,353	171,6	179,0	183,3	190,6	0,266	188,1	777	7,3
8	0,408	0,405	0,395	0,402	198,6	208,4	214,5	224,4	0,299	221,5	1032	9,8
9	0,455	0,455	0,452	0,455	232,9	245,8	255,6	273,4	0,328	270,2	1687	17,8
10	0,501	0,504	0,505	0,505	283,8	299,8	315,1	339,0	0,350	335,5	2869	23,9
11	0,548	0,552	0,550	0,554	350,0	370,2	388,0	423,0	0,369	419,2	4532	34,9
12	0,603	0,603	0,599	0,601	438,9	463,4	488,6	533,9	0,390	529,9	5343	45,4
13	0,641	0,652	0,649	0,650	550,5	582,3	614,8	673,7	0,413	669,3	6054	58,8
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												

LEVELS



Datum	Levels	Relative levels
Z_C	83,80	+ 0,80
Z_N	83,00	0 (borehole top)
Z_W	86,00	- -3,00
Z_S	81,00	- 2,00

BOREHOLE		
Localization system		X =
		Y =
Drilling rig		BE 2050
Drilling method (table C abbreviations)		THC.63
Drilling tool	type	fishtail
	diameter (mm)	63,5
Casing foot at (m depth)		n.a.
Drilling fluid		none
Drilling length before testing	from level (m)	2,00
	to level (m)	2,70
	time completed	

UNITS		
Elevations	metre	m
Times	second	s
Volumes	cubic centimetre	cm^3
Pressures	Megapascal	MPa

Typical PMT test report and interpretation

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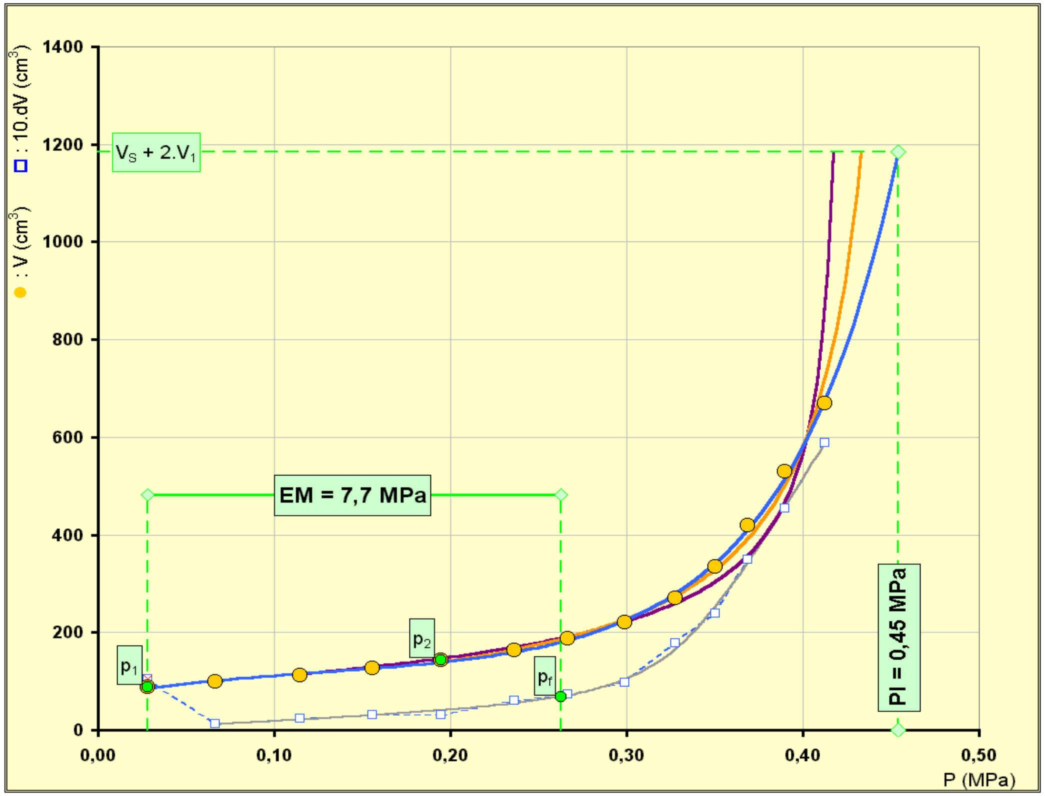
MENARD PRESSUREMETER REPORT AND INTERPRETATION

Borehole expansion test conforming to EN ISO 22476-4 procedure

File	2366
Test reference	ES11120202
Job site identification	EVRY
Borehole	FP.401
Test depth	2,00



CALCULATED NORMATIVE RESULTS	
σ_{hs}	0,018
p_1	0,03
p_2	0,19
p_f	0,26
p_l	0,45
p_l^*	0,44
E_M	7,7
E_M / p_l	16,9
E_M / p_l^*	17,6

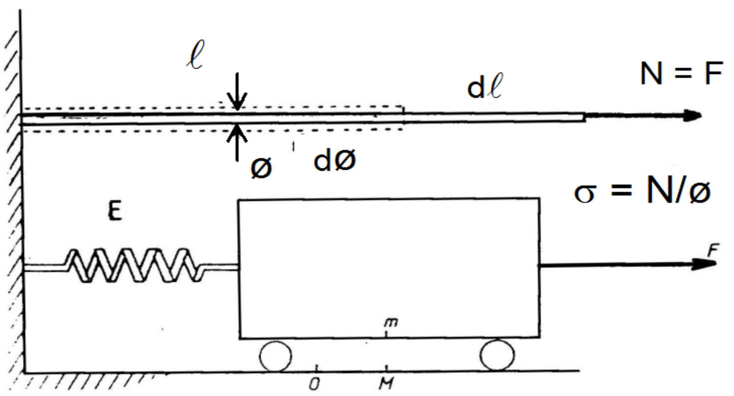
EXTRAPOLATION METHODS PARAMETERS		
inverse volumes	A	-2,64E-02
	B	1,23E-02
	Average error (cm³)	1,44E+01
hyperbolic	C	4,22E-01
	D	1,12E+04
	Average error (cm³)	3,49E+01
double hyperbolic	A1	1,42E+06
	A2	-7,12E+04
	A3	2,84E+07
	A4	3,00E+02
	A5	-2,00E+01
	A6	5,74E-01
	Average error (cm³)	5,21E+00

COMMENTS

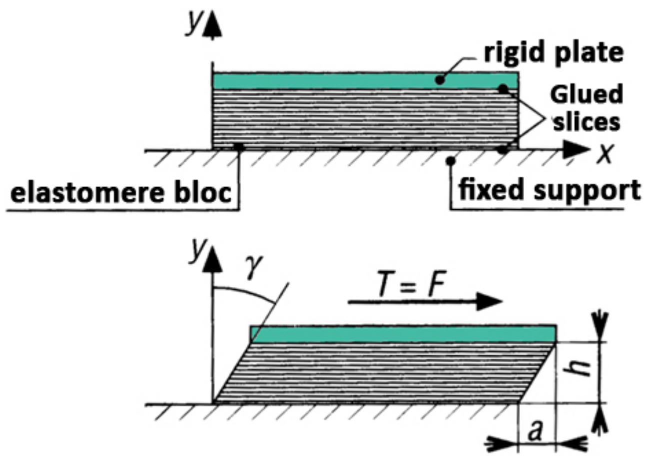
Geomatech XPressio 2.10

Various moduli deformation linear elastic case

Traction/compression $\varepsilon = d\ell / \ell$



Shear anguler deformation under shear



Young's modulus (not applicable in soils!)

