STANDARDS , CORRECTIONS, DATA Quality, ETC

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OBTAINING RELIABLE DATA and PRESENTATION

Rubbish in – Rubbish out!

Quality in – Quality out (hopefully/possibly)

How to have a better chance of Reliable data

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CPT/CPTU DATA etc

- Available standards and guidelines
- Equipment
- Procedures
- Corrections
- Accuracy and precision - Classes
- Calibration requirements
- Checks

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CPT/CPTU DATA etc

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

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CPT/CPTU Available standards and guidelines

- *ISSMGE: IRTP (International Reference Test Procedure) 1999/2001*
- ASTM D:5778-95, 1996
- ASTM D:5778-07, 2007 – includes the CPTU
- BS:1377, Part 9, 1990 & BS:5930, 1999
- Dutch Standard, NEN 5140, 1996
- French Standard, NFP 94-113,1989
- Norwegian Geotechnical Society Guidelines, 1995
- Eurocode, ENV 1997-3, 1999
- *CEN TC341 - WG2 Standard for CPT and CPTU (CEN/ISO 22476-1)*
- Other National standards and codes
- *Offshore*

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New European Standard

CEN/TC 341

EN/ISO 22476-1 and EN/ISO 22476-12

Ground investigation and testing — Field testing

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

— Part 12: Mechanical cone penetration test (CPT) published

- Until now IRTP(1999) was the official *International* Document

(but prEN has often been referenced)

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Main elements of the new CEN/ISO on CPT/CPTU

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Equipment

- 4. Equipment
- 4.1 Cone penetrometer
- 4.2 Tolerances
- 4.3 Surface roughness
- 4.4 Cone
- 4.5 Friction sleeve
- 4.6 Filter element
- 4.7 Gaps and soil seals
- 4.8 Push rods
- 4.9 Measuring system
- 4.10 Thrust machine

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Test Procedures

- 5 Test procedures
- 5.1 Selection of cone penetrometer
- 5.2 Selection of equipment and procedures
- 5.3 Position and level of thrust machine
- 5.4 Preparation of the test
- 5.5 Pushing of the cone penetrometer
- 5.6 Use of friction reducer
- 5.7 Frequency of logging parameters
- 5.8 Registration of penetration length
- 5.9 Dissipation test
- 5.10 Test completion
- 5.11 Equipment checks and calibrations
- 5.12 Safety requirements

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Test Results

- 6 Test results
- 6.1 Measured parameters
- 6.2 Correction of parameters
- 6.3 Calculated parameters

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Reporting

- 7 Reporting
- 7.1 General
- 7.2 Reporting of test results
- 7.3 Presentation of test results
- 7.4 Presentation of test results and calculated parameters

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Annexes

- Annex A (normative) Maintenance, checks and calibration
- Annex B (normative) Calculation of penetration depth
- Annex C (informative) Correction of sleeve friction for water pressure
- Annex D (informative) Preparation of the piezocone
- Annex E (informative) Uncertainties in cone penetrometer testing

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Annexes

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Main elements of ISO/CEN standard

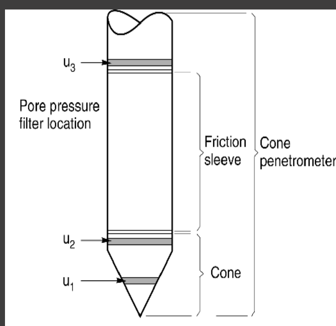
Equipment:

- **Cone apex angle : 60 deg.**
- **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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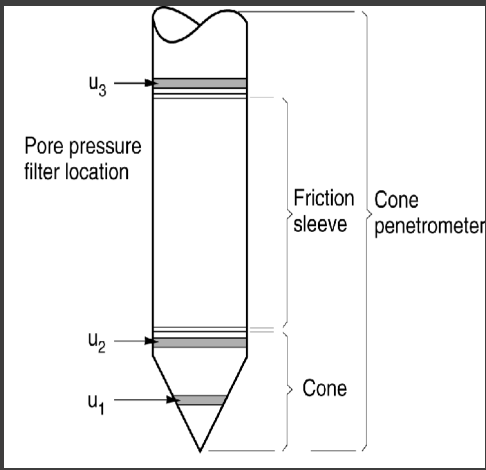
Pore Pressure measurement



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Recommendations on cone size

CEN/ISO

: 'the cross-sectional area of cone shall nominally be 10 sq.cm, which corresponds to a diameter of 35.7 mm. Cones with diameters between 25 mm(A_c =500 sq.mm) and 50 mm (A_c =2000 sq.mm) are permitted for special purposes, without the application of correction factors.

Cones outside this range should not be used for deriving soil design parameters before documentation with parallel tests of standard size'

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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 just shown.

- 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 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 has confirmed that the measured pore pressure varies with the soil type and also the location of the filter element.

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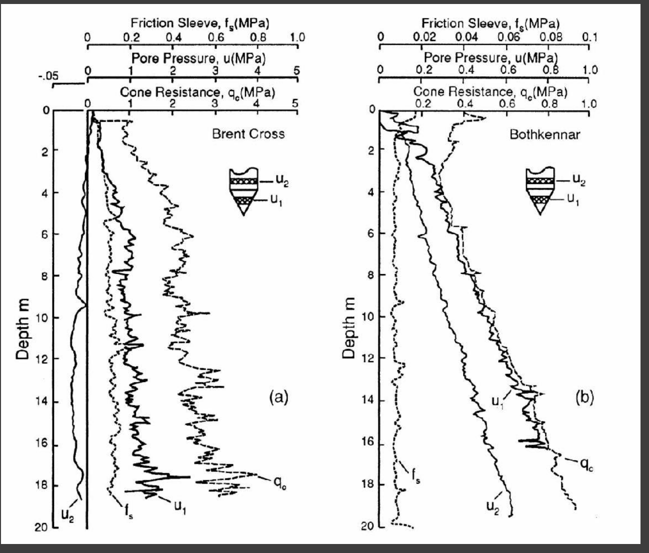
Filter location



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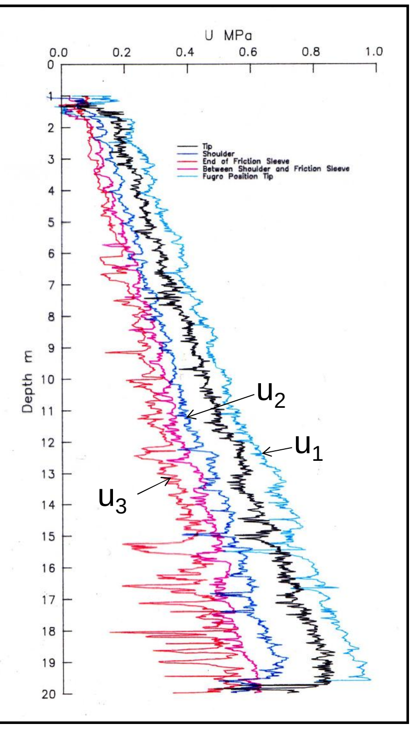
Example of effect of pore pressure location on measured pore pressure



