CPT/CPTU

- Available standards and guidelines
- Procedures
- Corrections
- Accuracy and precision
- Calibration requirements

CPT/CPTU AVAILABLE STANDARDS AND GUIDELINES

- International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE): IRTP (International Reference Test Procedure) 1999
- ASTM D: 5778-95, 1996
- BS: 1377, Part 9, 1990
- Dutch Standard, NEN 5140, 1996
- Norwegian Geotechnical Society Guidelines (1995)
- Eurocode, prEN 22476-1.10
- And other National Standards/codes

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Coming European Standard

CEN/TC 341

Date: 2004-03

prEN 22476-1.10

Ground investigation and testing — Field testing

— Part 1: Electrical cone and piezocone penetration tests (CPT and CPTU)

— Part 15: Mechanical cone penetration test (CPT)

Present stage : CEN Enquiry

Plan to be valid: 2007 **(Later to become ISO standard)**

Untill then IRTP(1999) is the official international document

NGI

ASTM D 5778 (1995/2000)

Designation: D 5778 – 95

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils[1]

NGI

Main elements of IRTP/new Eurocode on CPT/CPTU prEN 22476-1.10

- Equipment
- Procedures
- Corrections
- Other aspects

Main elements of IRTP/new Eurocode on CPT/CPTU prEN 22476-1.10

Equipment:

- Cone apex angle : 60 degr.
- Diameter : 36 mm (opens up for range : 25 to 50 mm)
- Area friction sleeve 150 sq.cm
- Prefered filter location for CPTU behind cone

Procedures

Corrections

Other aspects

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Pore Pressure

- The pore pressure, u, is the fluid pressure measured during penetration and dissipation testing. The pore pressure can be measured at several locations as shown in Figure 2.3.

- The following notation is used:
- u_1: Pore pressure measured on the cone face
- u_2: Pore pressure measured at the cylindrical extension of the cone
- u_3: Pore pressure measured immediately behind the friction sleeve

Note: The measured pore pressure varies with soil type, in situ pore pressure and filter location on the surface of the cone penetrometer. The pore pressure consists of two components, the original in situ pore pressure and the additional or excess pore pressure caused by the penetration of the cone penetrometer into the ground.

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Filter location

Theoretical studies and practical experience have shown that the measured pore pressure varies with the soil type and also the location of the filter element.

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Example of effect of pore pressure location on measured pore pressure

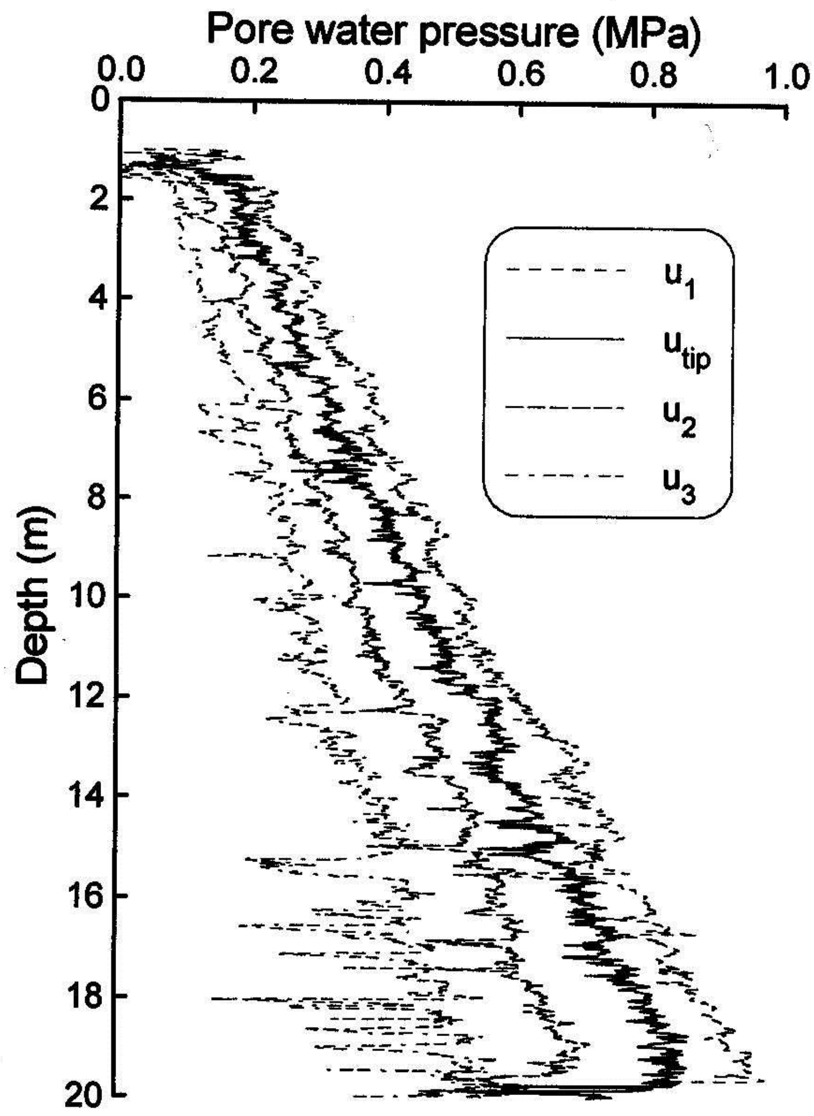
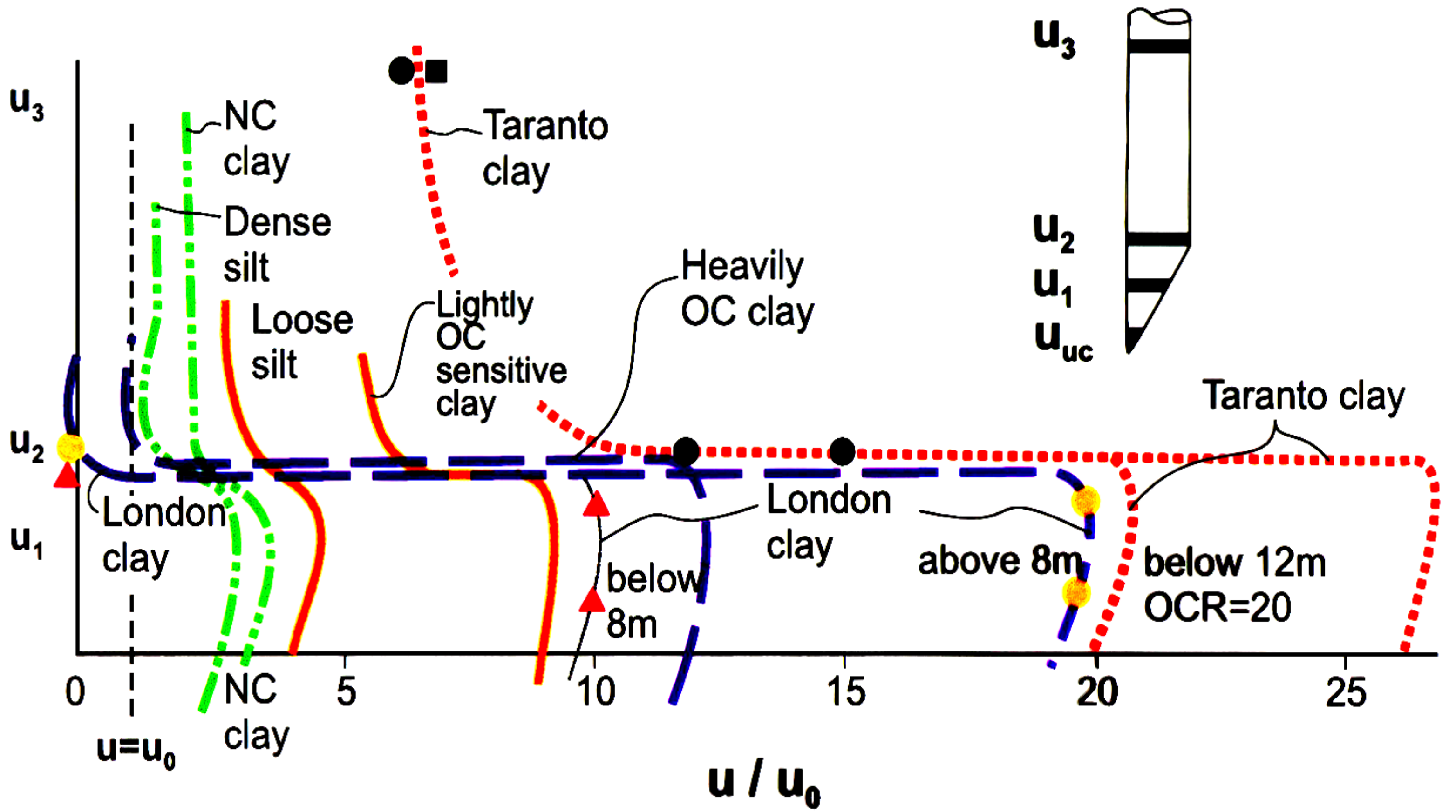


Fig 3.

Bothkennar, UK soft clay

Measured pore pressure distributions



Filter location

The new European Standard (and also IRTP (1999))
refers to the location behind the cone (u_2) as the recommended filter location. The advantages of this filter location can be summarised as:

- **The filter is much less prone to damage and wear**
- **Measurements are less influenced by element compressibility**
- **Pore pressures measured can be used directly to correct cone resistance .**
- **Measured pore pressures during a dissipation test are less influenced by procedure (locking rods or not)**

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Main elements of new Eurocode on CPT/CPTU prEN 22476-1.10

Equipment

Procedures:

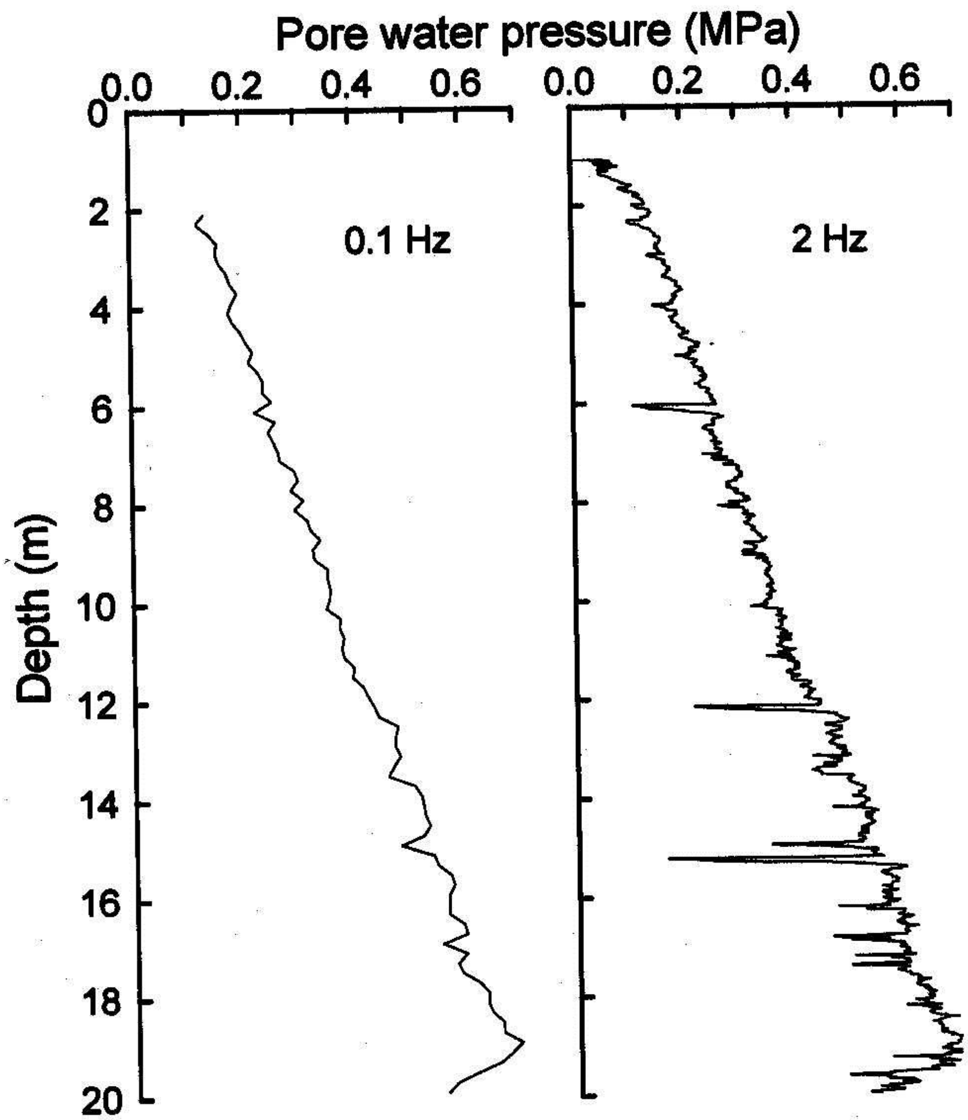
- Penetration speed : 2 cm/sec
- Log at least one set of readings every sec (2.0 cm)
- Requirements to saturation of pore pressure measurement system
- Dissipation tests: stop penetration and log u vs time