$$\sigma = E \,.\, \varepsilon$$

Shear modulus
Angular definition proportional to tangential stress

$$\tau = G \,.\, \gamma$$

The expansion cylindrical cavity is an elastic medium according to Lamé :

$$G = V \,.\, \frac{\Delta P}{\Delta V}$$

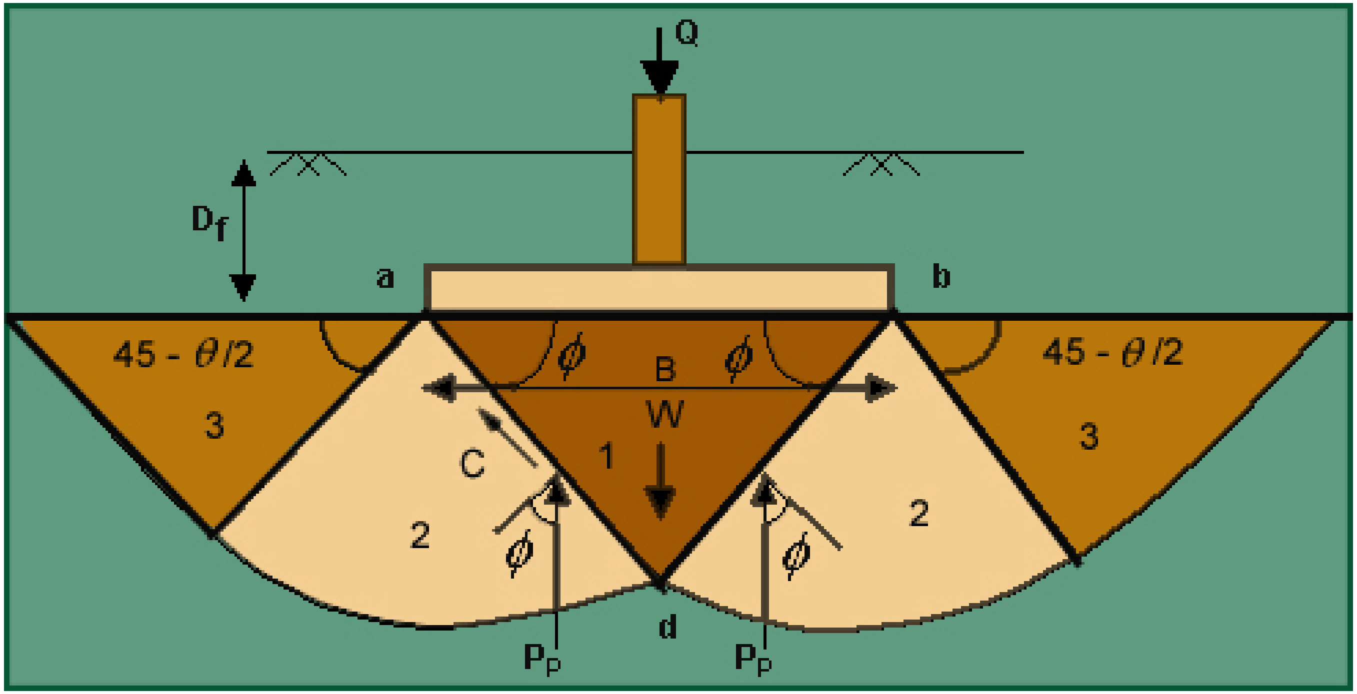
What is a pressuremeter modulus

- Compression modulus $E = \sigma / \varepsilon$
- Shear modulus $G = \tau / \gamma$
- Poisson coefficient (ν) $\nu = - \left(\frac{d\phi}{\phi} \right) \Big/ \left(\frac{d\ell}{\ell} \right)$
- The relation between moduli is $E = 2(1+\nu) \cdot G$
- Ménard proposes to always adopt $\nu = 1/3$

so $E_M = 2(1+\nu) \cdot V_m \cdot \frac{\Delta P}{\Delta V}$ or $E_M = \frac{8}{3} \cdot (V_S + \frac{V_1 + V_2}{2}) \cdot \frac{\Delta P}{\Delta V}$

Bearing capacity

- Prandtl and Terzaghi theory and limitations



Prandtl's Theory on Bearing Capacity Analysis

Prandtl 1920 developed an equation based on his study of penetration of long hard metal puncher into softer materials for computing the ultimate bearing capacity. He made the following assumptions for the derivation.

- The material is softer, homogeneous and isotropic.
- The material is weightless and possesses only friction and cohesion.
- The problem is two dimensional
- The base of the puncher is smooth.
- The material behaves as a rigid body.
- The volume change will be Zero.
- The resulting deformation will be a plastic deformation.

Bearing capacity after Terzaghi	Bearing capacity after Ménard
Function of (h, γ, D, c, Φ)	Function of $q_L - q_o = k_p (p_{LM} - p_o)$

$$q_L - q_o = k_p (p_{LM} - p_o)$$

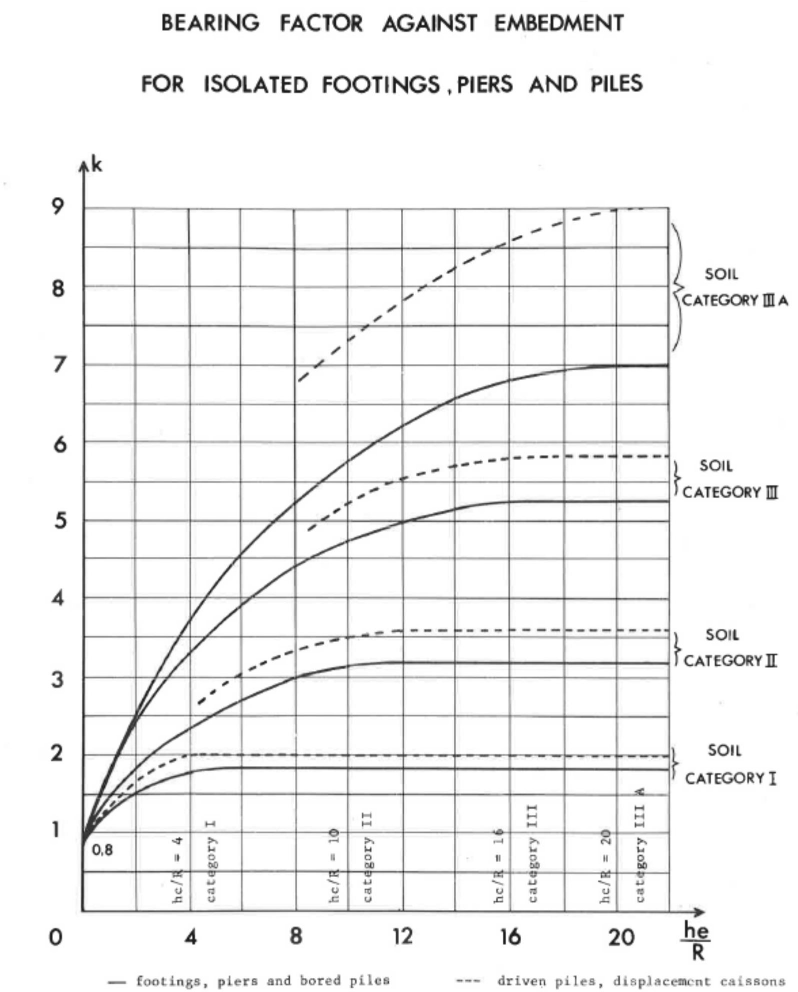
here qL is the ultimate bearing stress at the footing or pile tip

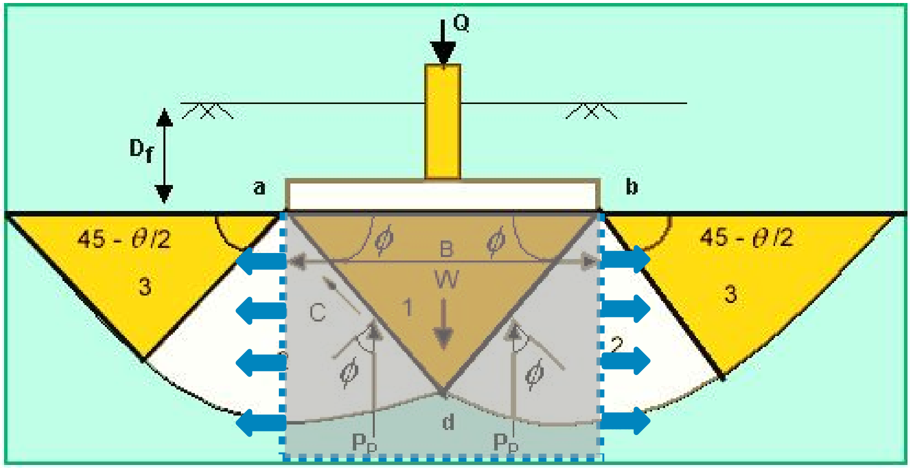
- q_o the vertical overburden stress at pile tip depth
- k_p the Ménard Bearing Factor at footing or pile tip and type of soil
- p_{LM} the Ménard limit pressure at footing or pile tip depth
- p_o the insitu horizontal effective stress at footing or pile tip depth

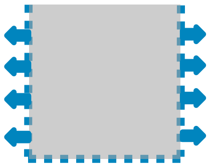
and it appears that, below a “critical depth”, the tip bearing capacity alone is much

less than predicted by the c’ and Φ’ (Mohr - Coulomb)