Bothkennar, UK clay

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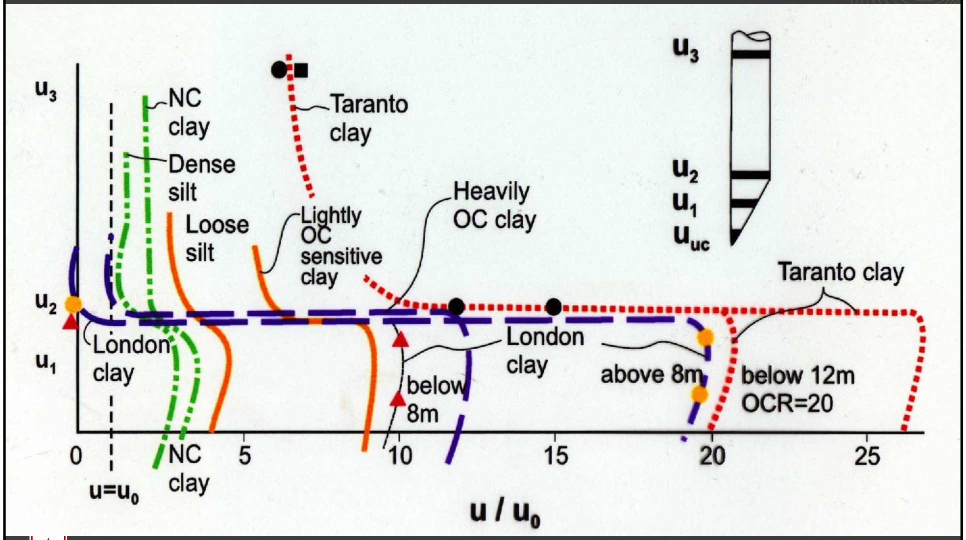
Measured pore pressure distributions in clay



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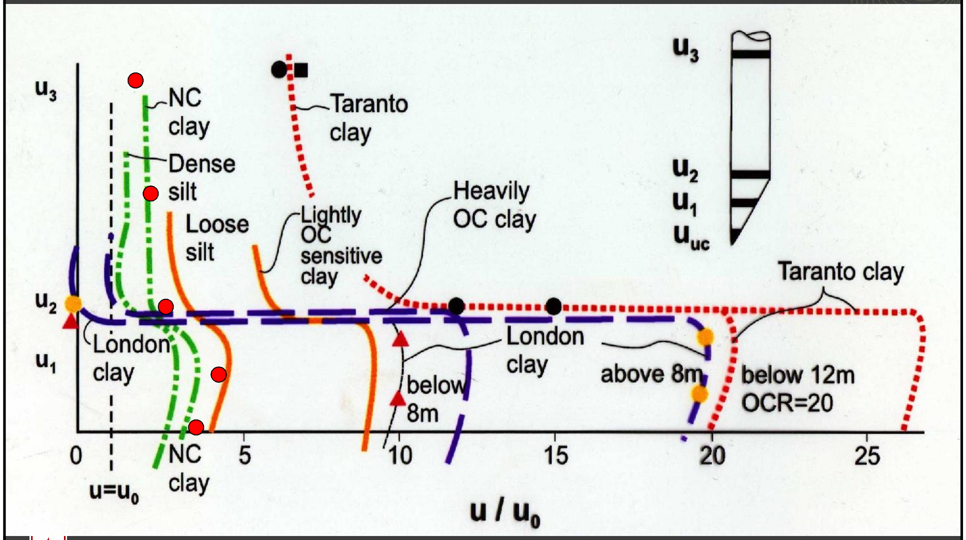
Measured pore pressure distributions in clay



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Filter location

The new CEN/ISO Standard 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)
- Filters should be replaced before each test

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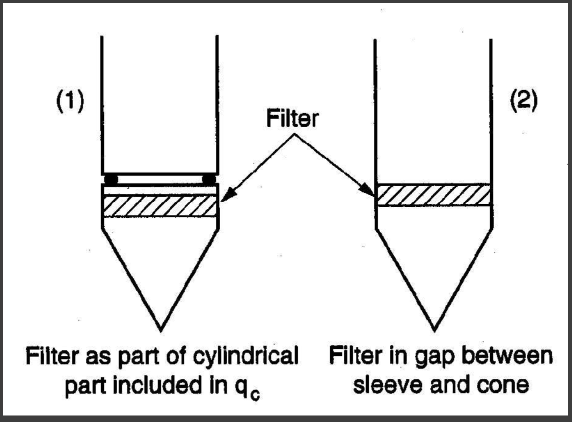
Two different positions of u_2 filter



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Main elements of ISO/CEN standard

Equipment:

Procedures:

- **Penetration speed (rate) : 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:

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Main elements of ISO/CEN standard

Equipment:

Procedures:

- **Penetration speed (rate) : 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:

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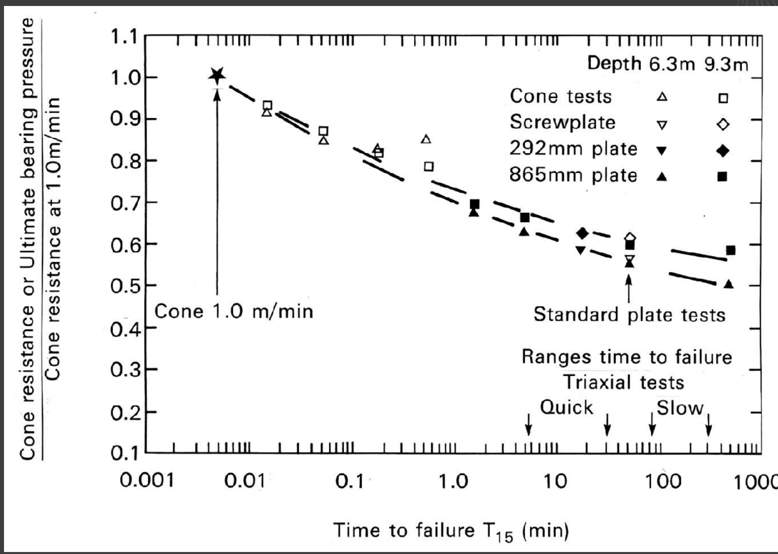
Rate and scale effects (clays!) consider options



Main elements of ISO/CEN standard

Equipment:

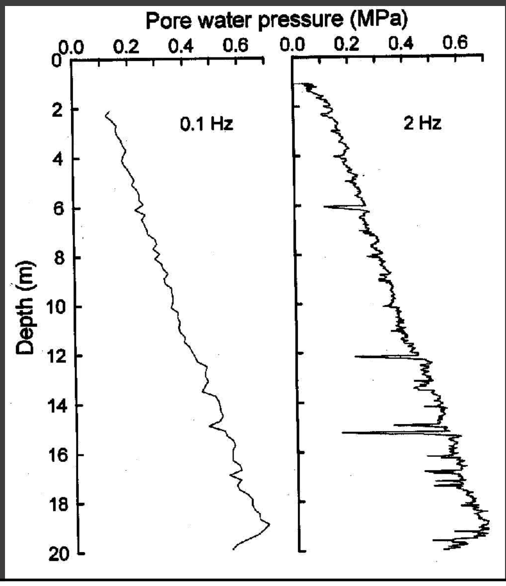
Procedures:

- **Penetration speed (rate) : 2 cm/sec**
- **Log at least one set of readings every sec (20/50 mm) !!!**
- **Requirements to saturation of pore pressure measurement system**
- **Dissipation tests: stop penetration and log u vs. time**

Corrections:

Other aspects:

Effects of frequency of readings on pore water pressure profile (DETAIL)



Higher frequencies for better detail

Main elements of ISO/CEN standard

Equipment:

Procedures:

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

Corrections:

Other aspects:

Saturation of piezocones

There are no major differences in field test operations between standard CPT and CPTU soundings, except those required for the saturation of the piezocone.