Corrections

Other aspects

NGI

Effects of frequency of readings on pore water pressure profile



Field saturation of piezocone

Onsøy, Norway 2001

Field saturation of Pagani piezocone

Onsøy, Norway 2001

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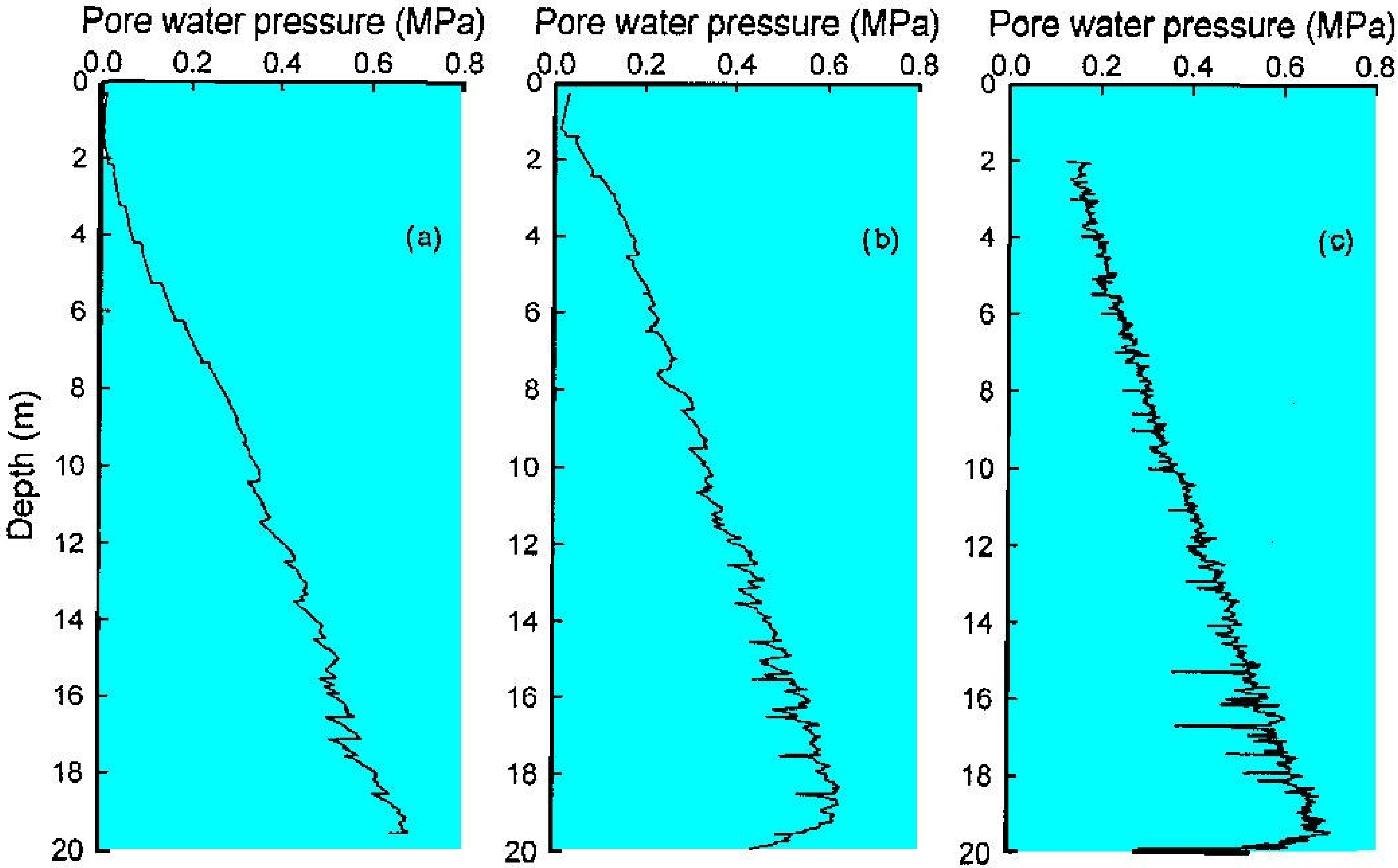
Importance of saturation on measured pore pressure response



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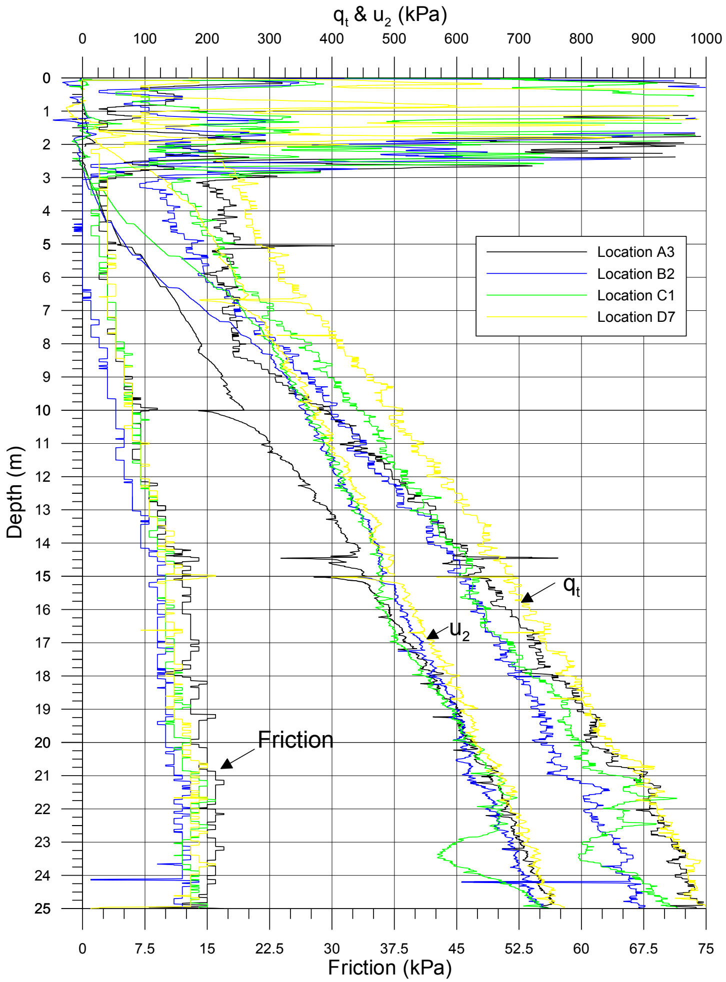
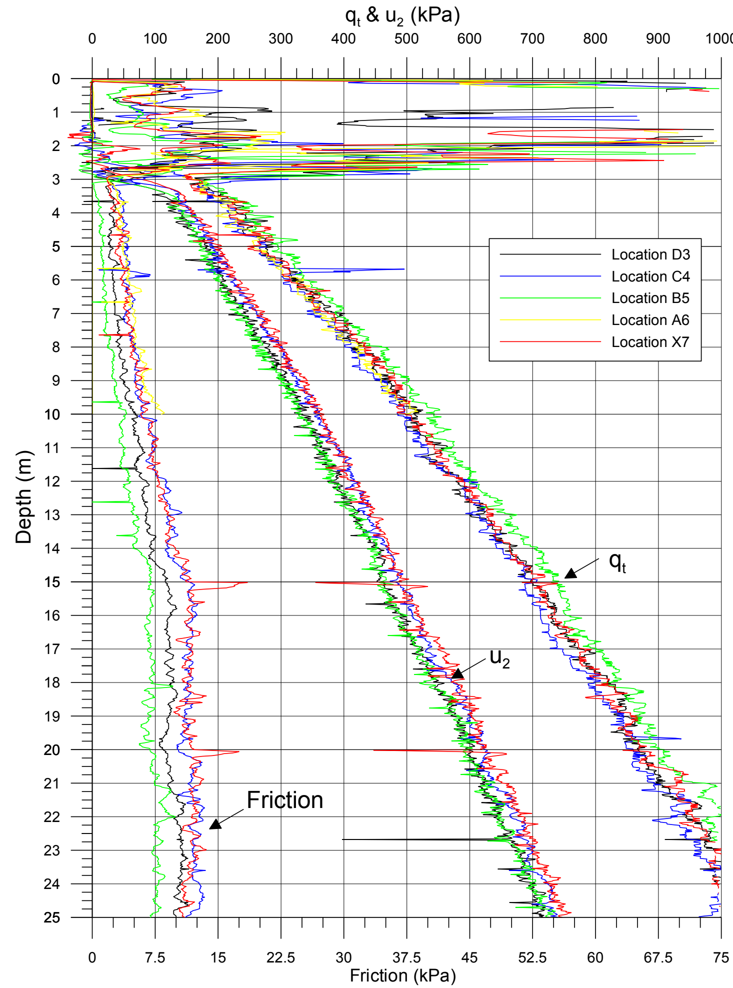
CPTUs at NGI's Onsøy site





Example of test series with bad saturation

Example of test series with satisfactory sturation

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Filter saturation

- Misleading results will be obtained if the filter and its measuring system is not fully saturated.
- Errors will then also occur in the calculation of q_t

Example of dissipation test

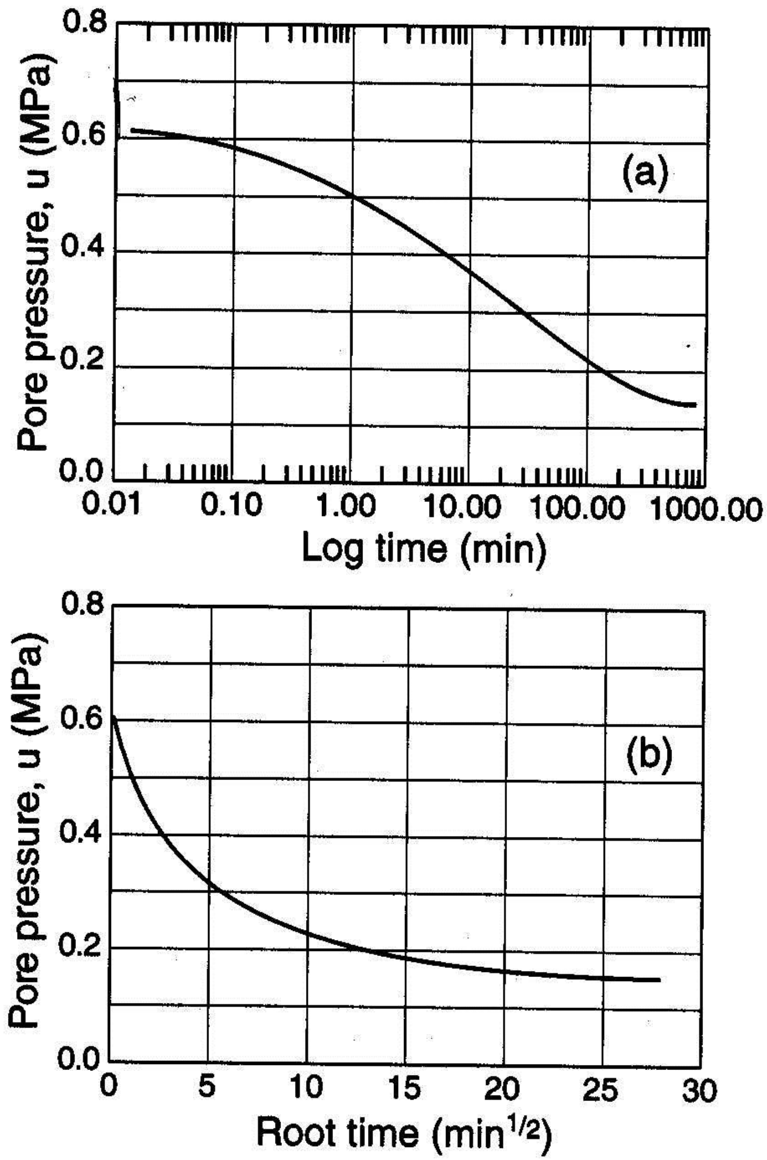

Fig 3.10

Required logging frequency according to prEN 22476-1.10

-1st minute at least: 1 Hz

-Thereafter may half every log (time) cycle

Main elements of new Eurocode on CPT/CPTU prEN 22476-1.10

Equipment

Procedures

Corrections:

- Pore pressure effects on cone resistance
- Effect of inclination

Other aspects

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Pore water pressure effects on q_c and f_s

- Due to the "inner" geometry of a cone penetrometer the ambient pore water pressure will act on the shoulder area behind the cone and on the ends of the friction sleeve.