Pressuremeter bearing capacity factor





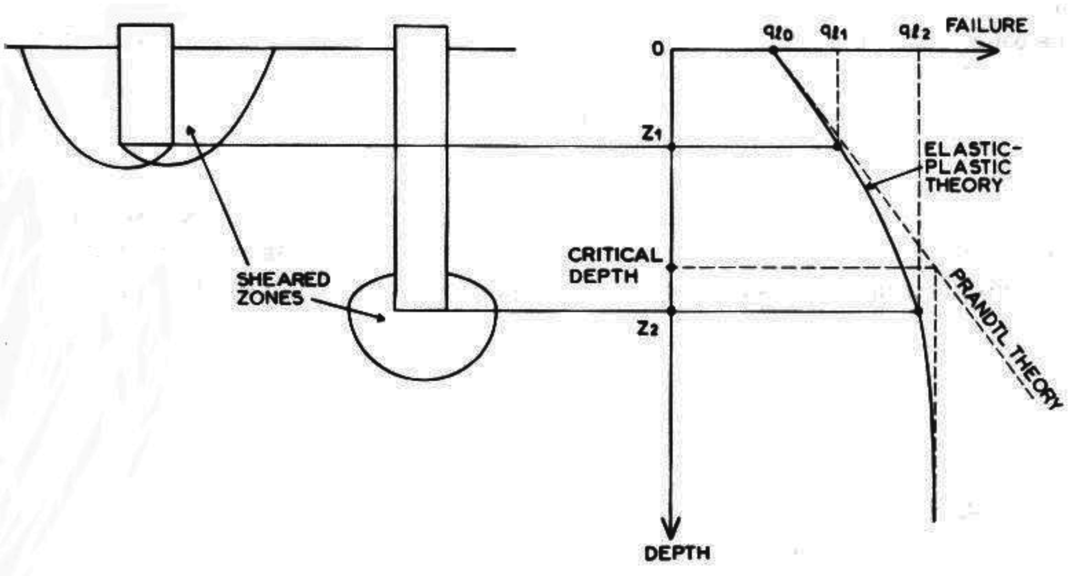


Pressuremeter probe, equal active zone
Surrounding soil passive reaction

Bearing capacity

- Piles and drilling shafts

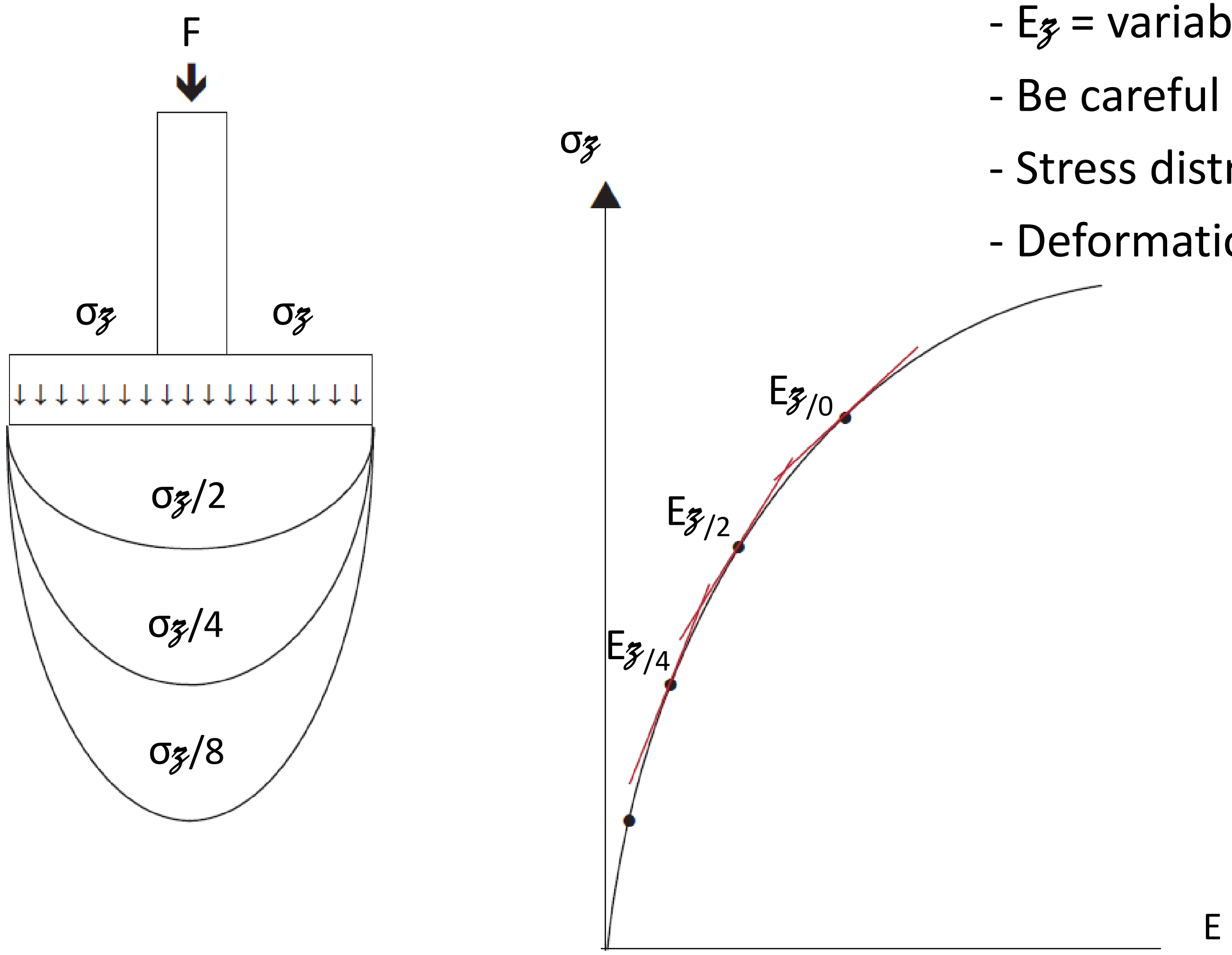
The soil response in a pressuremeter test behaves much closer to the way soil reacts to a loaded deep foundation a fact observed by many researchers. It is the estimate of the settlement, which provides the value of the bearing stress in service (Terzaghi & Peck, 1948), especially in sands, when deeper foundations are considered. The soil around the tip is in a plastic state and the soil reaction around this sheared volume can be compared with the response to the expansion of a deeply embedded cavity. Elastic/plastic theory must be used.

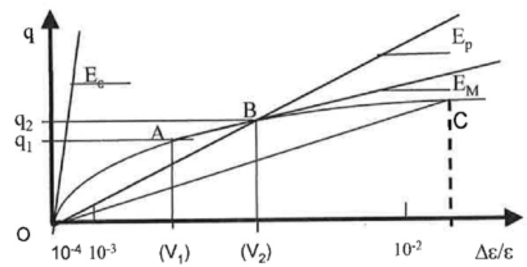


Shallow foundation bearing failure against pile tip bearing failure in an homogeneous soil (E_M & p_{LM} constant)**.**

Why E_y young modulus

- E_z = variable not applicable for soils
- Be careful with FEM
- Stress distribution FEM is OK
- Deformation analysis FEM not correct

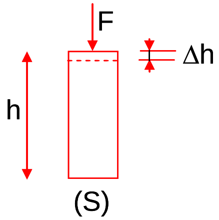




Duncan and Cheng

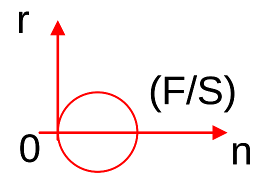
Settlement and deformation

A/ Simple compression

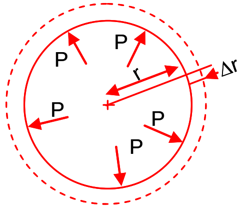


$$\frac{\Delta h}{h} = \frac{1}{E_{cs}} \frac{F}{S}$$

where E_{cs} is the compression

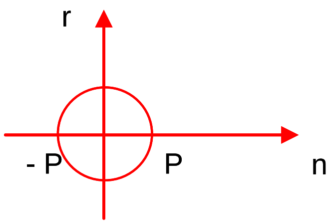


B/ Simple shear

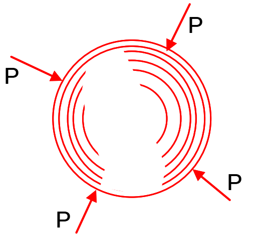


$$\frac{\Delta r}{r} = \frac{1+\nu}{E_{pr}} \quad p$$

where ν is the Poisson's coefficient

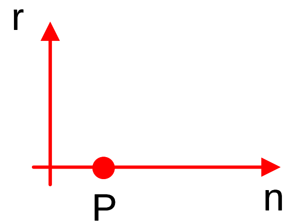


C/ Simple compressior



$$\frac{\Delta r}{r} = \frac{1-2\nu}{E^{+}} \quad p$$

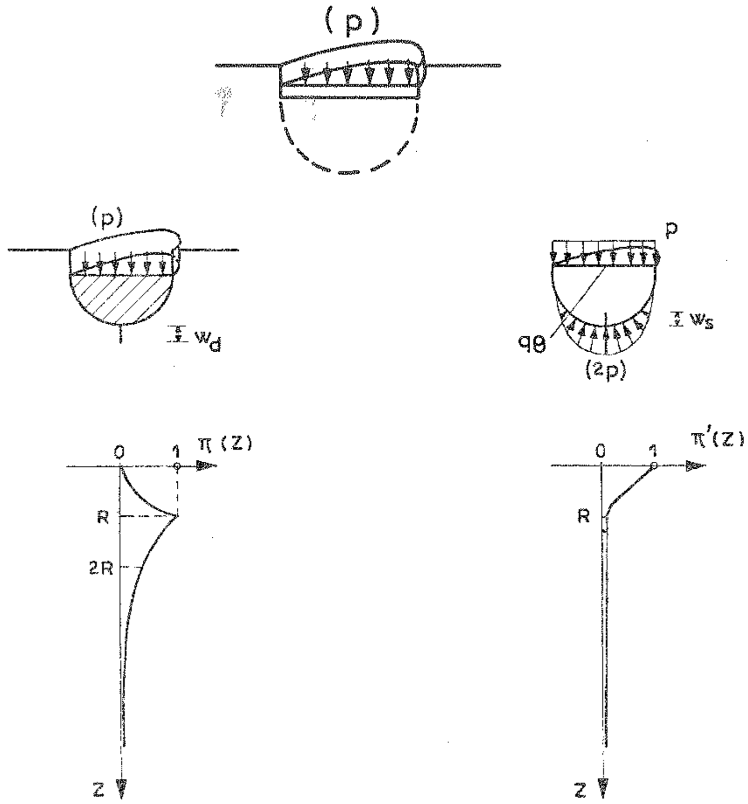
where E^{+} is the hydrostatic compression modulus