To have good pore pressure response during a piezocone test it is necessary to have a very rigid pore pressure measuring system and a fully saturated system.

To achieve this the following elements shall be completely saturated:

- the filter
- the channel or tubing between the filter and the transducer
- the transducer housing cavity

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Field saturation of piezocone

Onsøy, Norway 2001

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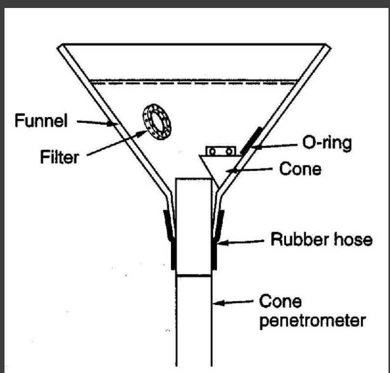
Field saturation of Pagani piezocone

Onsøy, Norway 2001

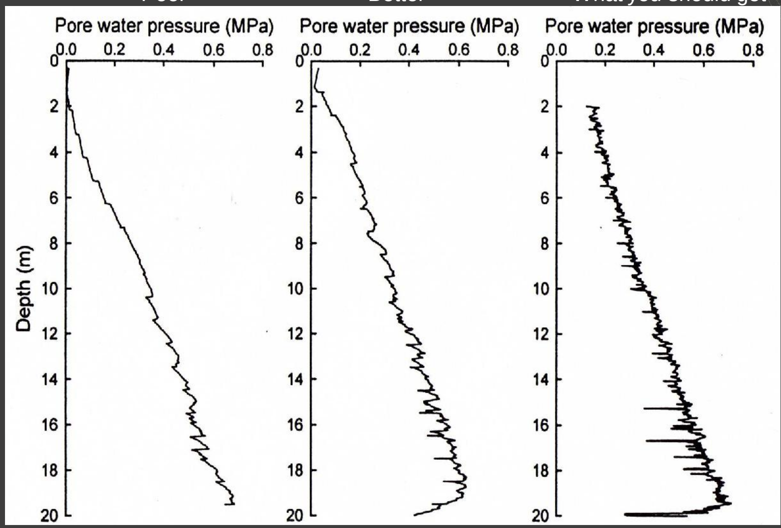
Example of mounting filter to maintain saturation-- using glycerine



Grease an option

Importance of saturation on measured pore pressure response

Poor | Better | What you should get



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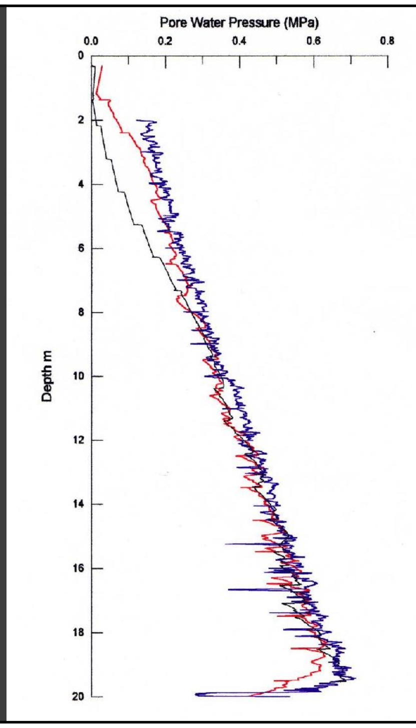
Importance of saturation on measured pore pressure response



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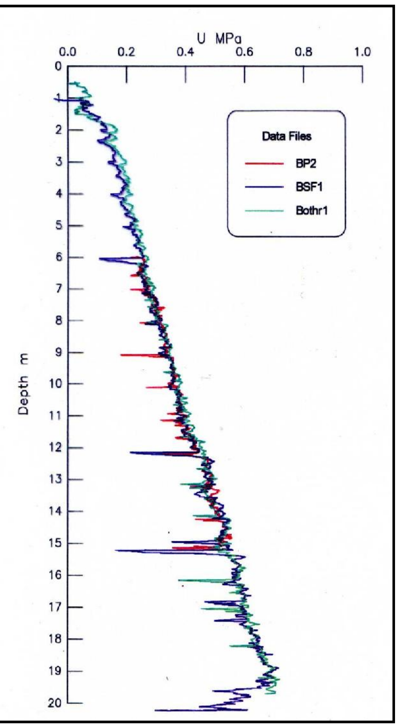
Importance of saturation on measured pore pressure response what we can get



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Filter saturation

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

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Main elements of ISO/CEN standard

Equipment:

Procedures:

- Penetration speed (rate) : 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:

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Dissipation test

During a pause in the penetration any excess pore pressures generated around the cone will start to dissipate. The rate of dissipation depends upon the coefficient of consolidation, which, in turn, depends on the compressibility and permeability of the soil.

- sometimes a fixed period of dissipation for all soil layers is used
- sometimes dissipation is continued to a predetermined percentage of degree of dissipation (U),
- it is frequently specified to continue the dissipation to at least U= 50% (!).

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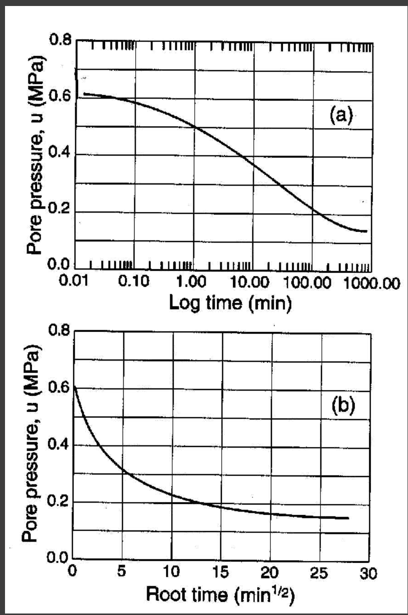
Example of dissipation test



Required logging frequency according to EN/ISO 22476-1

-1st minute at least: 1 Hz

-Thereafter may halved every log (time) cycle

Record all data

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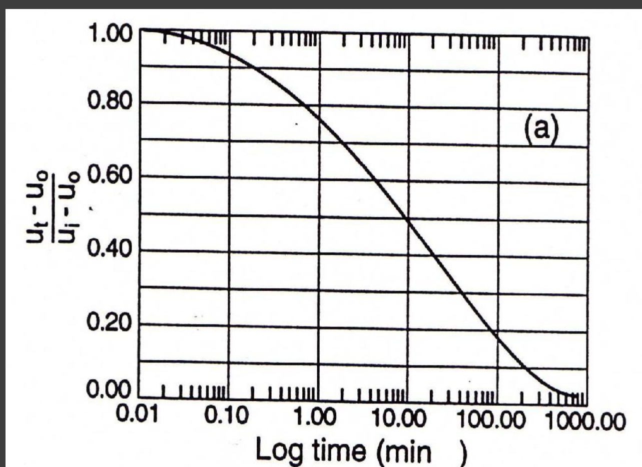
Example of a dissipation test (normalised!)