- This effect is often referred to as "the unequal area effect" and influences the total stress determined from the cone and friction sleeve.

- For the cone resistance the unequal area is represented by the cone area ratio 'a' which is approximately equal to the ratio of the cross-sectional area of the load cell or shaft, A_n, divided by the projected area of the cone A_c .

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Piezocone Testing in Clay

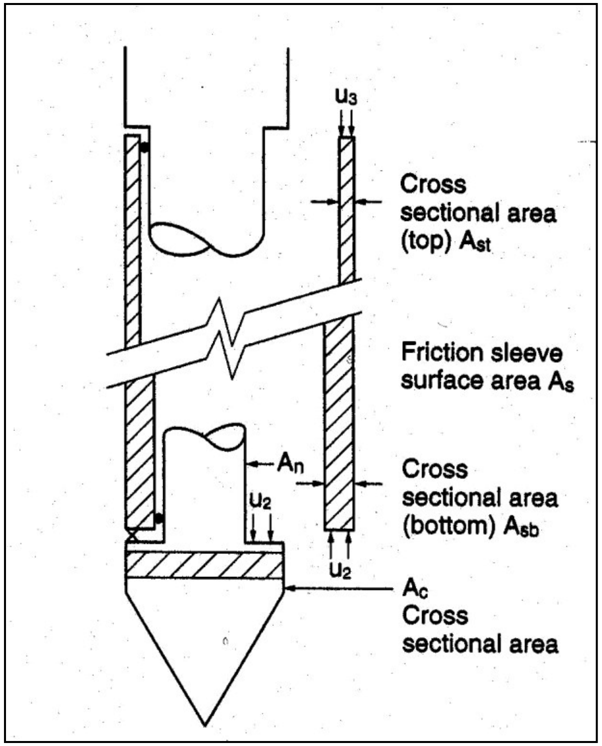
Correction for pore pressure effects on cone resistance:

$q_t = q_c + (1\text{-}a)u_2$

q_c = measured cone resistance

a = area ratio (0.3- 0.85)

u_2 = measured pore pressure behind cone



Simple chamber for calibration of a and b factors

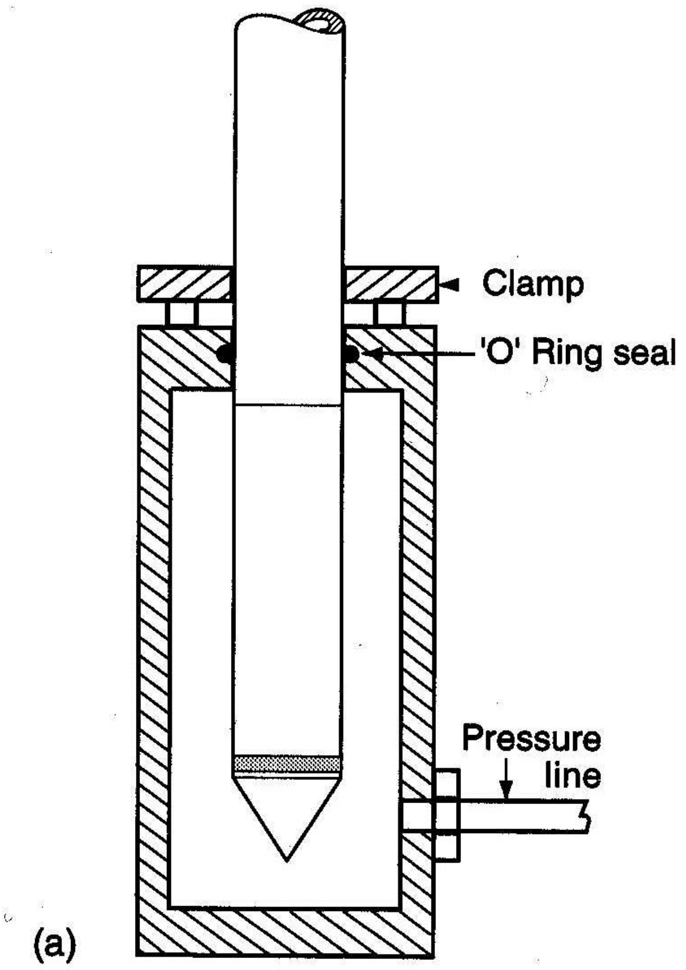


Fig 2.18a

Determination of area ratio, a, in calibration vessel

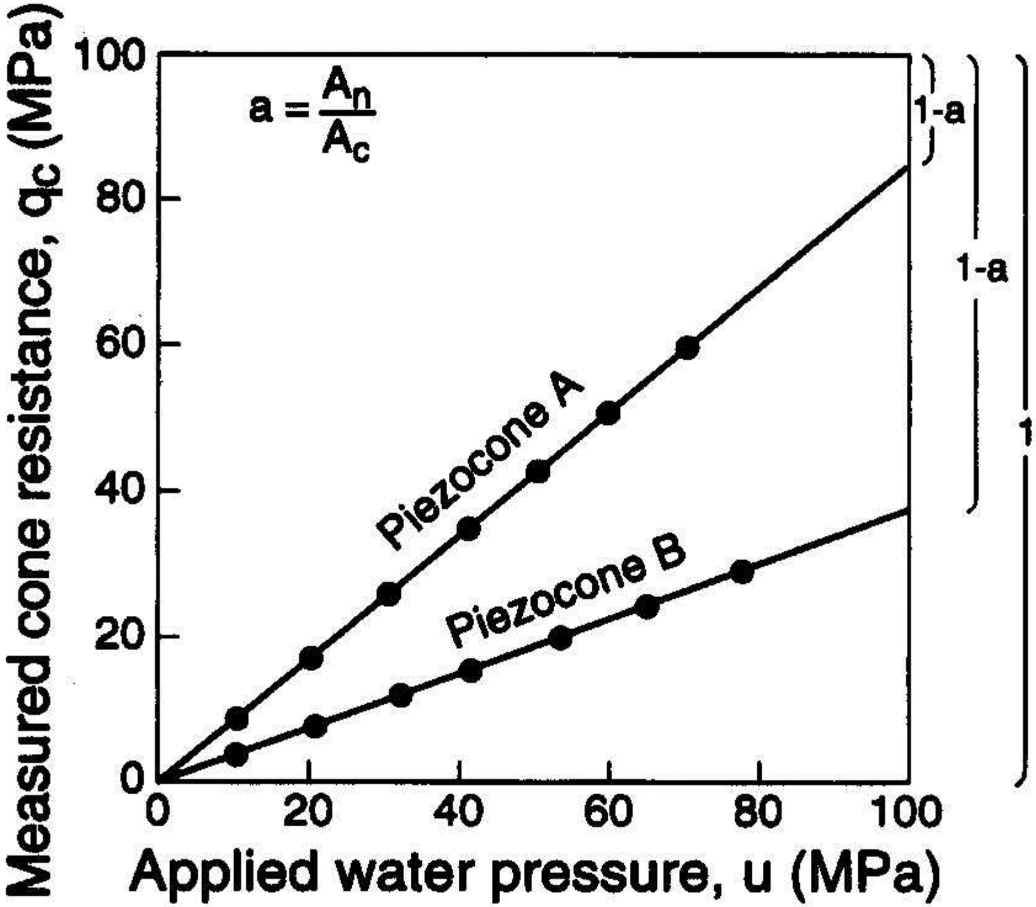
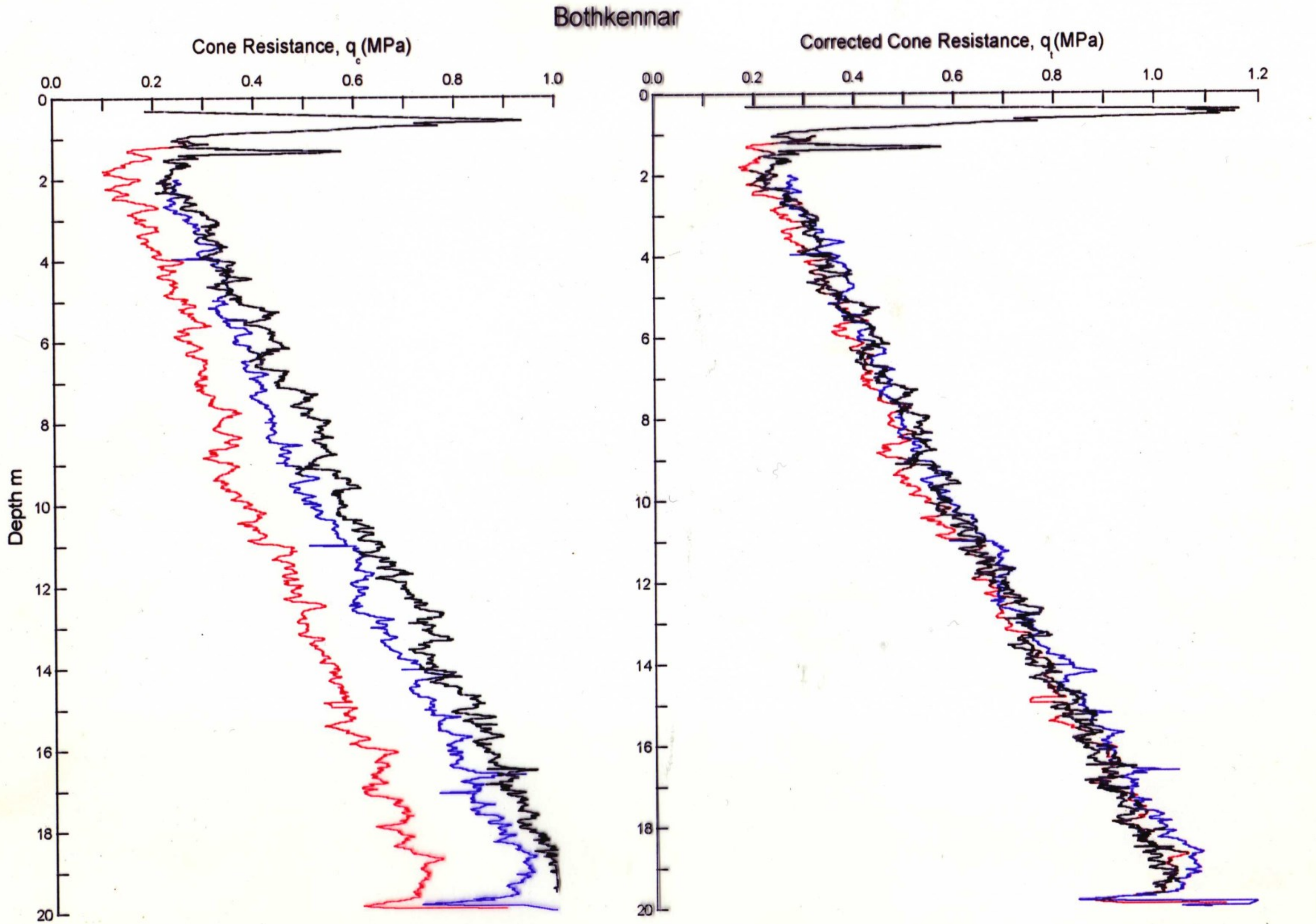


Fig 3.2

Effect of pore pressure on cone resistance



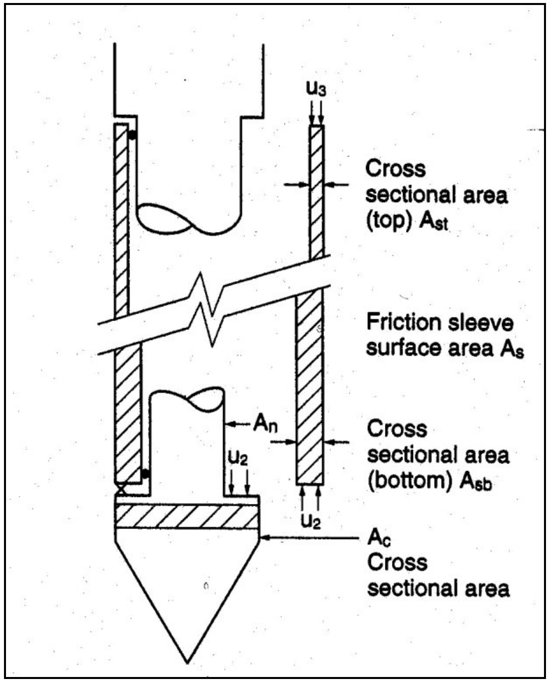
Cones with area ratio a = 0.59 to 0.9

Pore water pressure effects on f_s

When excess pore pressures are generated the pore pressures are normally different at the upper (u_3) and lower (u_2) ends of the sleeve.