Settlement and deformation

D/ Menard deformation approach

$W_{(10\ years)} =$



Shear domain

Spherical domain or volumetric

NO TENSION IN SOIL IMPACTS THE PMT MODULUS BECAUSE ELASTICITY ASSUMES TENSION

$$\varepsilon_r = \frac{\sigma_r}{E_r} - \nu_{\theta r}\frac{\sigma_\theta}{E_\theta} - \nu_{zr}\frac{\sigma_z}{E_z}$$

$$\varepsilon_\theta = -\nu_{r\theta}\frac{\sigma_r}{E_r} + \frac{\sigma_\theta}{E_\theta} - \nu_{z\theta}\frac{\sigma_z}{E_z}$$

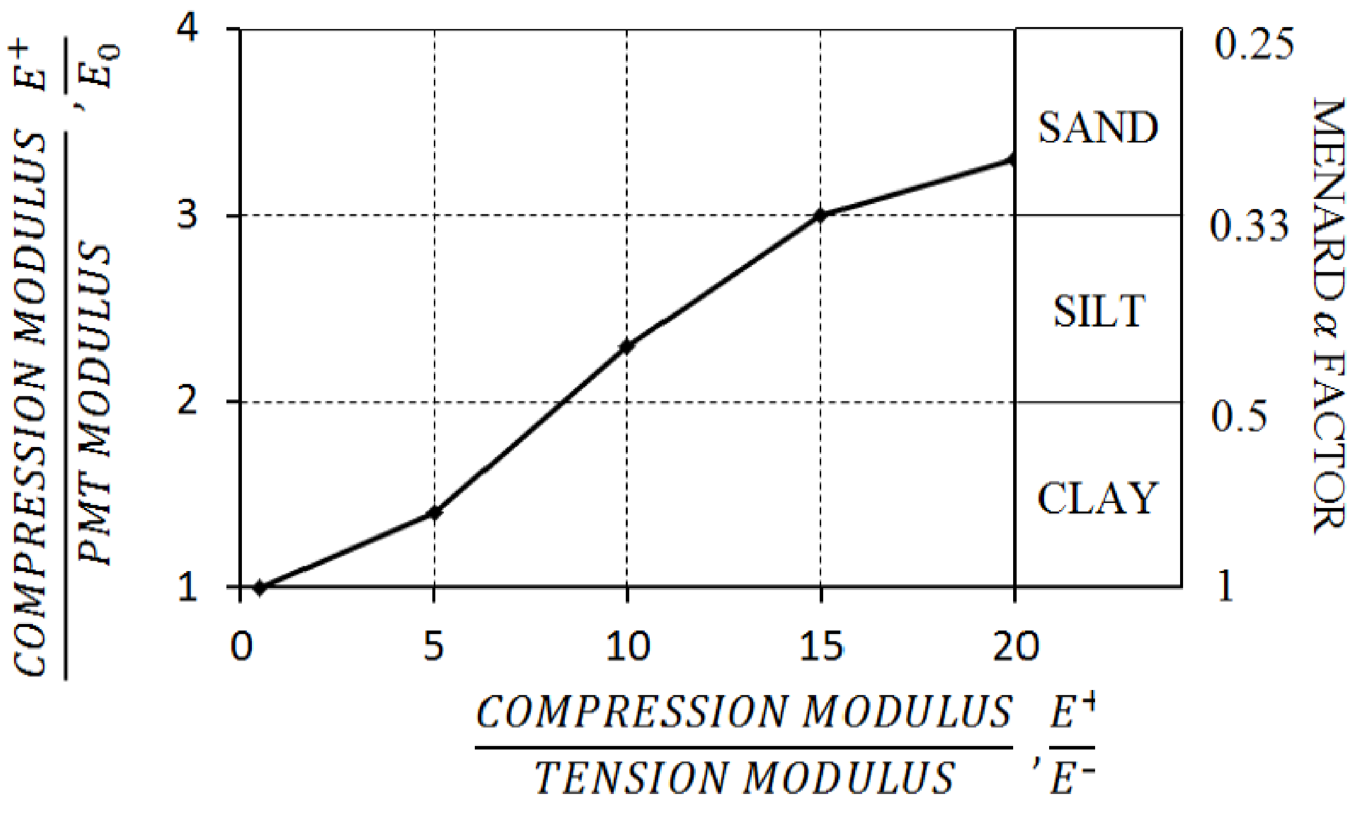
$$\varepsilon_z = -\nu_{rz}\frac{\sigma_r}{E_r} - \nu_{\theta z}\frac{\sigma_\theta}{E_\theta} + \frac{\sigma_z}{E_z}$$

ORTHOTROPIC
ELASTICITY

$$E_z = E_r = E^+ \qquad E_\theta = E^-$$

Briaud, Ménard lecture 2013

NO TENSION IN SOIL IMPACTS THE PMT MODULUS BECAUSE ELASTICITY ASSUMES TENSION

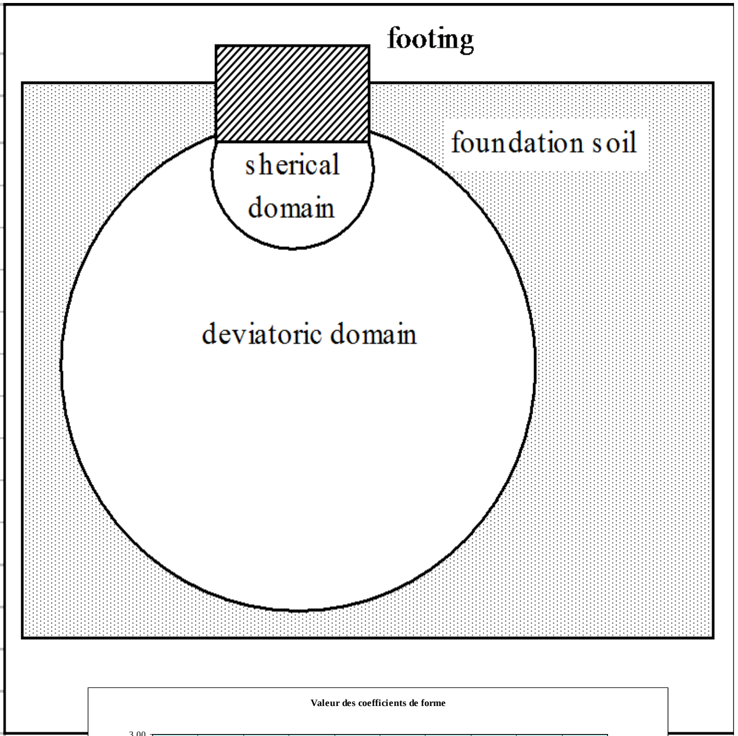


Briaud, Ménard lecture 2013

The Menard Pressuremeter : Settlement calculation under a footing

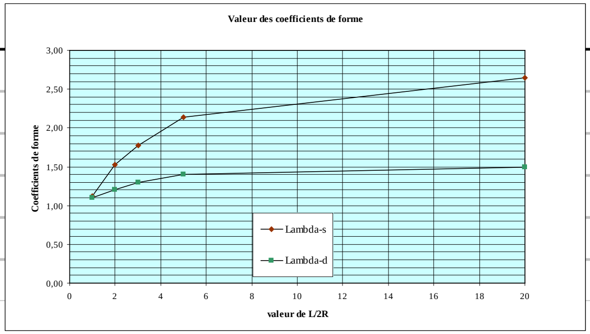
half width reference radius	R	0,30	m
Reference radius	R_0	0,30	m
Footing length	L	0,60	m
Pression sur la fondation	p	9,40	bars
PMT modulus in deviatoric domain	Ed	250	bars
PMT modulus in spherical domain	Es	250	bars
Rheological factor	α	1/4	
Shape factor	λd	1,10	
Shape factor	λs	1,12	

$$W = \frac{1.33}{3E_d} p R_0 \left(\lambda_d \frac{R}{R_0}\right)^{\alpha} + \frac{\alpha}{4.5E_s} p \lambda_s R$$