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Main elements of new CEN/ISO

Equipment:

Procedures:

Corrections:

- **Pore pressure effects on cone resistance +**
- **Effect of inclination**

Other aspects:

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Corrections required to CPTU results (according to new CEN/ISO standard)

- Pore pressure effect on cone resistance +
- Inclination correction to measured penetration length

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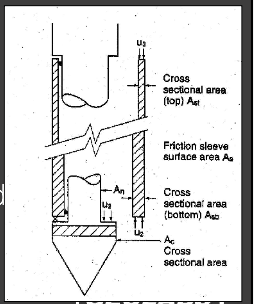
Pore water pressure effects on q_c and f_s

- 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 .

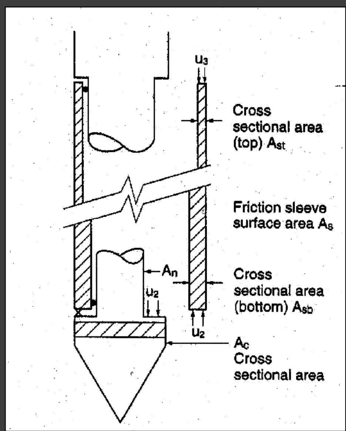


Pore water pressure effects on q_c and f_s (clay)

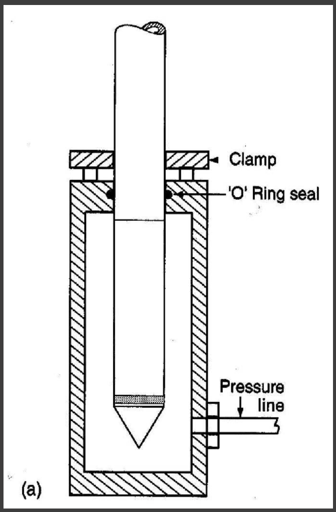
The corrected total cone resistance (q_t) is given by the equation:

$q_t = q_c + (1-a)\, u_2$

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



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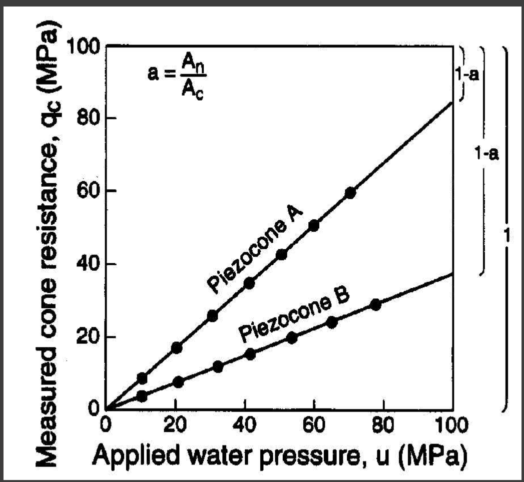
Determination of area ratio, a, in calibration vessel



NOT geometry
- calibrate

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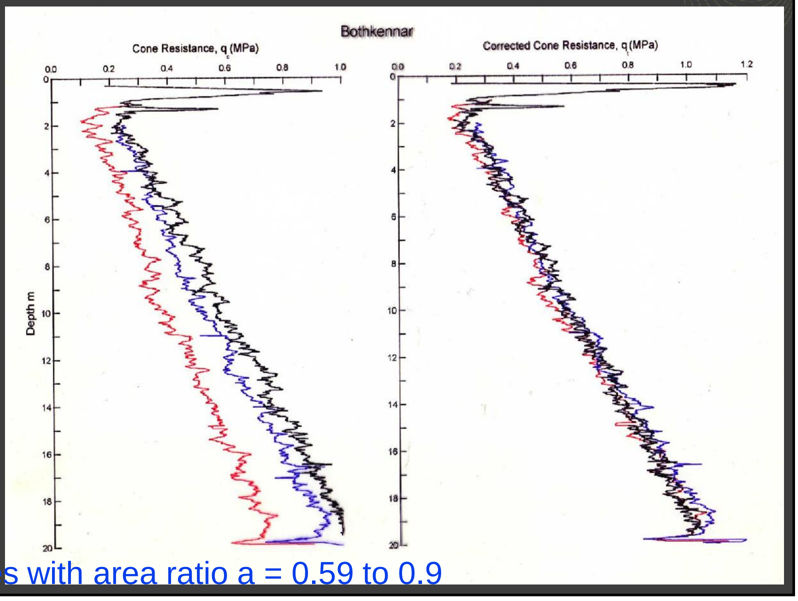
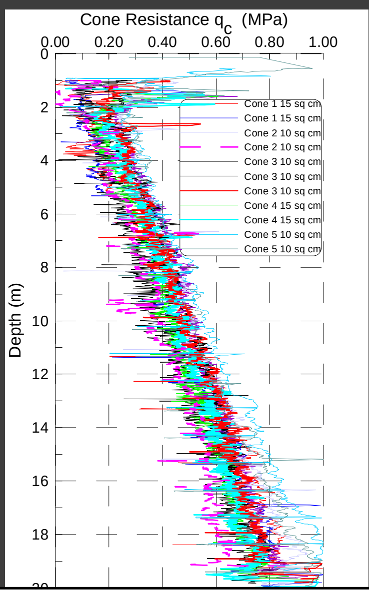
Effect of pore pressure on cone resistance