The corrected sleeve friction, f_t, can be given by:

$$f_t = f_s - (u_2 . A_{sb} - u_3 . A_{st}) / A_s$$



Example of correcting f_s for pore pressure effects

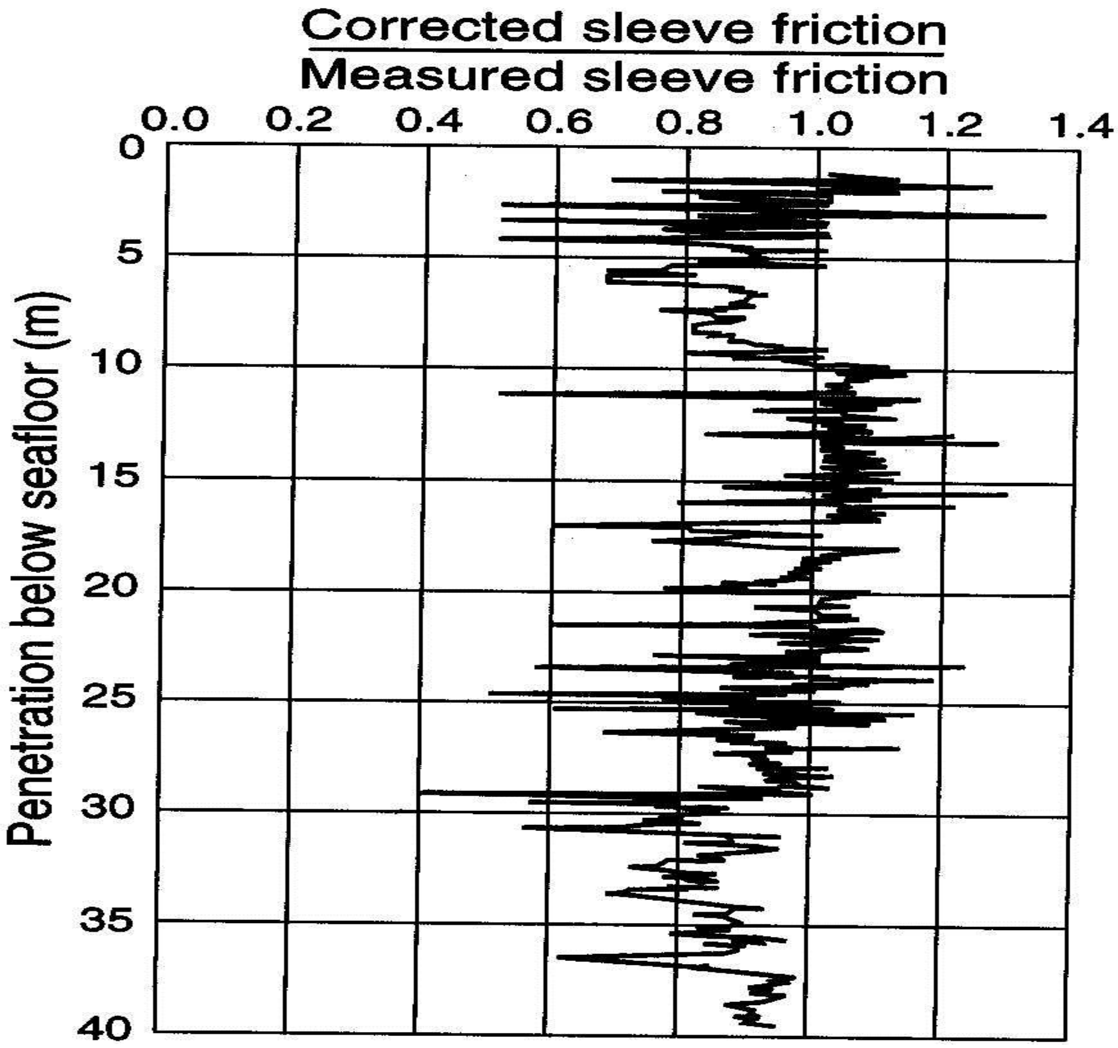
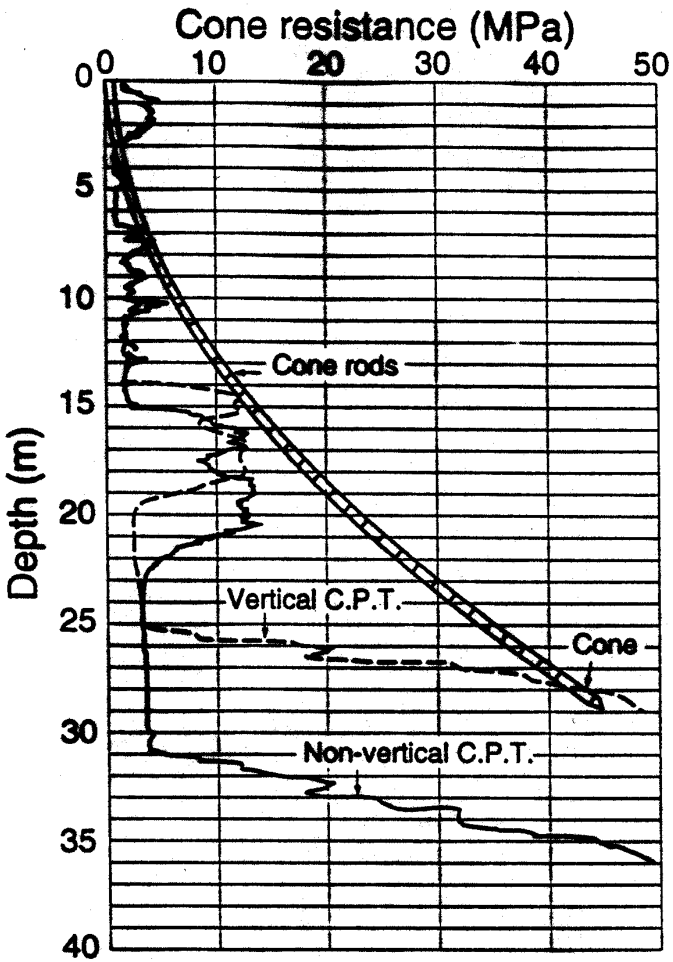


Fig 3.4

EFFECT OF VERTICALITY ON MEASURED DEPTH (FROM BRUZZI AND BATTAGLIO, 1987)



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CPT/CPTU

Penetration length and penetration depth

Penetration length and depth

- ***Penetration depth:*** **Depth of the base of the cone, relative to a fixed horizontal plane.**

- ***Penetration length*****: Sum of the length of the push rods and the cone penetrometer, reduced by the height of the conical part, relative to a fixed horizontal plane.**

- **Note: The fixed horizontal plane usually corresponds with a horizontal plane through the (underwater) ground surface at the location of the test.**

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Correction of penetration depth according to IRTP (1999)

$$z = \int_0^l C_h \cdot dl$$

z = penetration depth, in m;

l = penetration length, in m;

C_h = correction factor for the effect of the inclination of the cone penetrometer relative to the vertical axis

For single axis inclinometer : $C_h = \cos\alpha$

α is the measured angle relative to vertical axis

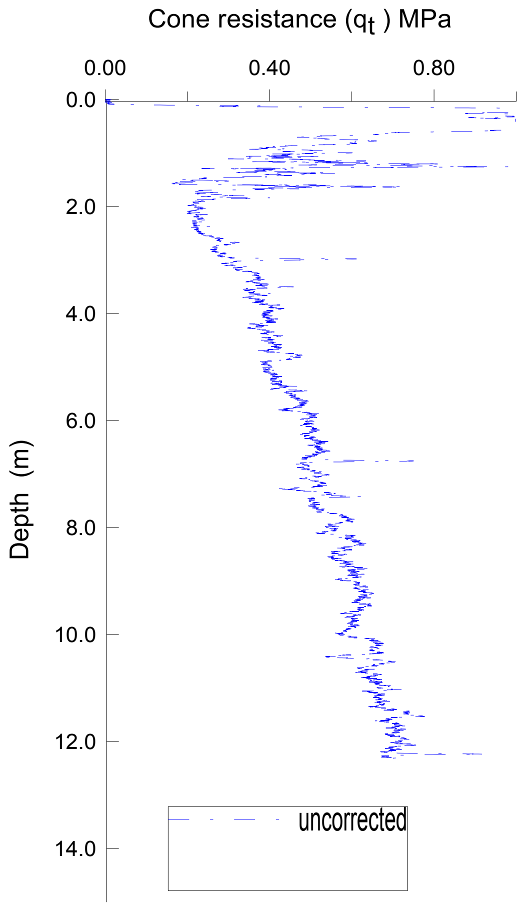
For bi-axial inclinometer: $C_h = (1 + \tan^2 \alpha + \tan^2 \beta)^{-1/2}$

α and β are the angles relative to vertical axis and perpendicular to each other

For Accuracy Classes 1, 2 and 3

NGI

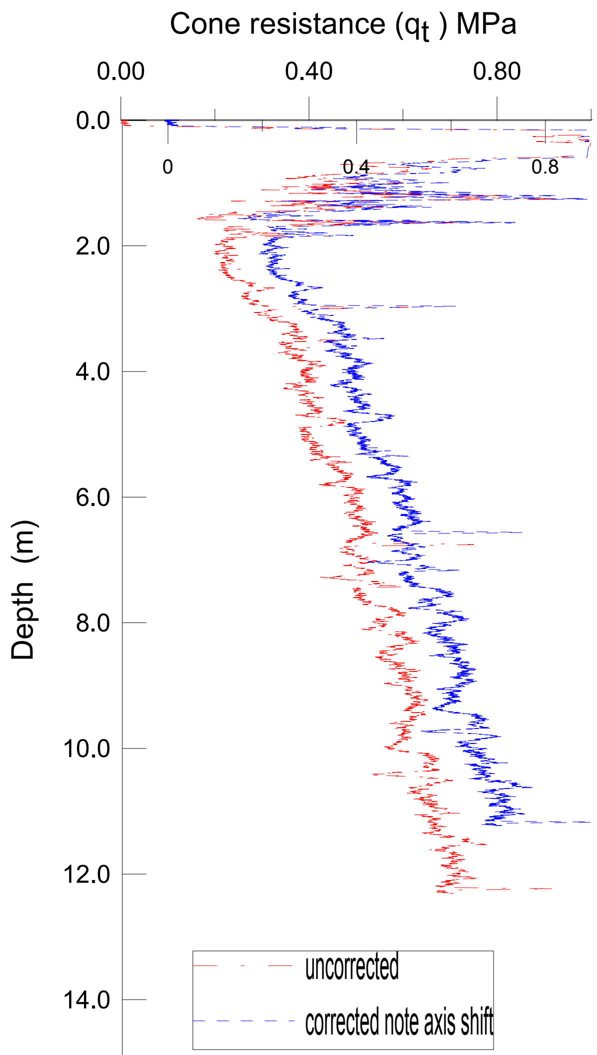
Effects of inclination, coiled rod system