Results

Spherical strain	Ws	0,07	cm
Deviatoric strain	Wd	0,51	cm
Calculated settlement	**W**	**0,58**	**cm**



Ménard Rheological coefficient α

Type of material	Peat		Clay		Alluvium		Sand		Sand and gravel	
	E/p_L	α	E/p_L	α	E/p_L	α	E/p_L	α	E/p_L	α
Over consolidated			>16	1	>14	2/3	>12	½	>10	1/3
Normaly consolidated		1	9 - 16	2/3	8 - 14	½	7 -12	1/3	6-10	1/4
Weather or altered			7 - 9	1/2		1/2		1/3		1/4

E = the pressuremeter modulus of the soil, assumed to be homogeneous

P = the mean contact stress added to soil by the rigid footing

R_O = a reference equal to 30 cm

α = The structure coefficient variable according to the nature of the soil and the ratio E/pL obtained from the pressuremeter, derived from the following table

Pile settlement prediction load transfer method

For the pile tip, the shear stress effect controls the settlement $\Delta R/R = [1/4G]\ \Delta p$ (6)

Thus, the settlement zp of a pile tip is simply given (Frank & Zhao 1982) by : $z_p = (B/\lambda_p)\ q_p$ (7)

where B is the diameter of the pile

- qp the pile tip pressure, with qp < qL, (Fig.2) and

- λp is a factor which varies from 4.8 EM in

5 times smaller above the qL / 2 stress.

follows :

$$z_{si} = (B/\lambda_s)\ q_{si} \quad (8)$$

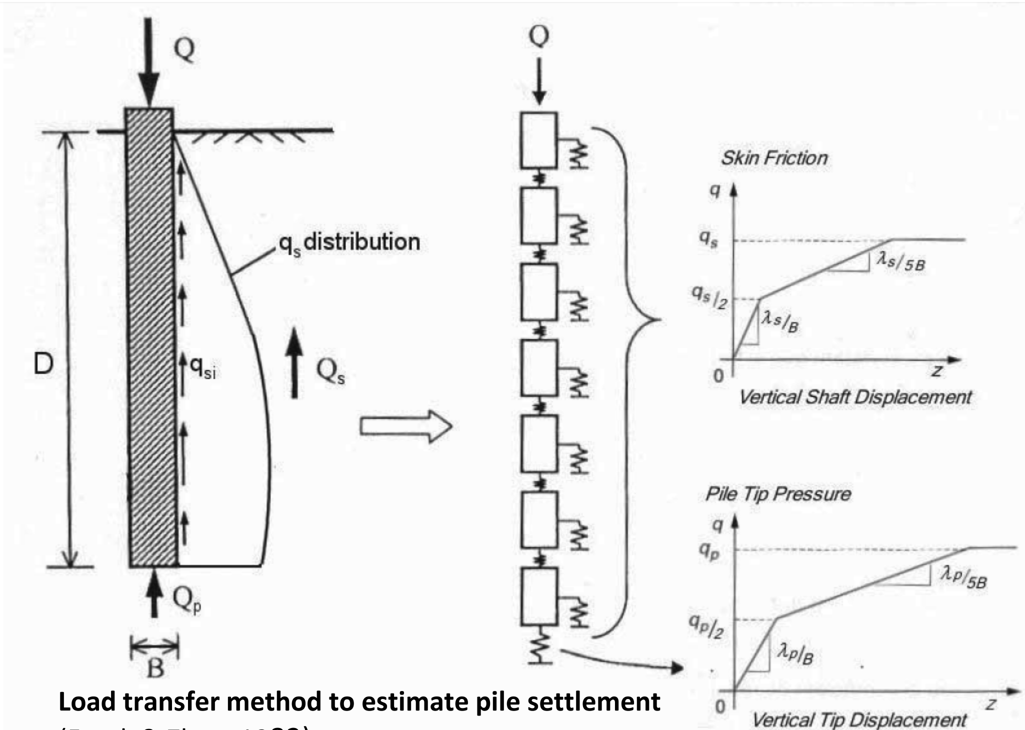
where B is the diameter of the pile,

qsi the estimated shaft friction of the ith element against the soil but limited by to a maximum of qs as shown in Fig.2 – values are given in Bustamante et al. (2009) and

- λs a factor which

- varies from 0.8 EM in coarse soils to 2 EM in fine soils up to a stress of qs /2

- and is 5 times smaller above the qs / 2 stress.



Load transfer method to estimate pile settlement (Frank & Zhao, 1982).

Description and Characteristics of 418 loaded and analyzed piles

Group Code	Type No.	Pile[2] Qty	B[3] (mm)	D[4] (m)	Pile Description
1	1	8	500-2,000	11.5-23	Pile or Barrette Bored in the dry
	2	64	270-1,800	6-78	Pile and Barrette Bored with Slurry
	3	2	270-1,200	20-56	Bored and Cased Pile (permanent casing)
	4	28	420-1,100	5.5-29	Bored and Cased Pile (recoverable casing)
	5[1]	4	520-880	19-27	Dry Bored Piles / or Slurry Bored Piles with Grooved Sockets / or Piers (3 Types)
2	6[1]	50	410-980	4.5-30	Bored Pile with a single or a double-rotation CFA (2 types)
3	7	38	310-710	5-19.5	Screwed Cast-in-Place
	8	1	650	13.5	Screwed Pile with Casing
4	9[1]	30	280-520	6.5-72.5	Pre-cast or Pre-stressed Concrete Driven Pile (2 types)
	10	15	250-600	8.9-20	Coated Driven Pile (concrete, mortar, grout)
	11	19	330-610	4-29.5	Driven Cast-in-Place Pile
	12	27	170-810	4.5-45	Driven Steel Pile, Closed End
5	13	27	190-1,22	8-70	Driven Steel Pile, Open End
6	14	23	260-600	6-64	Driven H Pile
	15	4	260-430	9-15.5	Driven Grouted [5 or 6] H Pile
7	16	15	-	3.5-2.5	Driven Sheet Pile
1	17	2	80-140	4-12	Micropile Type I
	18	8	120-810	8.5-37	Micropile Type II
8	19	23	100-1,220	8.5-67	SGP [5] Micropile (Type III) / or SGP Pile
	20	20	130-660	7-39	MRP [6] Micropile (Type IV) / or MRP Pile

[1] Some types may include several sub-types [2] Some piles subjected to several tests. [3] Minimum and maximum nominal diameter B. [4] Minimum and maximum full embedment depth D. [5] involving a Single Global Post grouting. [6] with Multiple Repeatable Post grouting.

Values for the tip bearing factor K_p

Group Code	Clay & Silt	Sand, Gravel	Chalk	Marl and Limestone	Weathered Rock
1	1.25	1.2	1.6	1.6 *	1.6
2	1.3	1.65	2.0	2.0	2.0
3	1.7	3.9	2.6	2.3	2.3
4	1.4	3.1	2.4	2.4 *	2.4 *
5	1.1	2.0	1.1	1.1 *	1.1 *
6	1.4	3.1	2.4	1.4 *	1.4 *
7	1.1	1.1	1.1	1.1 *	1.1 *
8	1.4	1.6	1.8	1.8	1.5*