Cones with area ratio a = 0.59 to 0.9

Base data q_c



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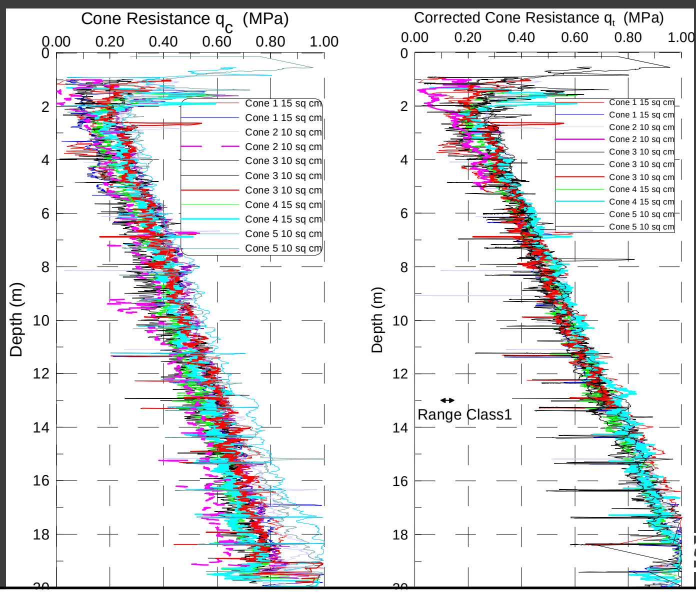
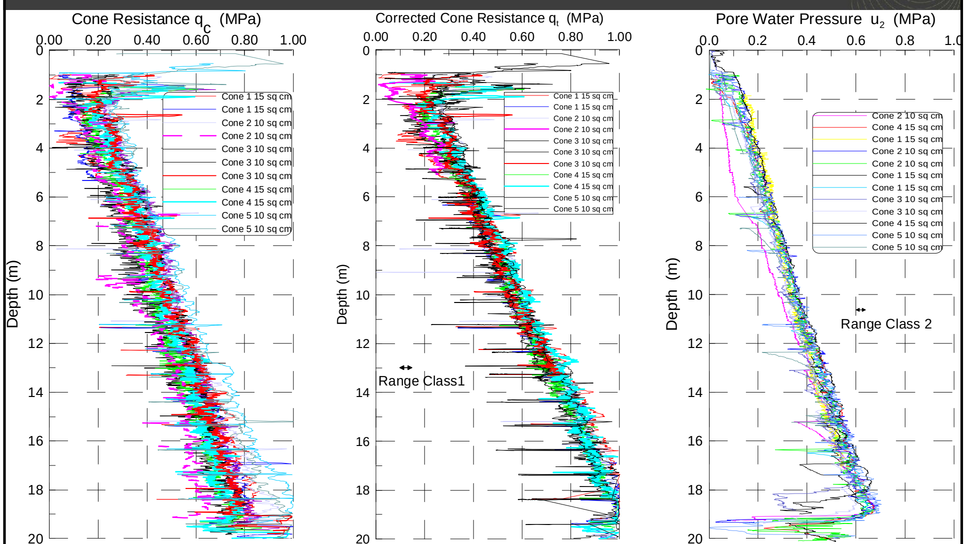
Base data q_c $q_t = q_c + u_2(1-a)$



Bothkennar (let us not forget pwp)



- Bothkennar

- Same operator,
- Same base for calibration
- Different cones!

- Life is wonderful

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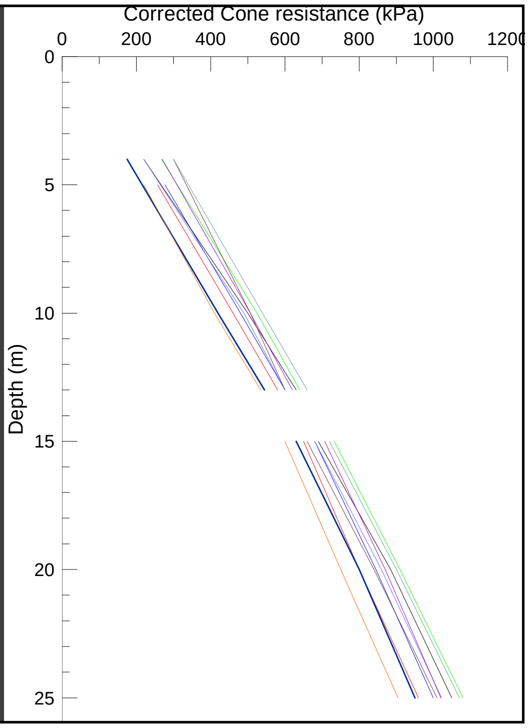
8 cones, mean values of q_t different results – why



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Why

Maybe

- Different operators
- Different cones, relative geometry!!
- Different calibration procedures?
- Do we understand??

- Should be said that these are at the limit of sensitivity of the cones used
- Will affect correlations!!

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Pore water pressure effects on q_c and f_s

When the pore pressure is only measured on the cone (u_1), a rough estimate of the pore pressure u_2 can be made based on an adjustment to u_1:

$$(u_2 - u_0) = K\,(u_1 - u_o)$$

where u_o is the in situ pore pressure and K is a constant.

The value of K will vary with the stress history of the deposit and the soil type. This procedure should only be used as a last resort when no other data are available. The engineer must have confidence that the soil type and stress history of the deposit have been sufficiently well determined to allow a reliable selection of K.

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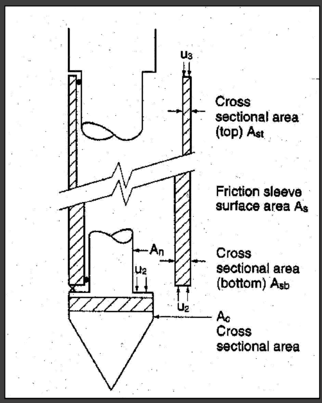
Pore water pressure effects on f_s

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; often so are the areas.

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

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

Seldom considered!!! Standard says '$A_{st} \nless A_{sb}$'
Many cones do not fulfill this!!!!



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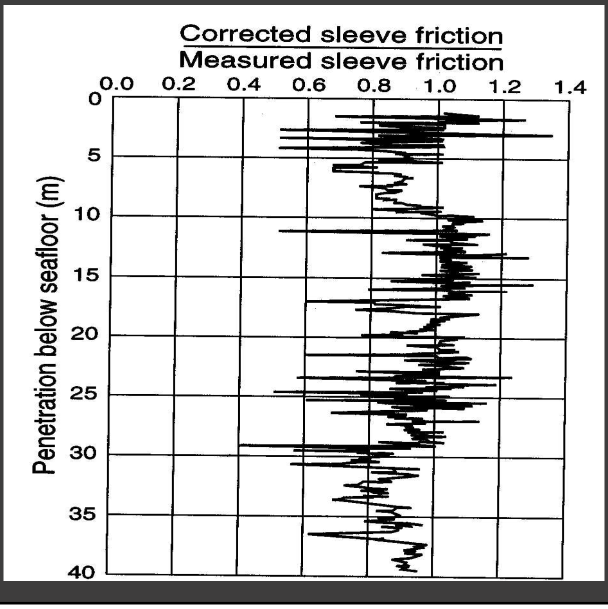
Example of correcting f_s for pore pressure effects



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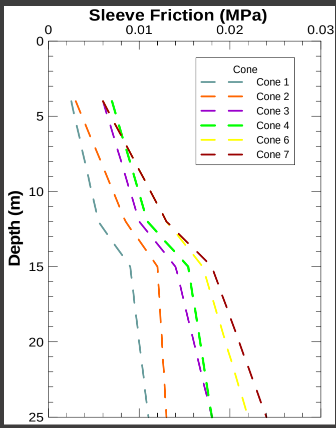
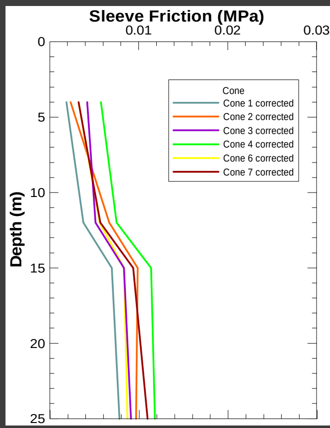
f_s correction





Not just pore water pressure then?