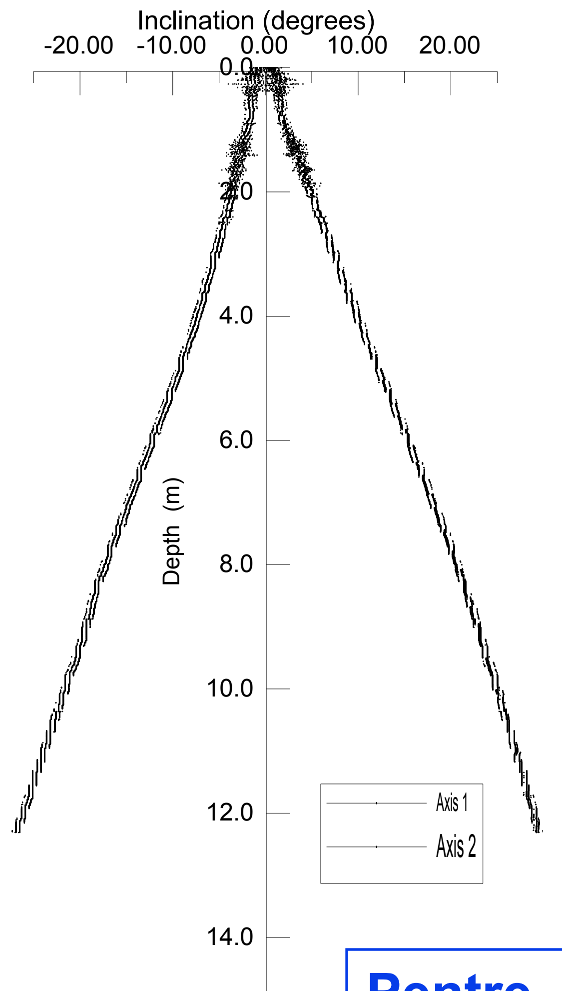


Pentre,UK

Powell,2001

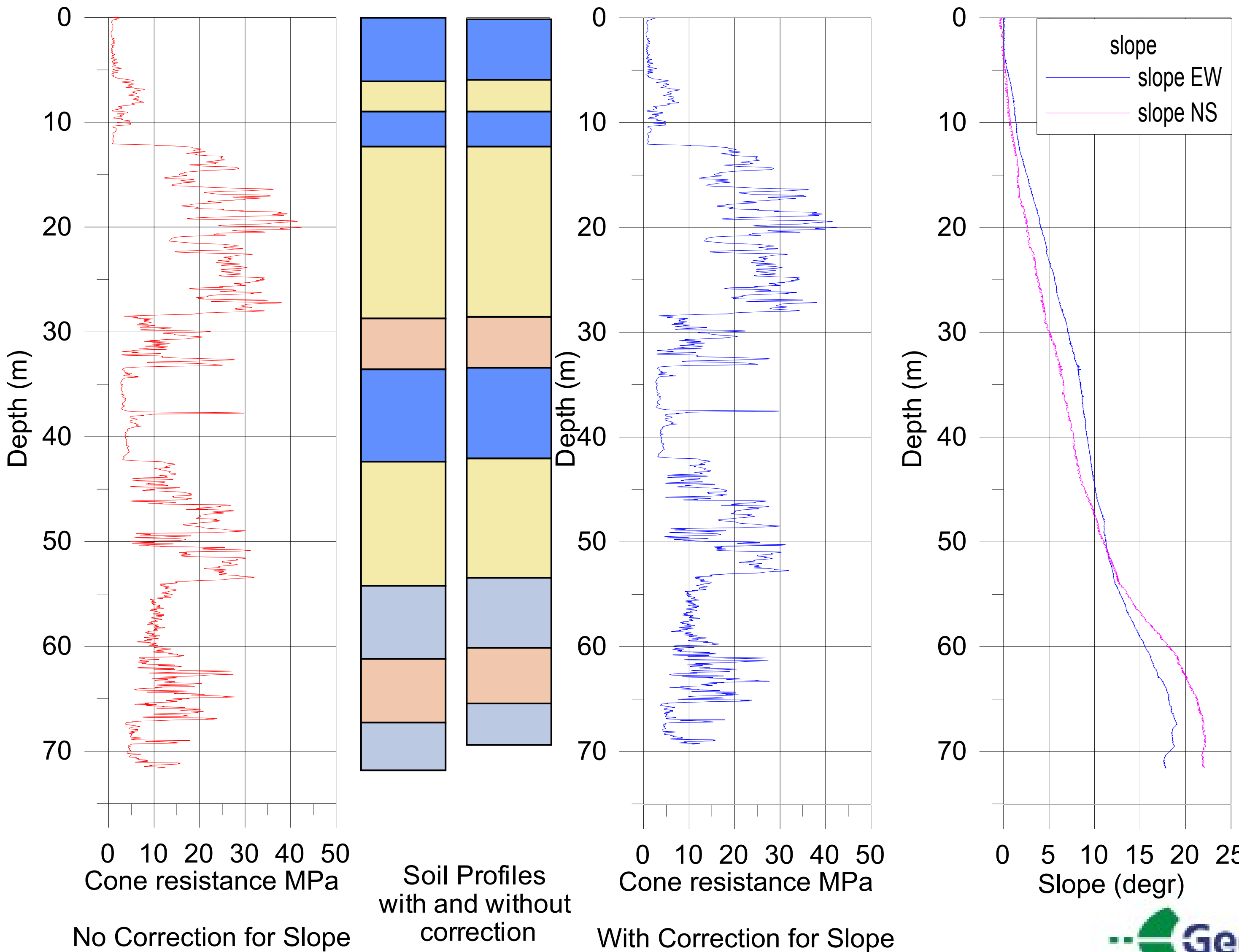
Effects of inclination, coiled rod system