* A higher k_p value can be used but must be proven by a load test

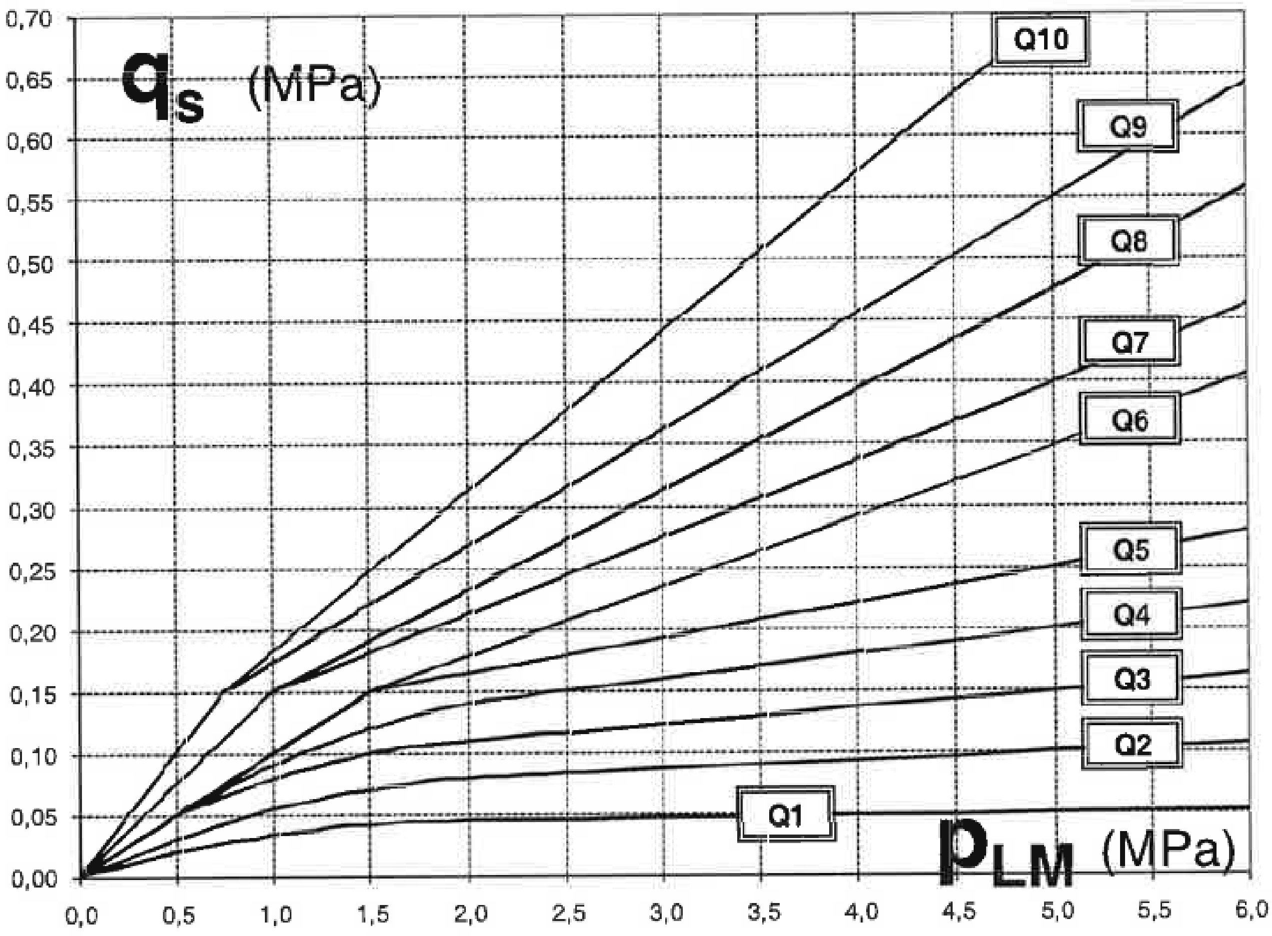
Selecting the Qi line to obtain the limit unit skin friction values q_s

Pile Type No.	Clay, Loam	Sand, Gravel	Chalk	Marl, Limestone	Weathered Rock
1	Q2	Q2*	Q5	Q4	Q6**
2	Q2	Q2	Q5	Q4	Q6**
3	Q1	Q1	Q1	Q2	Q1**
4	Q1	Q2	Q4	Q4	Q4**
5	Q3	Q3*	Q5	Q4	Q6
6	Q2	Q4	Q3	Q5	Q5**
7	Q3	Q5	Q4	Q4	Q4**
8	Q1	Q2	Q2	Q2	Q2**
9	Q3	Q3**	Q2	Q2**	(a)
10	Q6	Q8	Q7	Q7	(a)
11	Q2	Q3	Q6**	Q5**	(a)
12	Q2	Q2**	Q1	Q2**	(a)
13***	Q2	Q1	Q1	Q2	(a)
14***	Q2	Q2	Q1	Q2**	(a)
15***	Q6	Q8	Q7	Q7	(a)
16***	Q2	Q2	Q1	Q2**	(a)
17	Q1	Q1	Q1	Q2	Q6**
18	Q1	Q1	Q1	Q2	Q6**
19	Q6	Q8	Q7	Q7	Q9**
20	Q9	Q9	Q9	Q9	Q10**

* If ground properties permit. ** Use of a higher value must be proven by a load test. *** Cross section and perimeter estimated according to Fig.3.

(a) For pile groups No.9 – 16 and if rock condition permits penetration, choose the q_s value proposed for marl and limestone or a higher one if this can be proven either by a load test or by reference to an existing example in the same local area.

Direct Design using PMT Data. Chart for unit skin friction q_s



Software for geotechnical data

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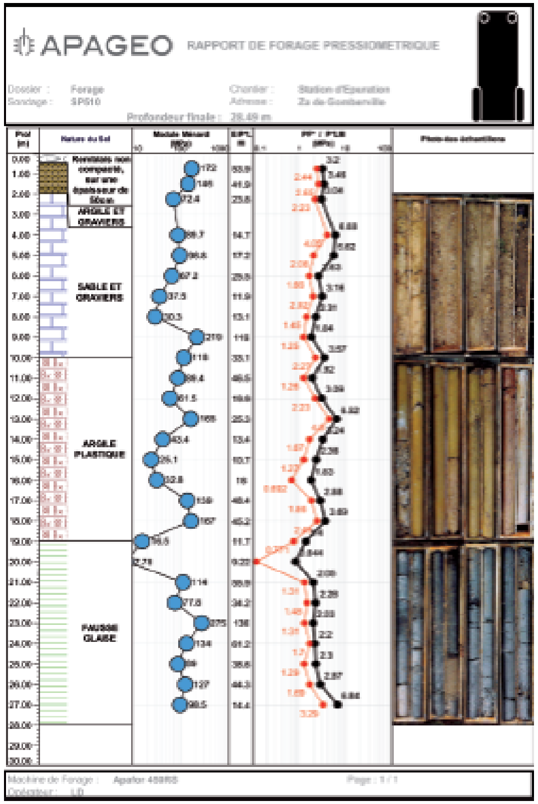
SOFTWARE
FOR GEOTECHNICAL DATA

THE +

- Easy to use and intuitive interface
- Personalized tables (diagraphy, graphs, reports)
- Easy manual data input
- Several work stations
- Compatible with all the recent versions of Windows

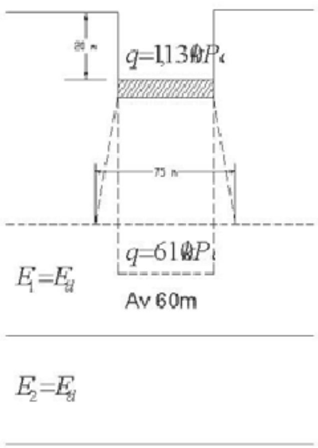


For each application, manual data input allows to complete data collected in soil.

GeoVISION® is a software that enables to extract, process and format of all data coming from APAGEO data loggers. Data is inserted through a USB device, memory stick, GPRS (option) or manual input. You can easily integrate notes, image or representative values of soil investigation.

SETTLEMENT UNDER HIGH RISE BUILDINGS IN CHICAGO

TERZAGHI LECTURE 2009
Clyde N. BAKER Jr



$E_{3,4,5} = 20 \times E_d$

$$E_B = \frac{3.2}{\frac{1}{E_1} + \frac{1}{0.85 \times E_2} + \frac{1}{E_{3,4,5}}}$$

$$E_B = \frac{3.2}{\frac{1}{94} + \frac{1}{0.85 \times 94} + \frac{1}{20 \times 94}}$$

$E_B = 135 MPa$

<u>Pressuremeter Data</u>

$E_{d_{Av}} = 94.3 Mpa$

$E^{+}_{Av} = 267 Mpa$

$\alpha = \frac{E_d}{E^+} = 0.35$, Use 0.4

<u>Settlement Calculation – Menard Empirical Method</u>

$$s_{Menard} = \frac{1.33}{3 \times E_B} q R_0 \left(\lambda_2 \frac{R}{R_0} \right)^{\alpha} + \frac{\alpha q \lambda_3 R}{4.5 E_1}$$

$\lambda_2, \lambda_3 = 1$ for a circle

$R_0 = 30 cm$

$s_{Menard} = 0.55 cm + 2.16 cm = 27.1 mm$

<u>Settlement Calculation – Elastic Theory</u>

$$s_{Elastic} = \frac{\mu_0 \mu_1 q B}{E}$$

$$s_{Elastic} = \frac{0.35 \times 0.92 \times 6{,}100 \times 75{,}000}{250{,}000} = 59 mm$$

Measured 24 mm

SETTLEMENT UNDER HIGH RISE BUILDINGS IN CHICAGO

TERZAGHI LECTURE 2009

Clyde N. BAKER Jr

Table 3 – Summary of Predicted and Surveyed Settlement for 111 S. Wacker

Location	Dead & live Load DL + LL	Est. Settlement DL + 0,5LL	Measured Settlement
Elastic Theory			
Core Mat on 34 Caissons	602,110 kN	1,9 cm	1,2 cm
Isolated Caisson	66,725	1,2 to 1,9 cm	2,2 cm
Ménard's Method			
Core Mat on 34 caissons	602,110	1,2 cm	1,2 cm
Isolated Caisson	52,490	1,9 to 2,5 cm	1,6 cm
NW Column on 3 Caissons	49,420	1,9 to 2,5 cm	1,6 cm
N Column on 3 Caissons	66,590	1,9 to 2,5 cm	2,0 cm