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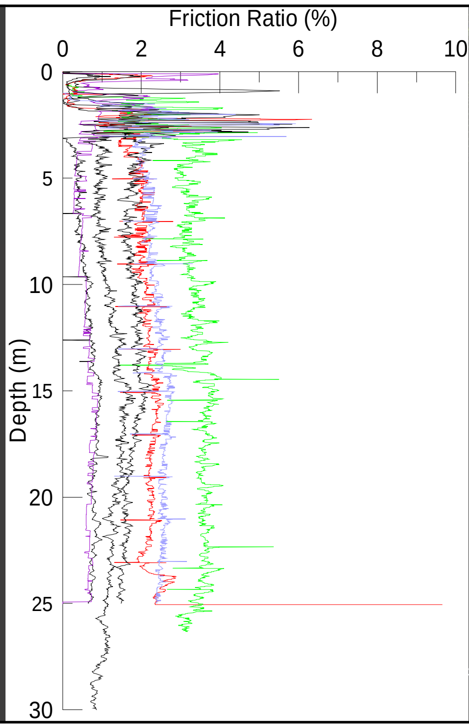
R_f readings - Onsoy



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Corrections required to CPTU results according to IRTP etc

- Pore pressure effect on cone resistance +
- Inclination correction to measured penetration length

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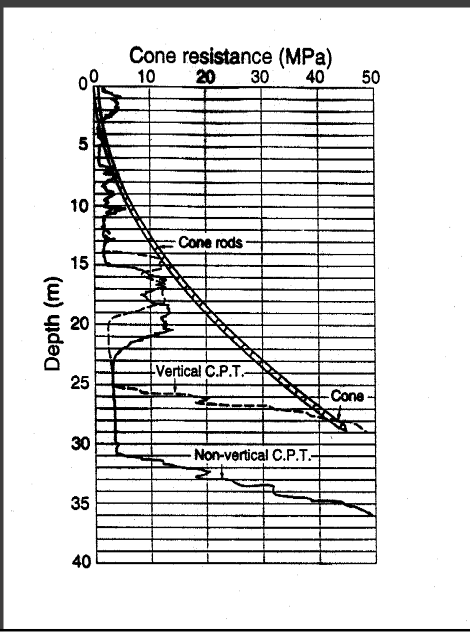
Effect of verticality on measured depth



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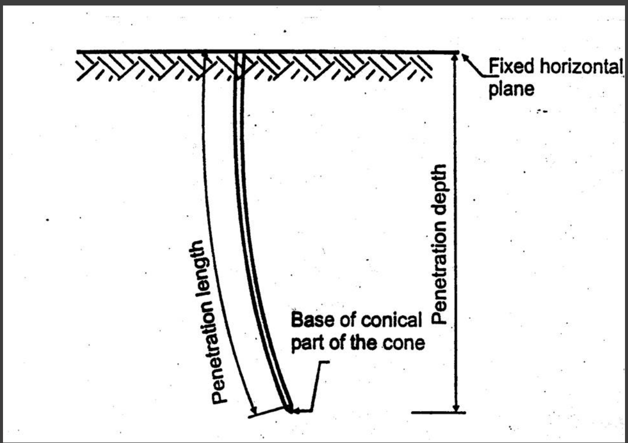
Penetration length and penetration depth



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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 <u>single</u> axis inclinometer : $C_h = \cos\alpha$
α is the measured angle relative to vertical axis

For <u>bi-axial</u> 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

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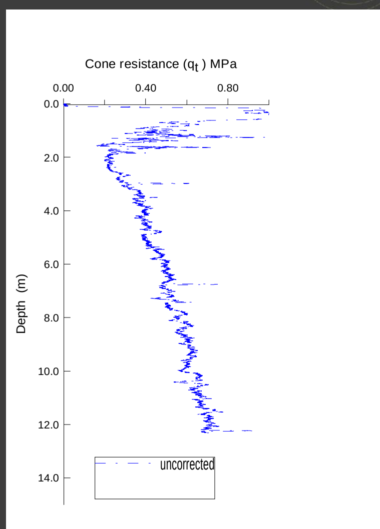
Effects of inclination, coiled rod system



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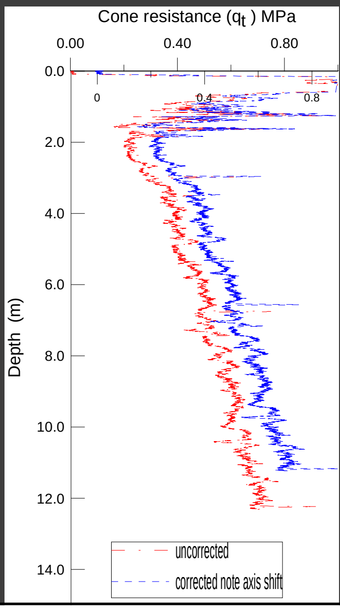
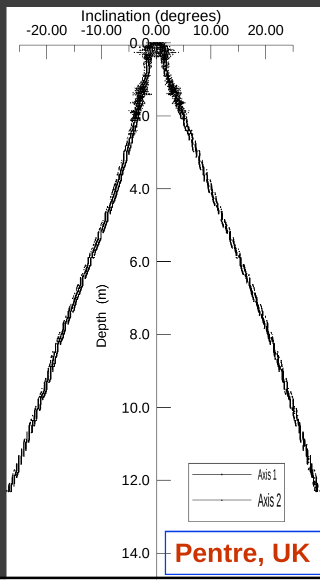
Effects of inclination, coiled rod system