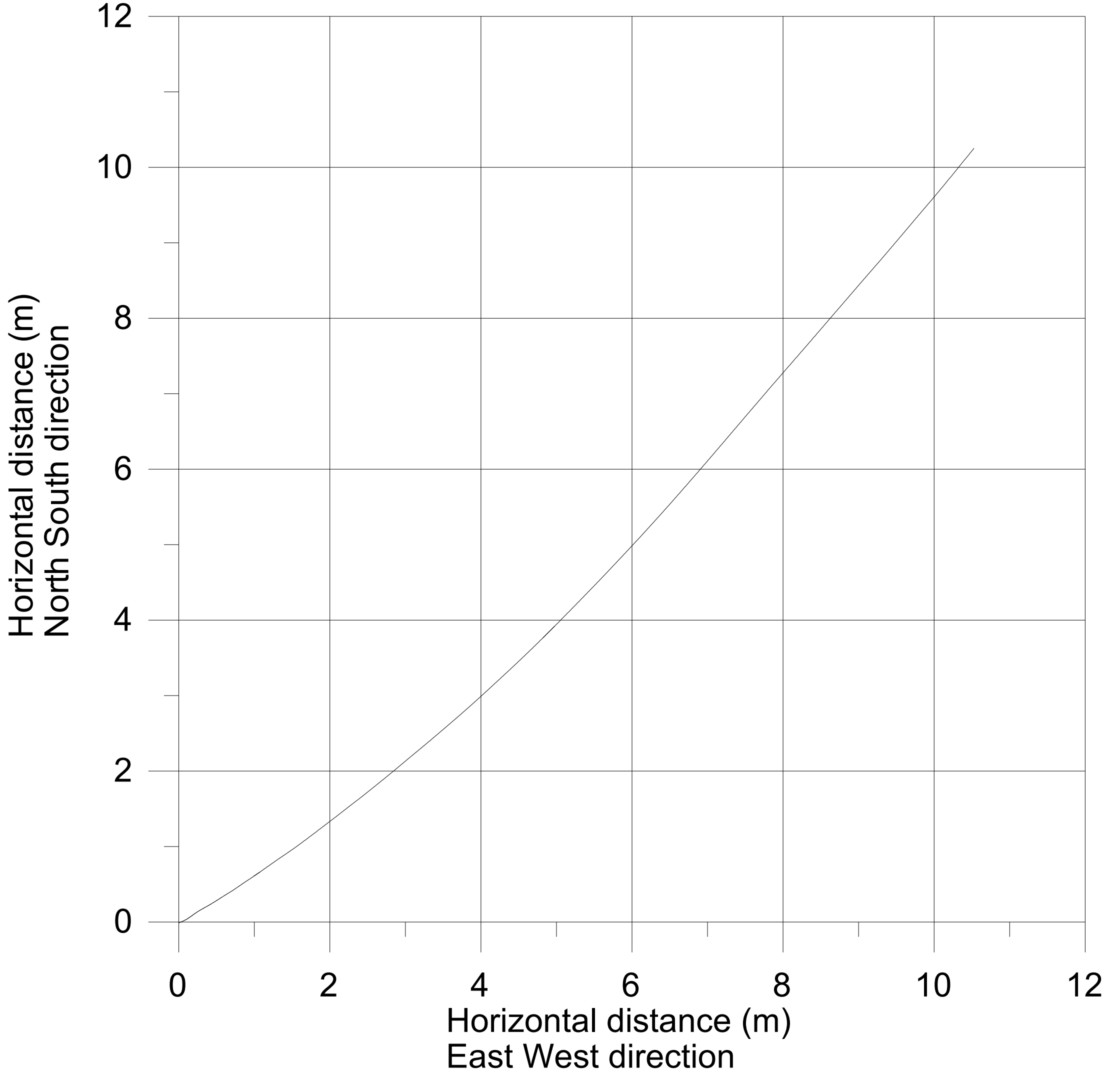
Pentre, UK

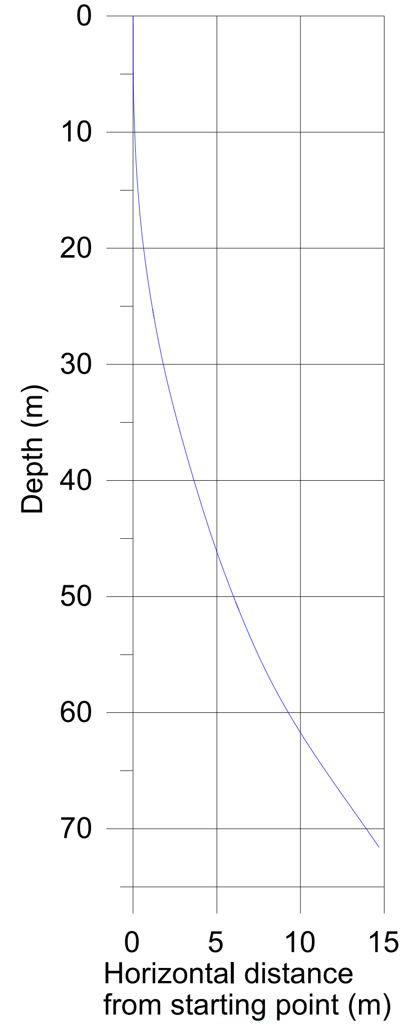
Example of depth correction



From Mandy Korff, Geodelft

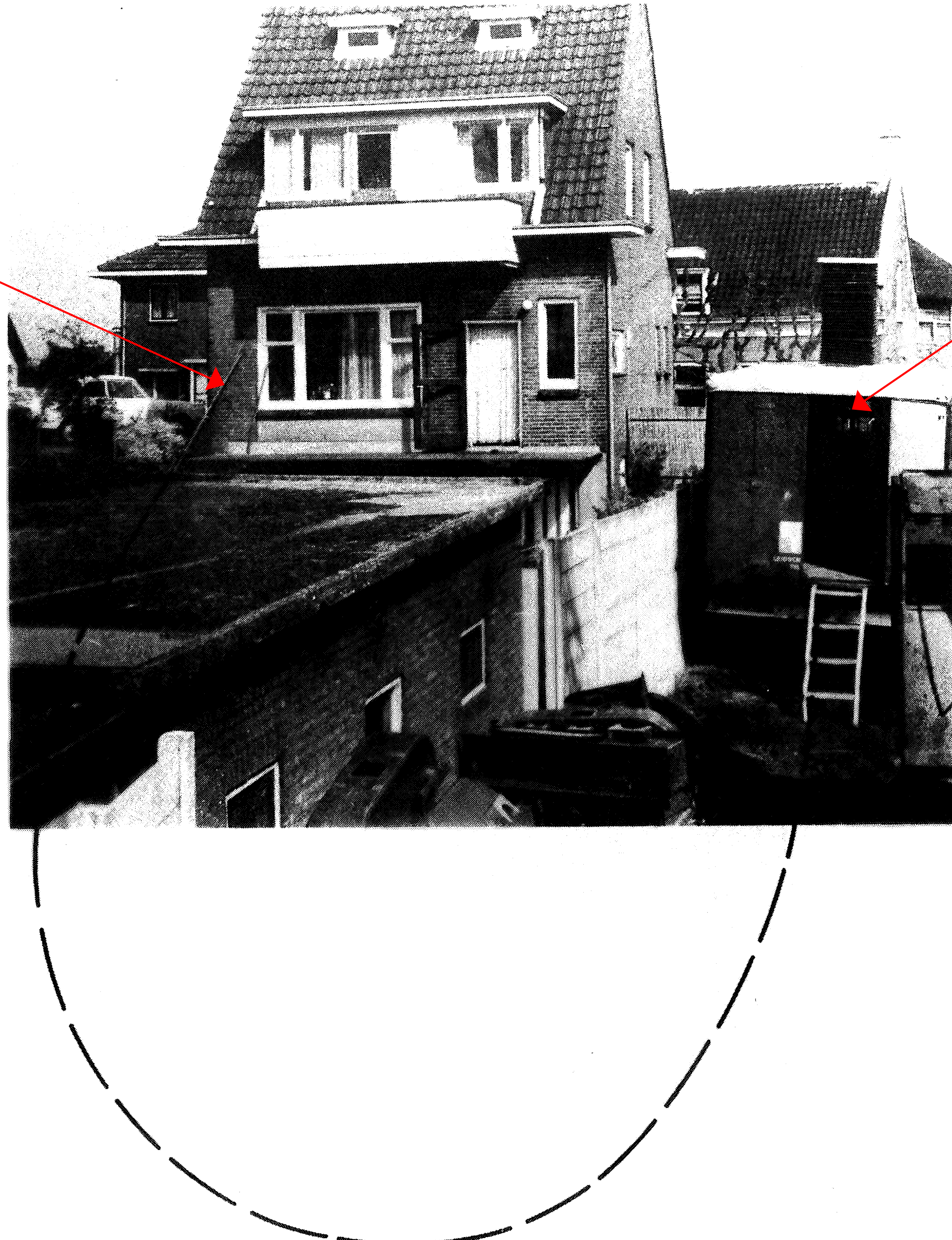
Example of effect of inclined test





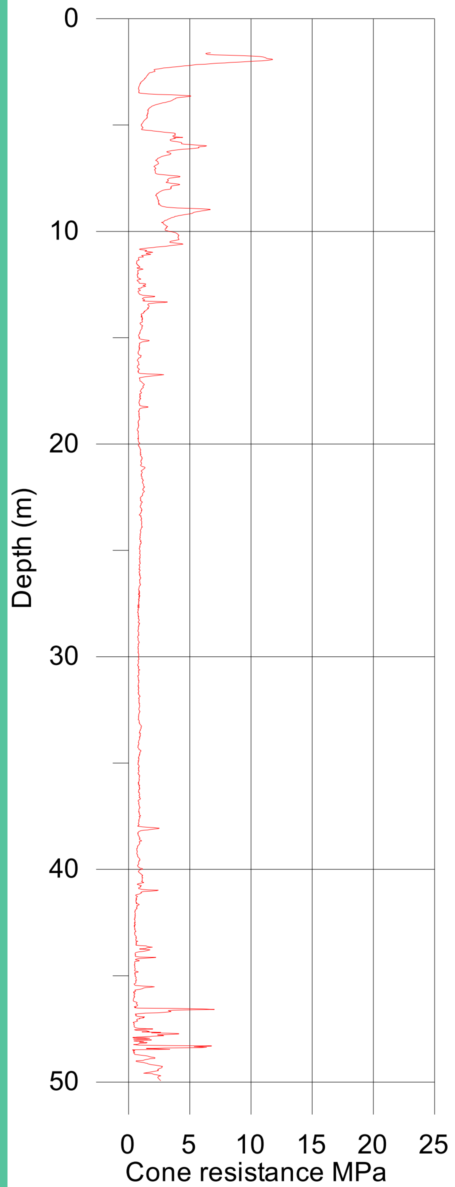
From Mandy Korff, Geodelft

Non-vertical CPT

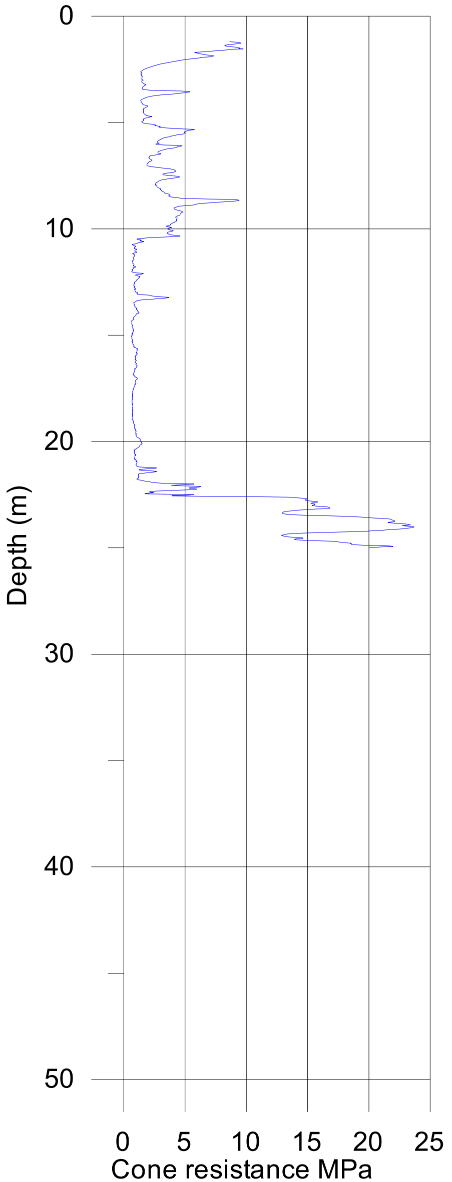


From Mandy Korff, Geodelft

Example of misleading CPT results without inclination measurement



No Slope Maesurement



With Slope Maesurement

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GeoDelft

Main elements of IRTP/new Eurocode on CPT/CPTU prEN 22476-1.10

- Equipment
- Procedures
- Corrections
- Other aspects
- Maintenance, calibration, requirements to accuracy, pore pressure response, wear, tolerances in dimensions,need for documentation when deviating from requirements, etc

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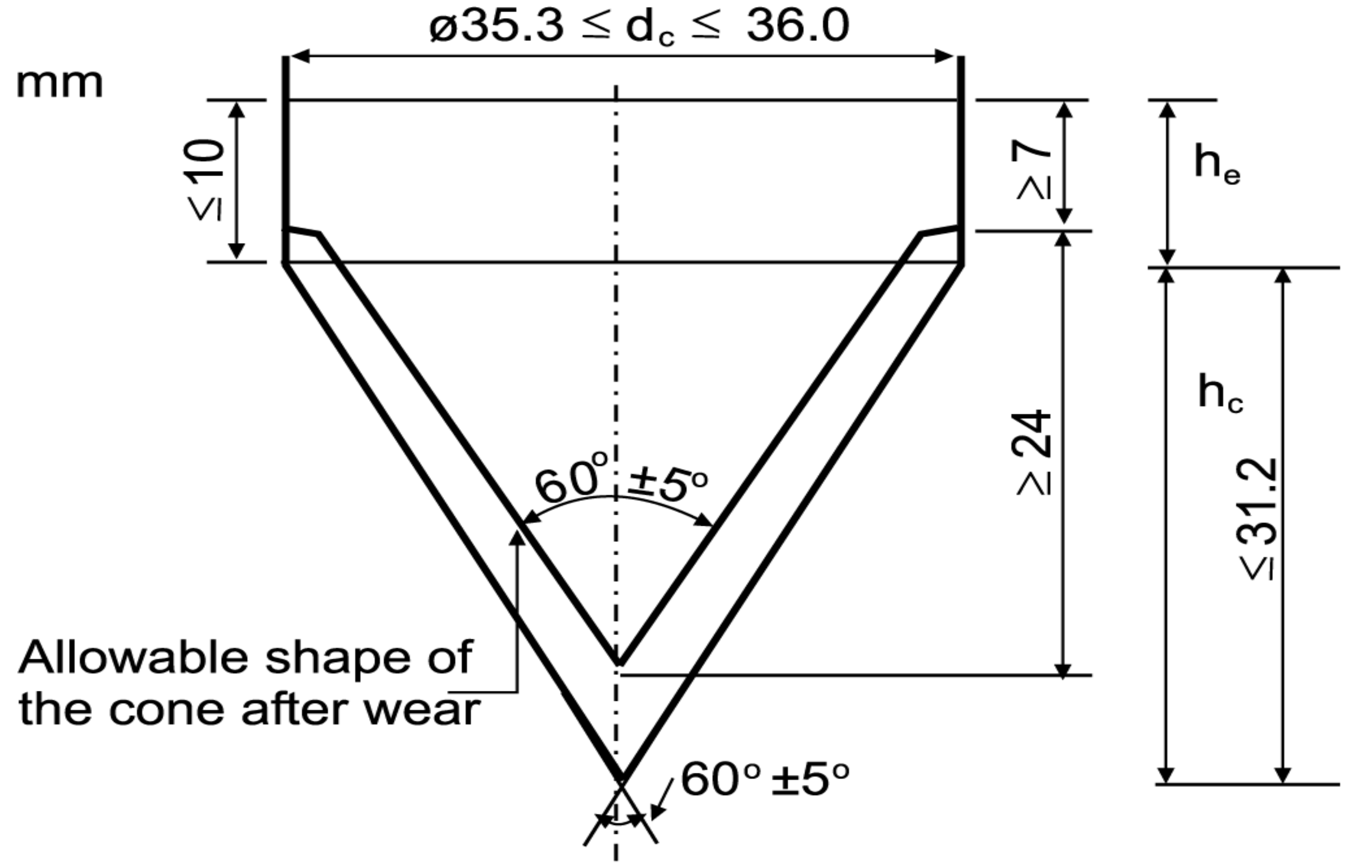
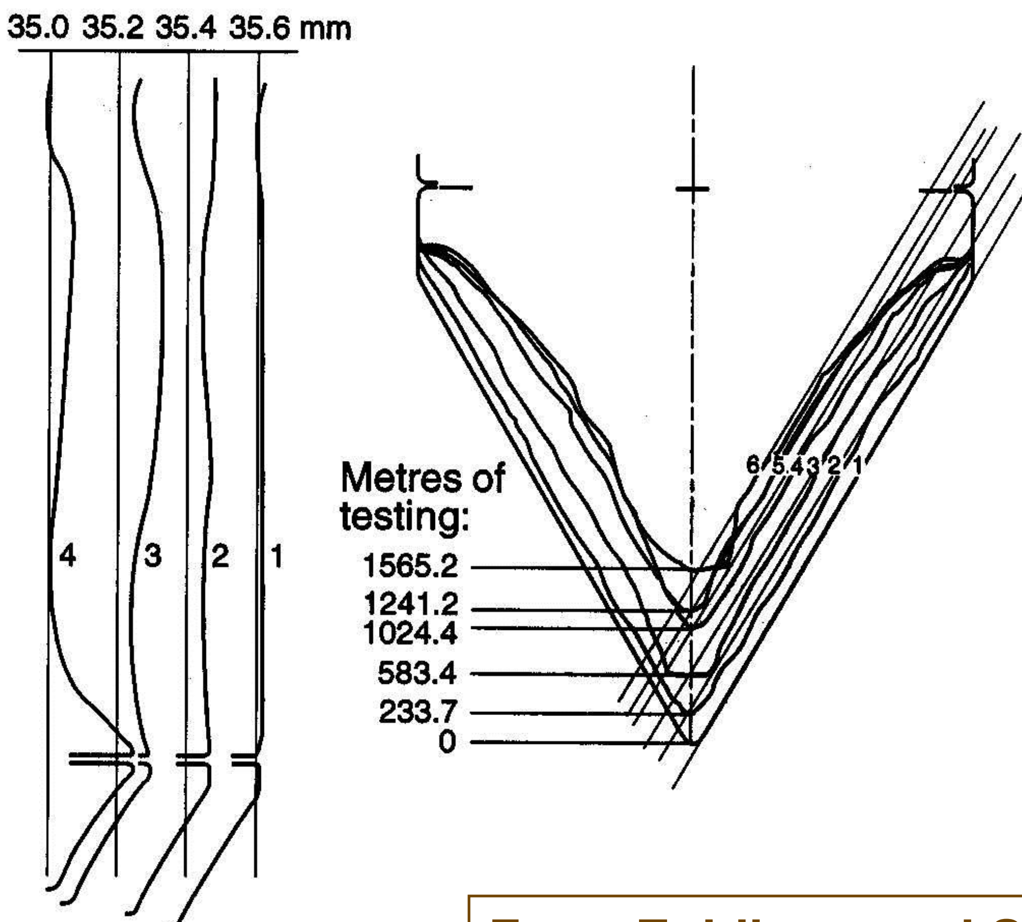
Cone geometry IRTP tolerances

Geometry in mm



Wear of cone and friction sleeve as function of meters penetrated



From Zuidberg and Schaap (1982)

Effect of Wear

- If the allowable tolerances of the IRTP for cone diameter are adhered to, then the maximum error in q_c that can be obtained by assuming a 10 cm^2 cross sectional area of the cone is 5%, simply from wear of the cone diameter.
- These errors can be significantly greater if regular checks are not made for wear of the cone and friction sleeve.