CONCLUSION OF SETTLEMENT '94

- **Soil non homogeneity disappears when using PMTs**
- **The ratio Settlement w / foundation width B remains constant**
- **Settlement curves are superposed when w/B is reported to measured p_{LM}**
- **Settlement curves w = f(q) can be predicted from PMTs results**
- **The Louis Ménard's bearing factor can be exactly derived from a simple analysis of the parameters of the loading test**
- **There is no size effect apparent in the settlement value of a square footing loaded up to the maximum safe load**
- **Then, the Terzaghi bearing capacity becomes questionable**

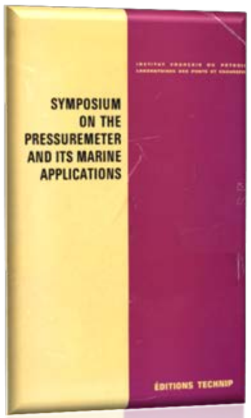
ASCE GSP No.41 Vol.2 (1994) after J.L BRIAUD

Pressuremeter or traditional soil mechanics???

	PRESSUREMETER RULES	TRADITIONNAL SOIL MECHANICS
BEARING CAPACITY	**Parameters :** P_L; P_0; h_e **Test :** pressuremeter all soils **Theory :** direct analysis (precise)	**Parameters** C, Φ, D, h, γ **Test :** triaxal if clay Only correlation if sand **Theory :** Prandtl, Therzaghi (approximate)
SETTLEMENT	**Parameters** E_P; α; $R(f(\alpha))$ **Test :** Pressuremeter, all soils **Theory :** - Deviatoric precise - Volumetric $f(\alpha)$	**Parameters** C_c; e_0; Boussinesq **Test :** oedometer, triaxal if clay, only correlation if sand **Theory :** - Therzaghi oedometer (approximate) - Correlation Schmertmann (approximate)

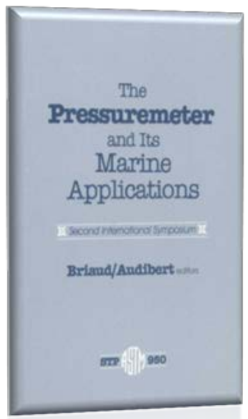
PRESSUREMETER THROUGH INTERNATIONAL SYMPOSIUMS AND NORMS

1982
Paris, FRANCE



23
papers

1986
Texas, USA

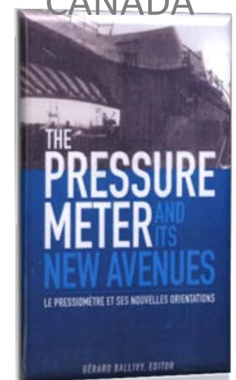


26
papers

1990
Cambridge, UK

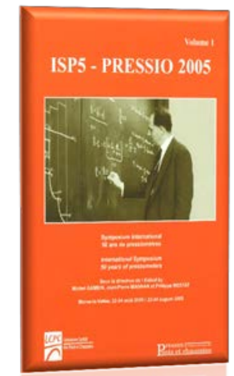
36
papers

1995
Sherbrooke, CANADA



54
papers

2005
Paris, FRANCE



72
papers

Applicable standards:

USA => ASTM D 4719
Europe => EN ISO 22476-4, DIN EN ISO 22476-4
Russia => GOST 20276-2012

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The probe

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Maximal work pressure : 25 or 50 MPa
Precision : pressure < 0,1 MPa
volume < 0.05 cm^3

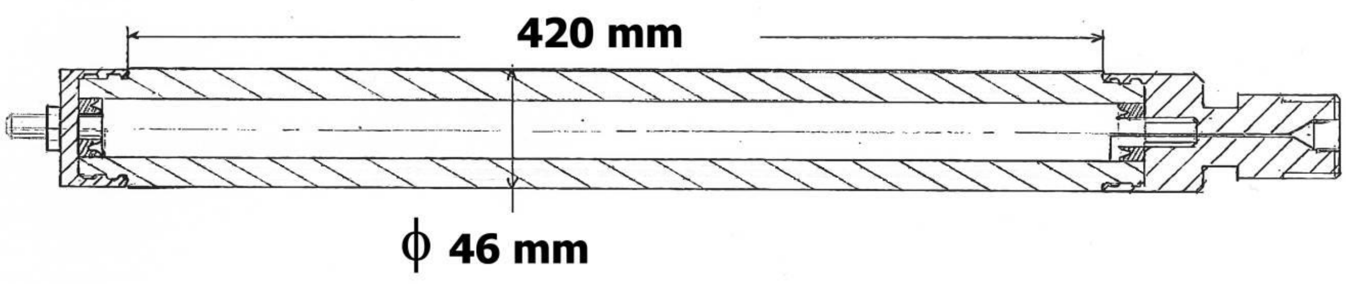
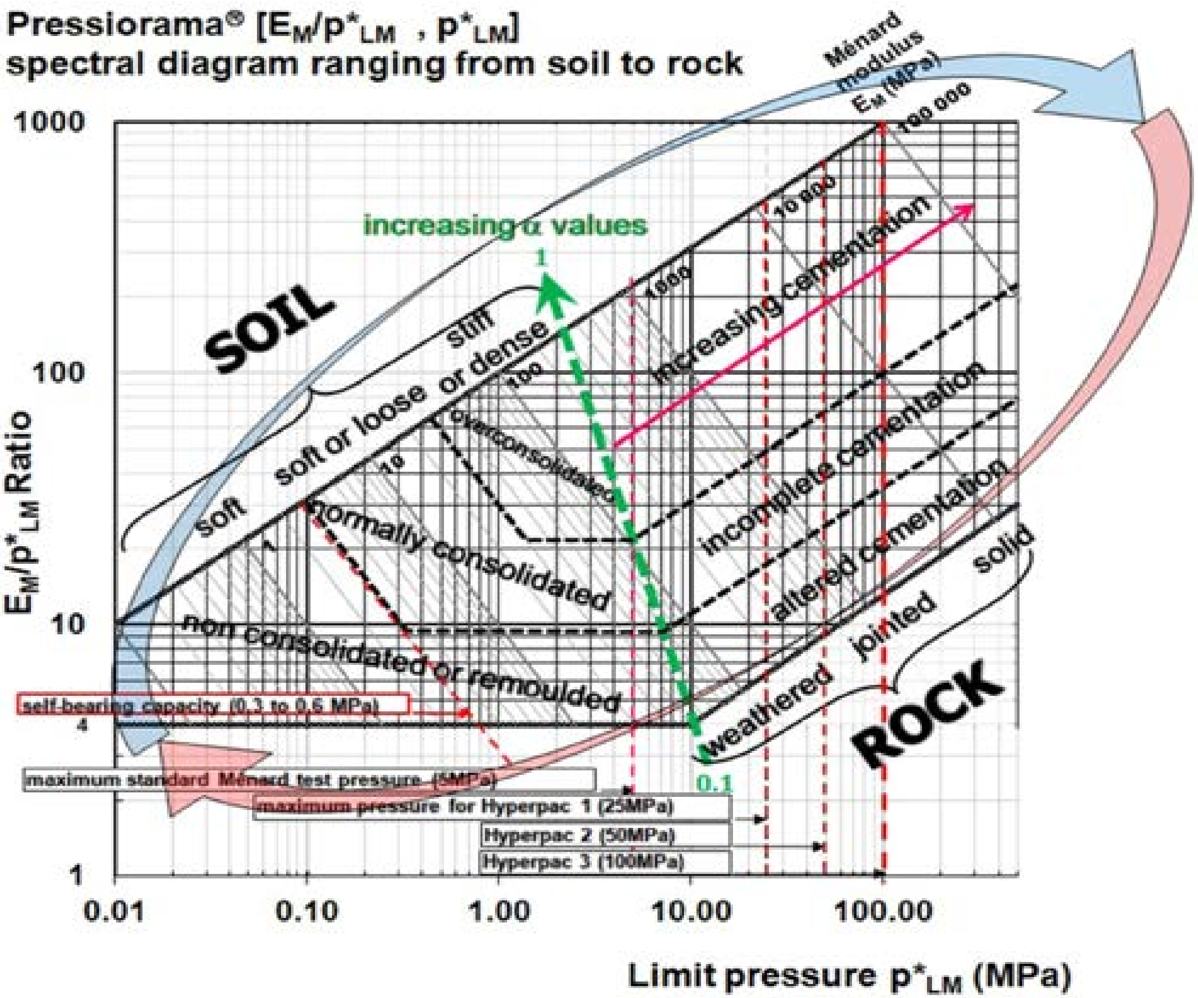
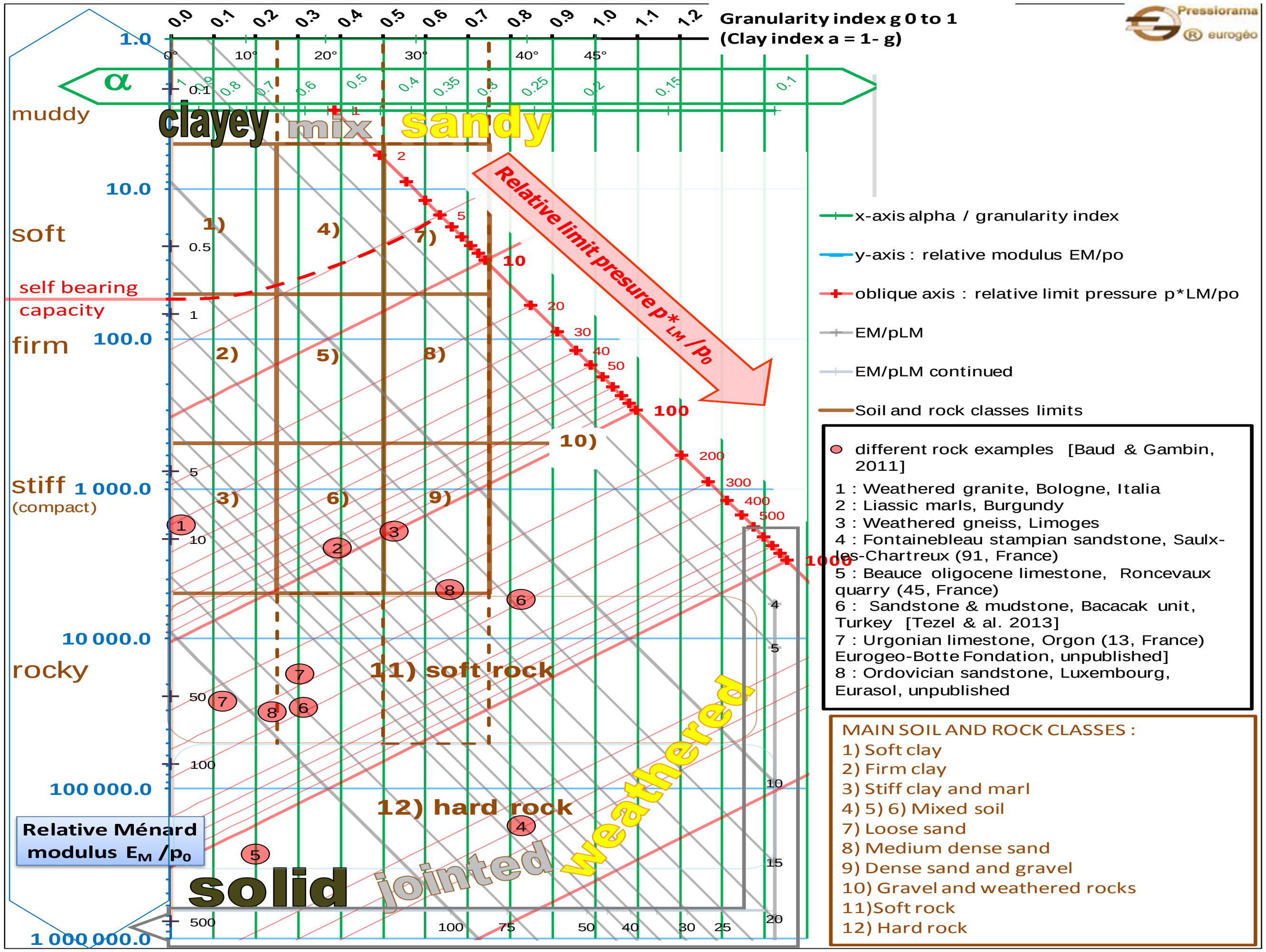