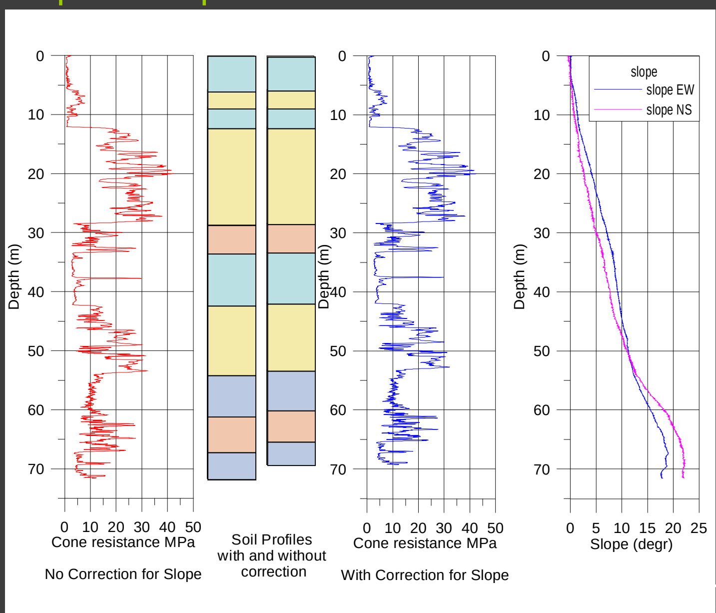
Shifted to right for clarity



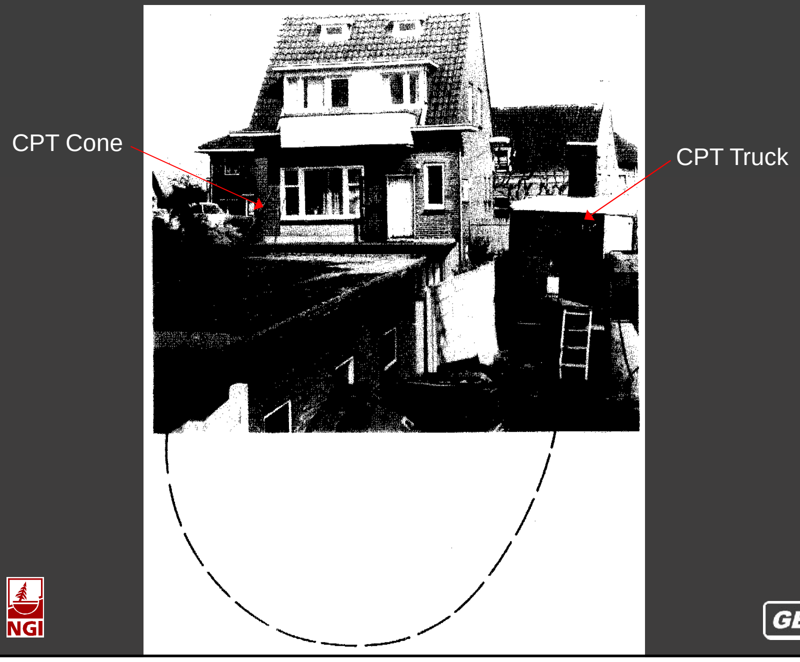


Pentre, UK

Example of depth correction



Non-vertical CPT



Main elements of new ISO/CEN

Equipment:

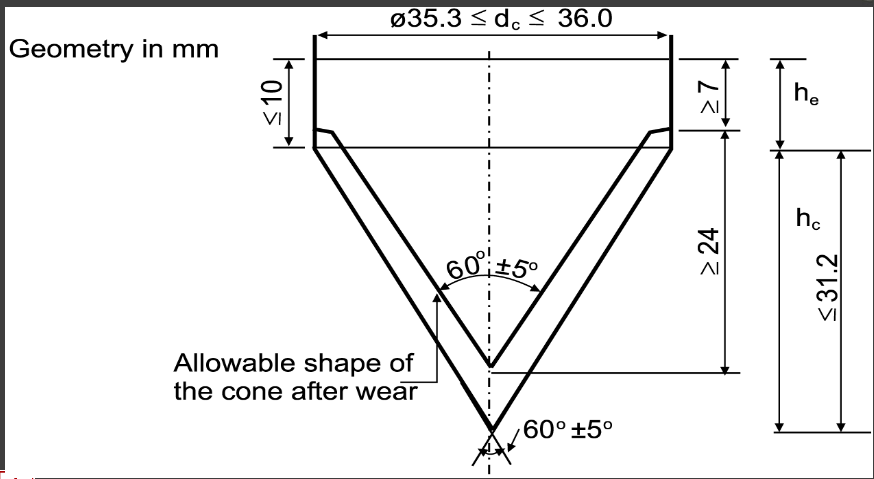
Procedures:

Corrections:

Other aspects:

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

Cone geometry ISO/CEN tolerances (wear) (error)



The cone shall not be used if a visual check indicates that it is asymmetrically worn or unusually rough, even if it otherwise fulfils the tolerance requirements.

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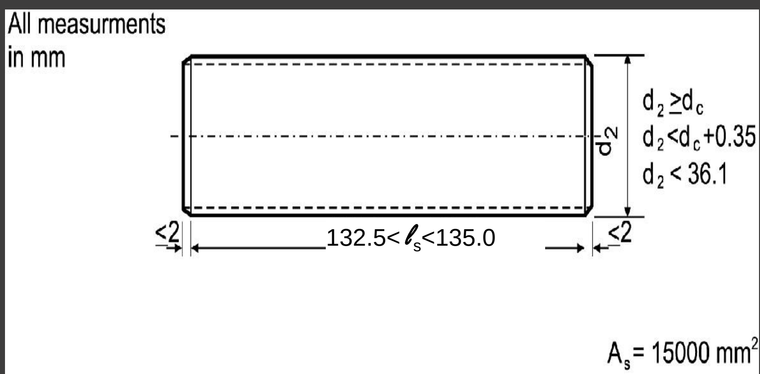
Friction Sleeve Tolerances

- **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.**
- The friction sleeve shall not be used if a visual check indicates that it is scratched, asymmetrically worn or unusually rough, even if it otherwise fulfils the tolerance requirements.



The dimensional tolerances are operational tolerances. Manufacturing tolerances should be stricter

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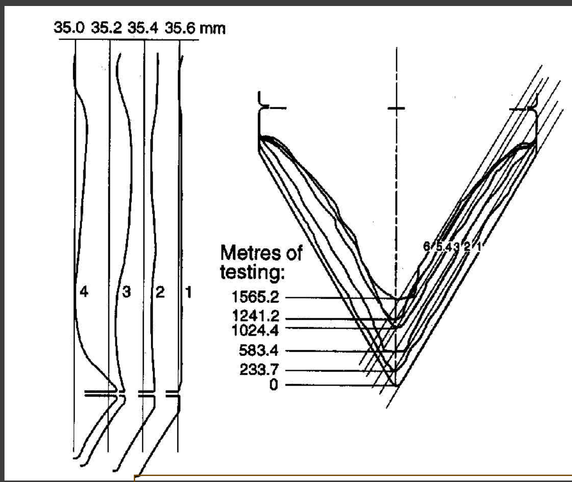
Wear of cone and friction sleeve as function of meters penetrated



From Zuidberg and Schaap (1982)

Effect of Wear

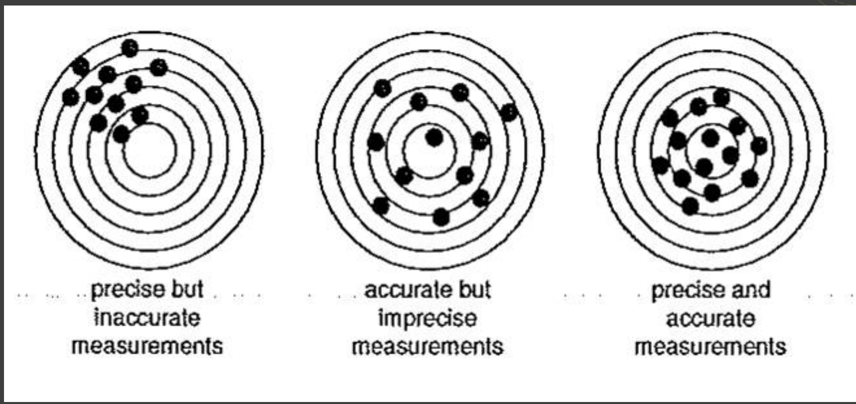
- If the allowable tolerances of the CEN/ISO for cone diameter are adhered to, then the maximum error in q_c that can be obtained by assuming a 10 cm^2 cross sectional area of the cone is 5%, simply from wear of the cone diameter.
- These errors can be significantly greater if regular checks are not made for wear of the cone and friction sleeve.
- CEN/ISO requires actual cone dimensions to be recorded for Class 1 testing (later)