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Important element of IRTP/new Eurocode on CPT/CPTU prEN 22476-1.10

<u>Introduction of Application Classes</u>

- Main purpose is to allow for differences in
  - *Soil conditions*
  - *Project requirements*
  - *Use of results*
    - Stratigraphy only
    - Engineering parameters
  - *National/ regional traditions and experience*

- Should lead to more comparable tenders
- Need to educate all parties involved:
  - *Clients*
  - *Contractors*
  - *Consultants*
  - *Others*

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International Reference Test Procedure (IRTP) Accuracy Classes

Test class	Measured parameter	Allowable minimum accuracy	Maximum length between measurements
1	Cone resistance Sleeve friction Pore pressure Inclination Penetrated depth	50 kPa or 3% 10 kPa or 10% 5 kPa or 2% 2° 0.1 m or 1%	20 mm
2	Cone resistance Sleeve friction Pore pressure Inclination Penetrated depth	200 kPa or 3% 25 kPa or 10% 25 kPa or 2% 2° 0.2 m or 2%	20 mm
3	Cone resistance Sleeve friction Pore pressure Inclination Penetrated depth	400 kPa or 5% 50 kPa or 15% 50 kPa or 5% 5° 0.2 m or 2%	50 mm
4	Cone resistance Sleeve friction Penetrated length	500 kPa or 5% 50 kPa or 20% 0.1 m or 1%	100 mm

From ISSMGE (1999)

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PRESENTATION of RESULTS

The information that should be presented falls naturally into the following 3 categories:

- ***Measured parameters***
- ***Corrected and derived parameters***
- ***Additional information***

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CPT/CPTU data processing and presentation of results

- **Measured Parameters**
  - *Cone resistance vs depth* — q_c - z
  - *Sleeve friction vs depth* — f_s - z
  - *Penetration pore pressure vs depth* — u_2 - z
  - *Other pore pressures vs depth* — u - z
  - *Pore pressure dissipation vs time* — u - t
  - *Inclination*

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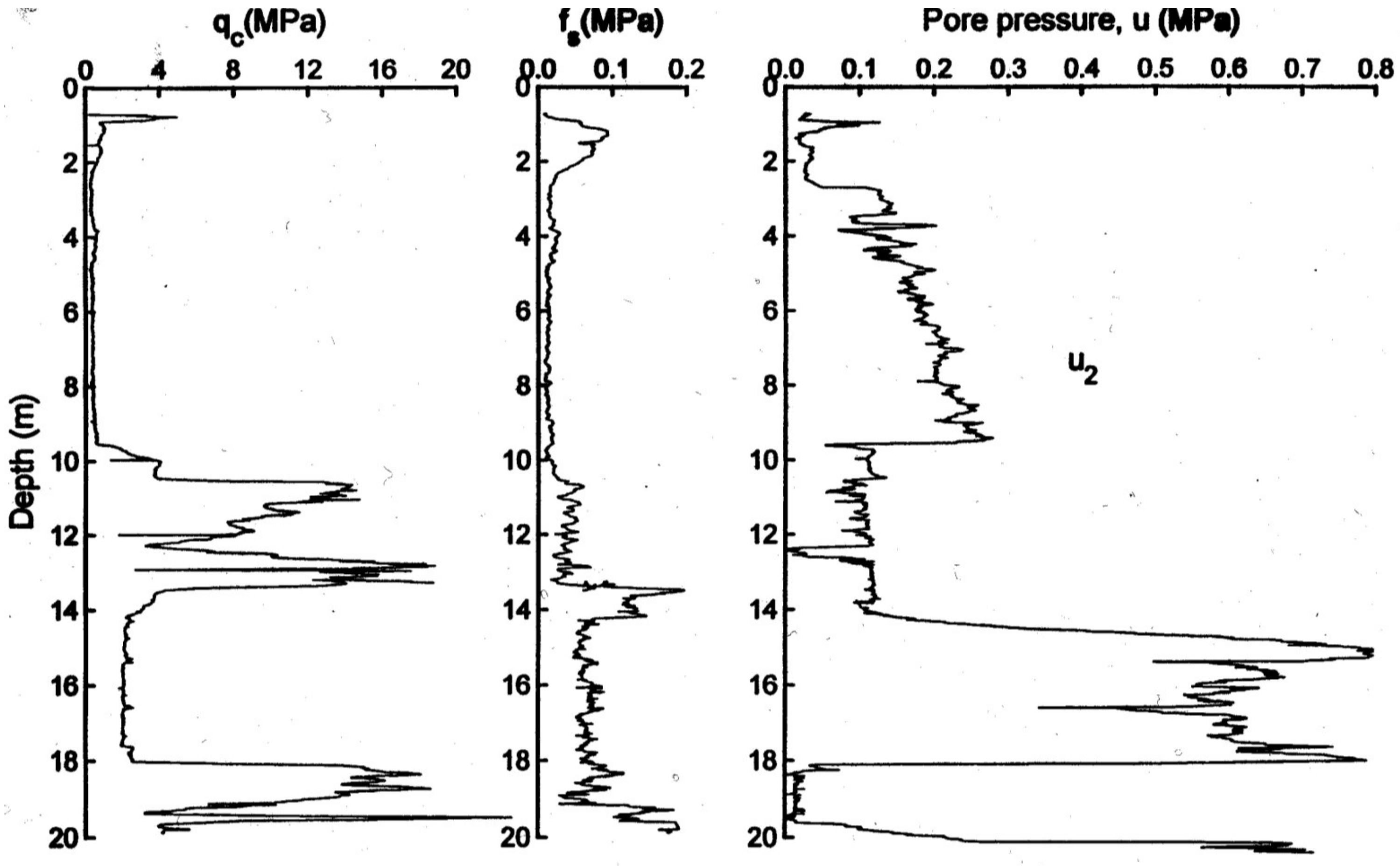
Examples measured CPTU parameters



Example: Measured CPTU Parameters

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CPT/CPTU New IRTP - presentation

- **Derived parameters**
  - *Excess pore pressure* $\Delta u = u_t - u_0$
  - *Corrected cone resistance* $q_t = q_c + (1 - a)u_2$
  - *Net cone resistance* $q_n = q_t - \sigma_{vo}$
  - *Friction ratio* $R_f = (f_s/q_c) \,.\, 100\%$
  - *Pore pressure ratio* $B_q = (u_2 - u_0)/q_t - \sigma_{vo})$
  - *Normalised excess pore pressure* $U = (u_t - u_o)/(u_i - u_o)$

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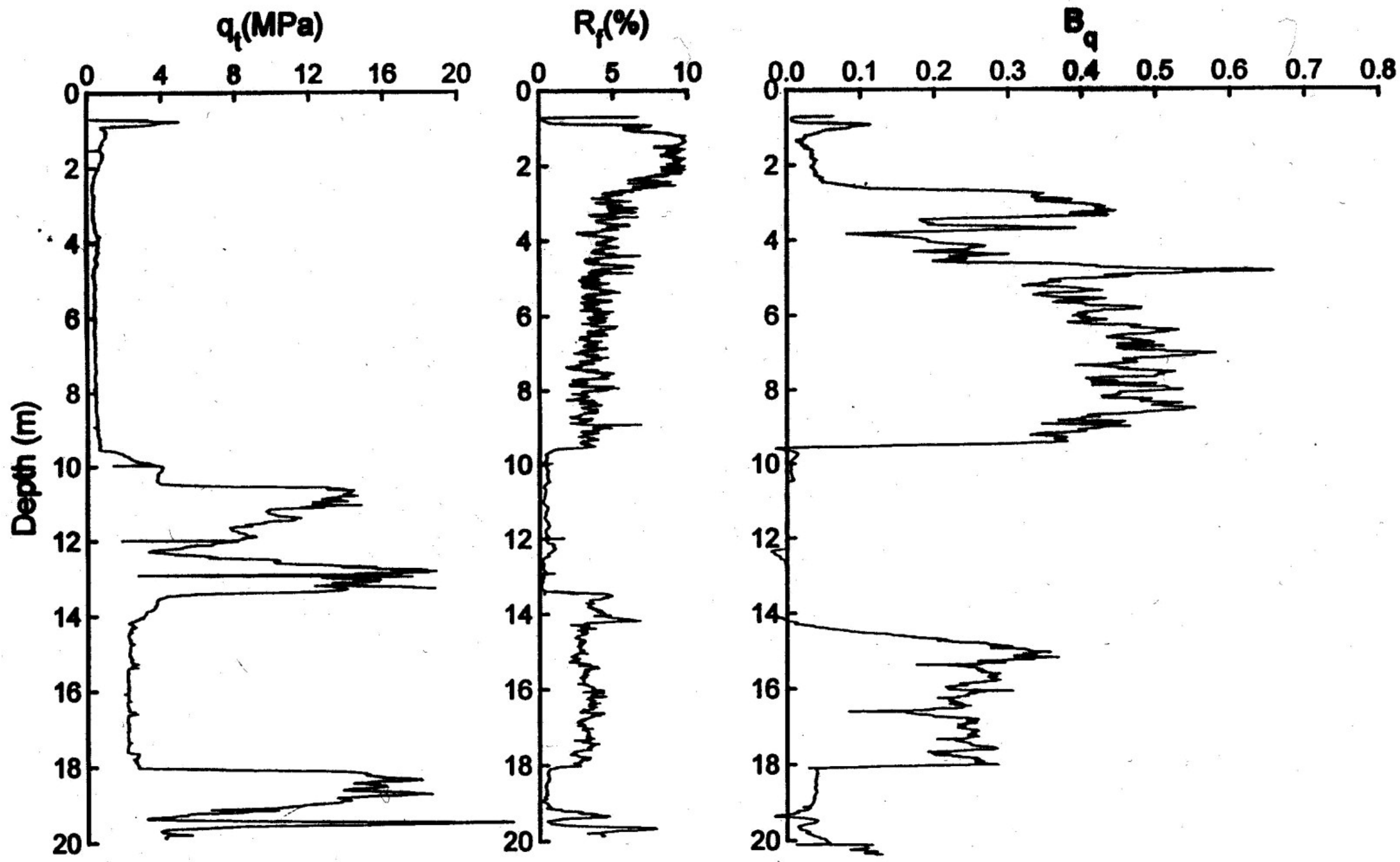
Example derived CPTU parameters



Example: Derived CPTU Parameters

Additional information

Information that must be provided

Each diagram with CPT or CPTU results shall include the following information:

- Site name
- Test No.
- Date of performing test
- Serial No. of cone penetrometer
- Position of porous element(s)
- Ground water level (or water depth)
- Name and signature of the operator and the company
- Depth of predrilling if relevant

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Additional information

In addition the field report should include the following information:

- Description of equipment used and name of manufacturer(s).
- Cone geometry and dimensions if deviating from ISSMFE International Reference Test Procedure.
- Calibration factors for all sensors and the load range over which they apply.
- Capacity of each sensor.
- Zero readings of all sensors before and after each test, and the temperature at which taken; alternatively change in zero readings expressed in kPa.
- Type of liquid used in the pore pressure measurement system.