Schéma de la sonde 46mm THP

Classification of soils and rocks based on pressuremeter parameters



SOIL AND ROCK CLASSIFICATION IN A E_M/P_0, P^*_{LM}/P_0 DIAGRAM TO ASSIST FINDING THE RHEOLOGICAL FACTOR α



French national project Arscop

ARSCOP

A French national project to promote and foster geotechnical engineering based on pressuremeter

3 main objectives

- Consolidate and reinforce the French practice
- Continue with the development of the pressuremeter and its calculation methods
- Foster the pressuremeter outside France

Work Packages

Task 1: Develop testing devices and test procedures to increase reliability and performance of the test

Task 2: Develop calculation methods and calculation models from the use of pressuremeter by incorporating the latest advances made in the field of numercial modeling of geotechnical structures

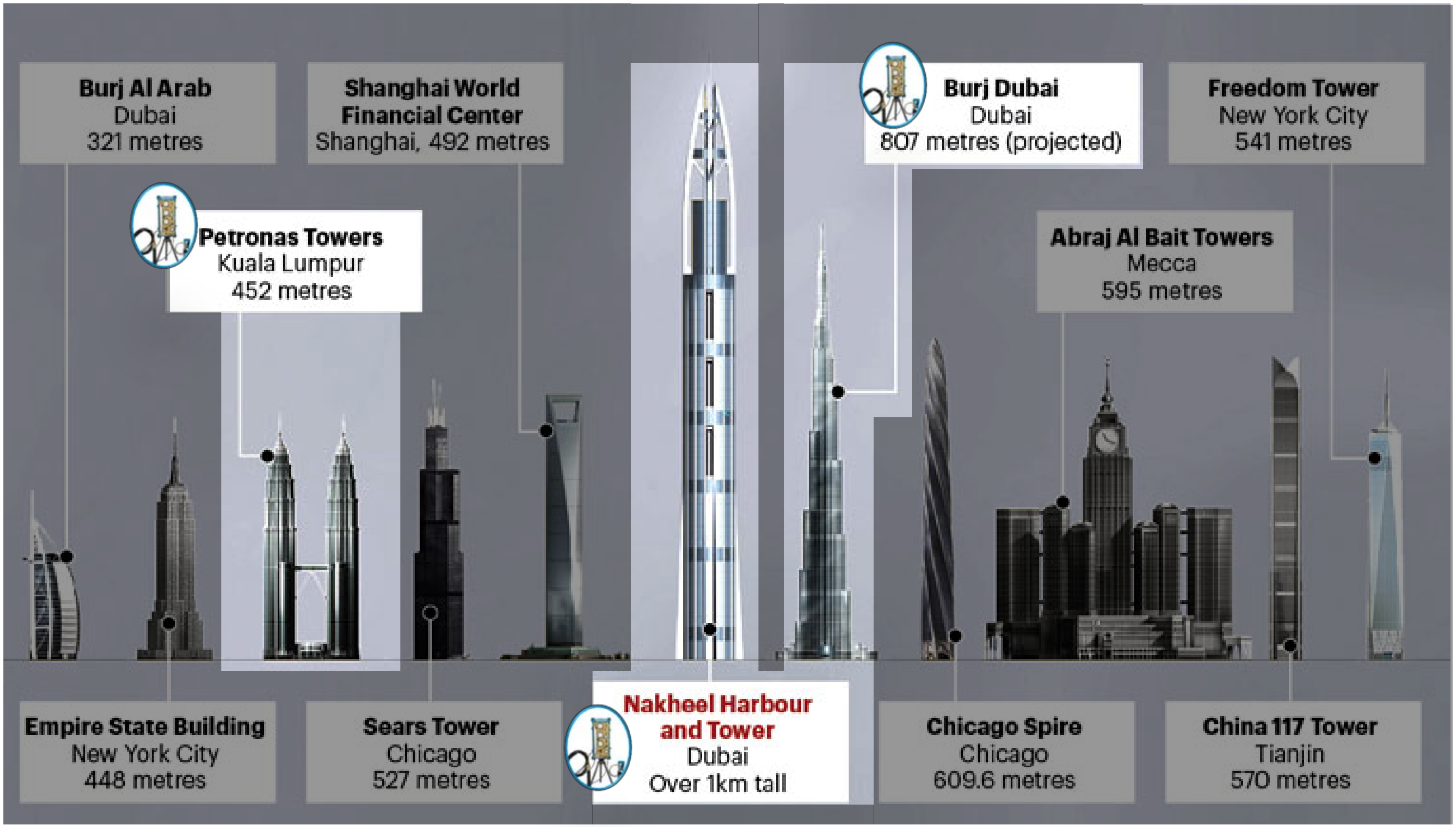
Task 3: Creation of database for calibration and validation of calculation methods using results obtained from pressuremeter tests

+

Communication and Dissemination

(research reports, articles, guidelines, recommandations, standards, etc.)

FOUNDATIONS DESIGNED WITH MÉNARD PRESSUREMETER



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