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Additional information

- Observed wear or damage on cone, friction sleeve or filter element.
- Any irregularities during testing relative to ISSMGE Reference Procedure or other standard being used.
- Area ratio of cone 'a' and the friction sleeve end areas.
- For dissipation tests it should be noted whether or not the rods were clamped or unclamped during dissipation

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CPT/CPTU: Sources of error

- Pore pressure effect on cone resistance and sleeve friction
- Zero shift including temperature effects
- Pore pressure measurement system not saturated
- Large inclination of cone penetrometer
- Cross talk between cone and friction sleeve
- Reduced area of cone due to wear
- Zeroing location
- Friction reducers too close to cone penetrometer
- Electrical faults
- Malfunctioning depth measurements

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Use of CPT/CPTU in Geotechnical Soil Investigations

Summary

- Equipment and procedures standardised
- Reliable results can be obtained

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Zero reading, reference reading and zero drift

- ***Zero reading*: The output of a measuring system when there is zero load on the sensor, i.e. the measured parameter has a value of zero, any auxiliary power supply required to operate the measuring system being switched on.**

- ***Reference reading*: the reading of a sensor just before the penetrometer is pushed into the soil e.g. in the offshore case the reading taken at the sea bottom - water pressure acting.**

- ***Zero drift*: Absolute difference of the zero reading or reference reading of a measuring system between the start and completion of the cone penetration test.**

NGI

ASTM D 5778 (1995)

D 5778

TABLE A1.1 Calibration of Cone Penetrometer—Cone Tip Calibration

DATE:
PROJECT:
FEATURE:
CLIENT:

CALIBRATED BY:	
CONE #:	361
FSO TIP:	100 MPA
FSO SLEEVE:	1000 KPA
TIP AREA:	10 CM^2
SLEEVE ARE	150 CM^2

	m	b
CALIBRATOR DATA:	0.04971	-0.07911
CALIBRATOR SETTING:	100KN	

TARGET GAUGE READING	ACTUAL GAUGE READING	APPLIED FORCE X kN	FULL SCALE OUTPUT FSO - %	MEASURED CONE RESISTANCE Y qc - mPA	MEASURED SLEEVE RESISTANCE fs - kN/M^2	ACTUAL CONE RESISTANCE qca mPa	BEST STRAIGHT LINE* Y'=mX+b mPA	LINEARITY Y-Y'/FSO % FSO	CALIBRATION ERROR qca-Y'/qca % MO
0.000 BASELINE				-0.2	-10.3				
0	0	-0.079	-0.1	-0.0	-0.2	-0.1	0.034	0.04	
40	40	1.909	1.9	2.1	-0.2	1.9	2.053	0.00	
100	100	4.892	4.9	5.1	0.2	4.9	5.081	0.04	
200	200	9.862	9.9	10.2	0.3	9.9	10.128	0.03	
500	507	25.122	25.1	25.5	1.2	25.1	25.623	0.08	1.99
1000	1001	49.678	49.7	50.6	0.6	49.7	50.556	0.02	1.77
500	499	24.725	24.7	25.2	0.3	24.7	25.219	0.01	
200	198	9.763	9.8	10.0	0.3	9.8	10.027	0.01	
100	100	4.892	4.9	5.1	0.4	4.9	5.081	0.03	
40	40	1.909	1.9	2.1	0.4	1.9	2.053	0.08	
0	0	-0.079	-0.1	0.0	0.0	-0.1	0.034	0.03	
0.000 BASELINE				-0.3	-9.8				

		RESULT	UNIT	ALLOWABLE	APPROVAL
*BEST FIT STRAIGHT LINE (Y=mX+b	m=	1.015			
	b=	0.114			
MAXIMUM LOAD TRANSFER -SLEEVE		0.1	%FSO	2.000	YES
MAXIMUM LINEARITY ERROR		0.1	%FSO	1.0	YES
MAXIMUM CALIBRATION ERROR		1.99	%MO	2.0%MO>20%FSO	NO
MAXIMUM ZERO LOAD ERROR -CONE		0.0	%FSO	0.5	YES
MAXIMUM ZERO LOAD ERROR - SLEEVE		0.1	%FSO	1.0	YES

COMMENTS:

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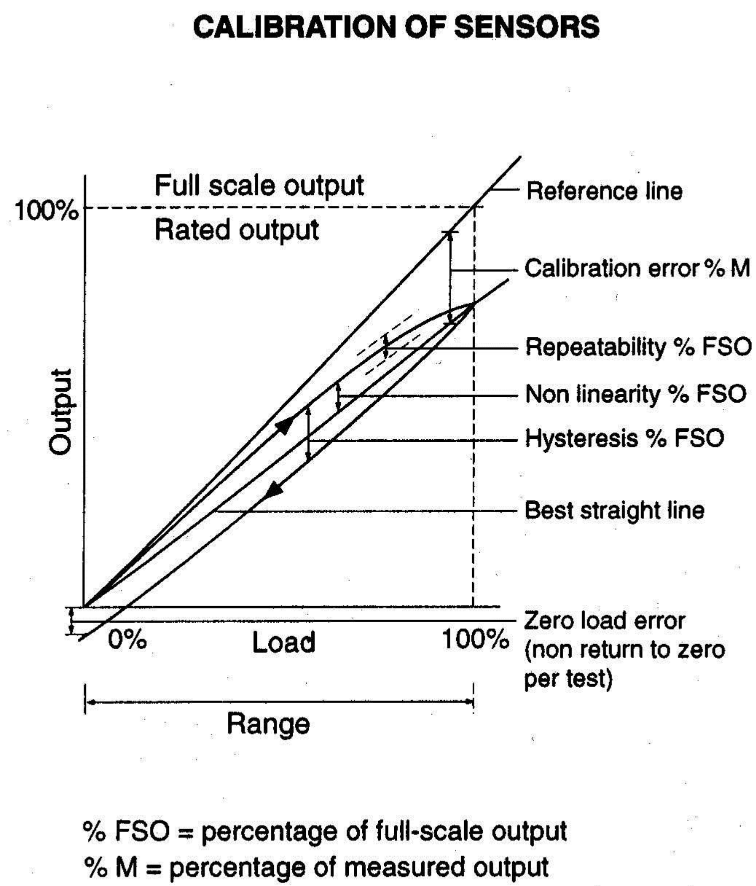
Definition of calibration characteristics



From Schaap and Zuidberg(1982)

Fig 2.17

Use of CPT/CPTU in Geotechnical Soil Investigations

Summary

- Equipment and procedures standardised
- Reliable results can be obtained by using:

Internationally recognized standards

International Reference Test Procedure

(ISSMGE, 1999)

New Eurocode on CPT/CPTU

prEN 22476-1.10

ASTM

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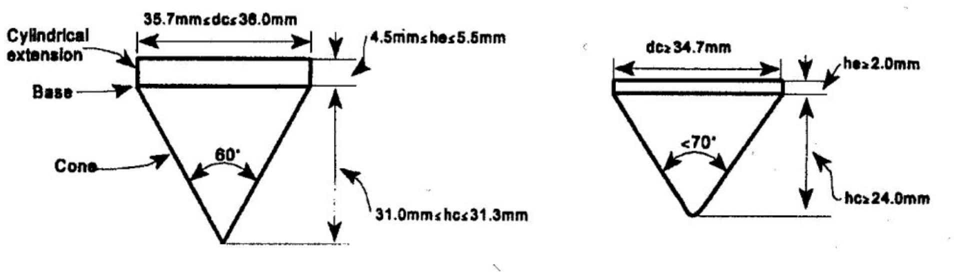
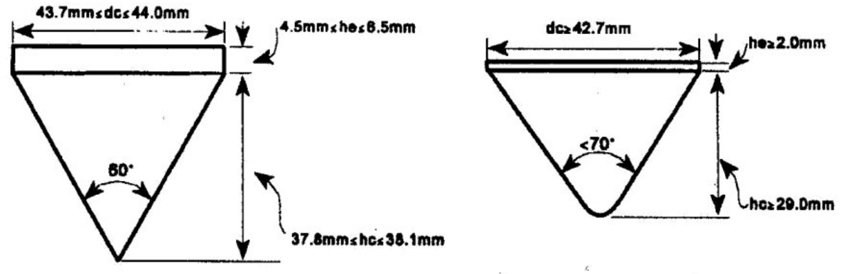
ASTM D 5778 (1995/2000)



(a) Manufacturing tolerances of 10 cm^2 cones.

(b) Operating tolerances of 10 cm^2 cones.



Manufacturing

Operational

CONE BASE AREA	NOMINAL			TOLERANCE MANUFACTURED (OPERATIONS)		
	BASE DIAMETER	CONE HEIGHT	EXTENSION			
cm^2	dc mm	hc mm	he mm	dc mm	hc mm	he mm
10	35.7	31.0	5.0	+0.3 - 0.0 (≥34.7)	+0.3 - 0.0 (≥24.0)	+0.0 - 0.5 (≥2.0)
15	43.7	37.8	5.0 - 6.0	+0.3 - 0.0 (≥42.7)	+0.3 - 0.0 (≥29.0)	+0.0 - 0.5 (≥2.0)

FIG. 2 Manufacturing and Operating Tolerances of Cones (2)

Some comments about ASTM D5778 - 95

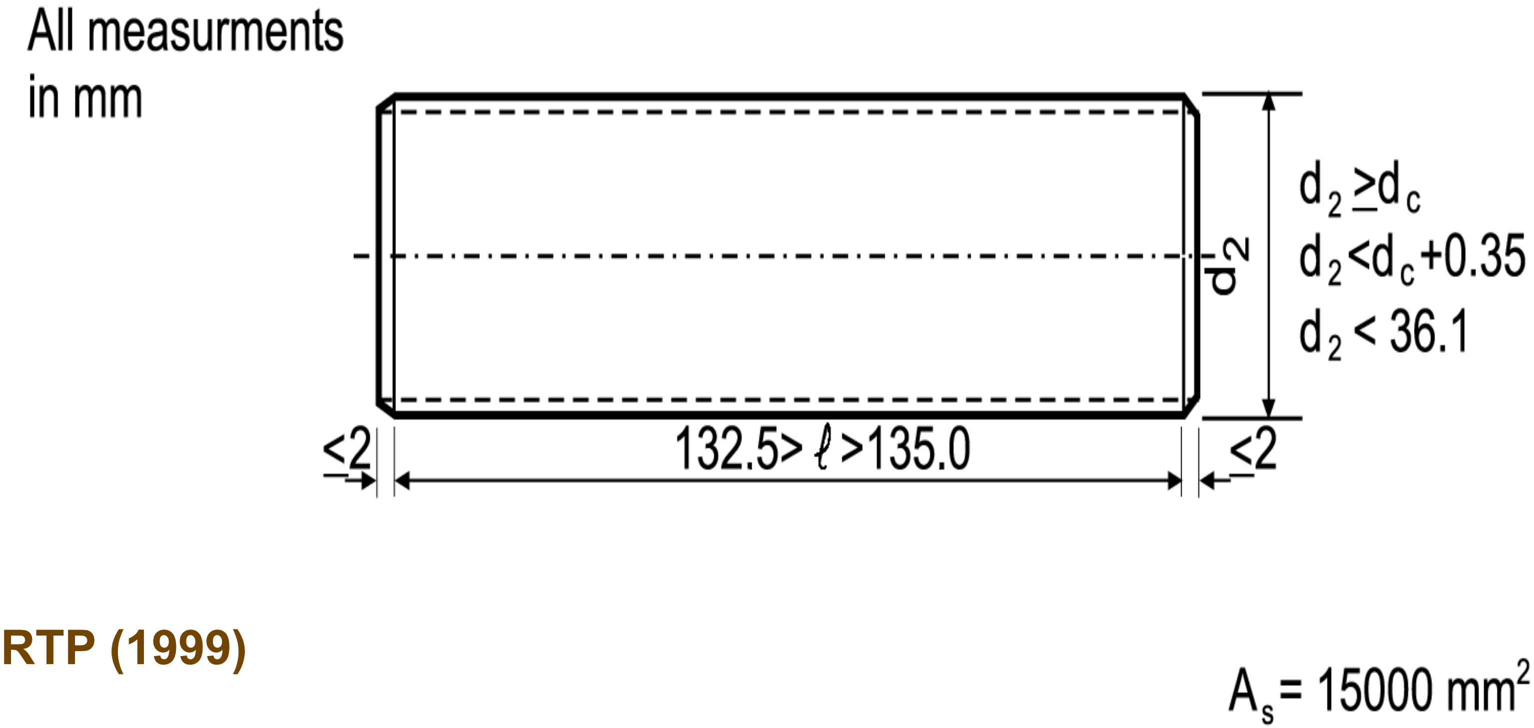
- **Detailed descriptions/instructions on large number of matters : filter types and fluids,friction reducers,calibration of new and repaired cone penetrometers. Includes allowance for 15 cm^2 cone area.**
- **Does not give any requirements to total accuracy of measurements. For new manufactured or repaired penetrometers the following requirements are given:**
  - *linearity better than 1 % of FSO (full scale output)*
  - *zero load better than +- 14 kPa (1.0 lb/in^2)*

  SI units

NGI

Friction Sleeve Tolerances

- The diameter of the friction sleeve shall be equal to the maximum diameter of the cone, with a tolerance requirement of 0 to +0.35 mm.



IRTP (1999)