Precision and Accuracy

Precision and Accuracy

- **Accuracy** is the closeness of a measurement to the true value of the quantity being measured. Accuracy of a measuring device to be used in testing is evaluated during its calibration against another independent device of known and traceable accuracy (taken as the true value). It is the accuracy of the measuring system as a whole that is ultimately important not the individual parts.
- **Precision** is the closeness of each set of measurements to each other. It is synonymous with repeatability and can be expressed as a value with say a standard deviation indicating the scatter.
- The resolution of a measuring system is the minimum size of the change in the value of a quantity that it can detect. It will influence the accuracy and precision of a measurement
- CEN ISO requires resolution to better than one third of required Accuracy.

Precision and Accuracy



CEN/ISO accuracy requirements related to data use

- Requirements to accuracy and repeatability according to what results are to be used for
- Introduction of Application (Accuracy) Classes
  - Class 1 : Most strict, design parameters in soft clays
  - Class 4 : Least strict : profiling

So - Types of tests

Table 1 — Types of cone penetration tests

Type of cone penetration test	Measured parameter
TE1	Cone resistance and sleeve friction
TE2	Cone resistance, sleeve friction and pore pressure

NOTE Cone penetration tests with measurements of pore pressures at more than one location are variants of type TE2.

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Table 1 — Application classes

Applic. Class	Test type	Measured parameter	Allowable minimum accuracy [a]	Maximum length between measurements	Use: Soil [b]	Use: Interpretation / evaluation [c]
1	TE2	Cone resistance	35 kPa or 5 %	20 mm	A	G, H
		Sleeve friction	5 kPa or 10 %			
		Pore pressure	10kPa or 2 %			
		Inclination	2°			
		Penetration length	0,1 m or 1%			
2	TE1 TE2	Cone resistance	100 kPa or 5 %	20 mm	A B C D	G, H* G, H G, H G, H
		Sleeve friction	15 kPa or 15 %			
		Pore pressure [d]	25 kPa or 3 %			
		Inclination	2°			
		Penetration length	0,1 m or 1 %			
3	TE1 TE2	Cone resistance	200 kPa or 5 %	50 mm	A B C D	G G, H* G, H G, H
		Sleeve friction	25 kPa or 15 %			
		Pore pressure [d]	50 kPa or 5 %			
		Inclination	5°			
		Penetration length	0,2 m or 2 %			
4	TE1	Cone resistance	500 kPa or 5 %	50 mm	A B C D	G* G* G* G*
		Sleeve friction	50 kPa or 20 %			
		Penetration length	0,2 m or 2 %			

NOTE For extremely soft soils even higher demands on the accuracy may be needed.

[a] The allowable minimum accuracy of the measured parameter is the larger value of the two quoted. The relative accuracy applies to the measured value and not the measuring range

[b] According to EN ISO 14688-2:
- A Homogeneously bedded soils with very soft to stiff clays and silts (typically q_c < 3 MPa)
- B Mixed bedded soils with soft to stiff clays (typically q_c = 3 MPa) and medium dense sands (typically 5 MPa ≤ q_c < 10 MPa)
- C Mixed bedded soils with stiff clays (typically 1,5 MPa ≤ q_c < 3 MPa) and very dense sands (typically q_c > 20 MPa)
- D Very stiff to hard clays (typically q_c = 3 MPa) and very dense coarse soils (q_c = 20 MPa)

[c]
- G profiling and material identification with low associated uncertainty level
- G* indicative profiling and material identification with high associated uncertainty level
- H interpretation in terms of design with low associated uncertainty level
- H* indicative interpretation in terms of design with high associated uncertainty level

[d] Pore pressure can only be measured if TE2 is used.

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[d] Pore pressure can only be measured if TE2 is used.

Application classes

- ***Application class 1*** is intended for soft to very soft soil deposits. Class 1 penetration tests are normally not apt for mixed bedded soil profiles with soft to dense layers (although pre-drilling through stiff layers can overcome the problem). Tests can only be performed with use of the CPTU.

- ***Application class 2*** is intended for precise evaluation for mixed bedded soil profiles (see note 1) with soft to dense layers, in terms of profiling and material identification. Interpretation in terms of engineering properties is also possible, with restriction to indicative use for the soft layers. Penetrometer type to be used depends on project requirements.

Application classes

- ***Application class 3*** is intended for evaluation of mixed bedded soil profiles (see note 1) with soft to dense soils, in terms of profiling and material identification. Interpretation in terms of engineering properties in achievable for very stiff to hard and dense to very dense layers. For stiff clays or silts and loose sands only an indicative interpretation can be given. Penetrometer type to be used depends on project requirements.
- ***Application class 4*** is only intended for indicative profiling and material identification for mixed bedded soil profiles with soft to very stiff or loose to dense layers. No appreciation in terms of engineering parameters can be given. Tests are to be performed with an electrical cone penetrometer (type TE1) and inclination measurement may be omitted.

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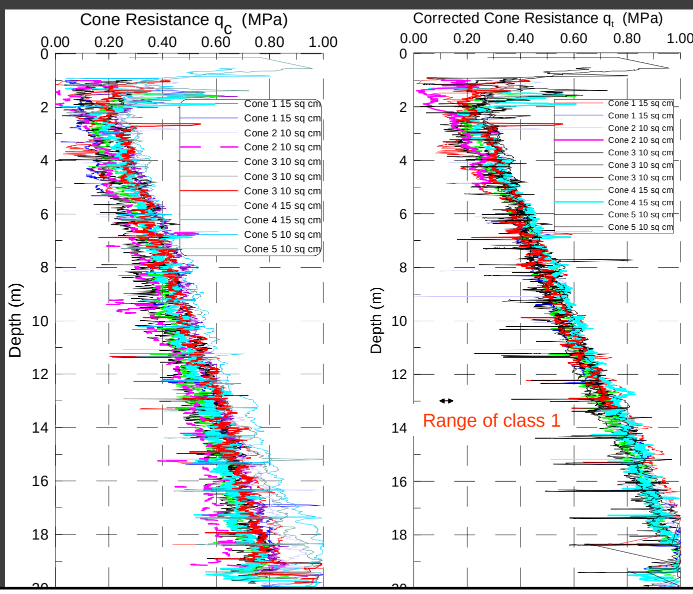
Base data $q_t = q_c + u_2(1-a)$

35kPa 5%
50kPa 3%



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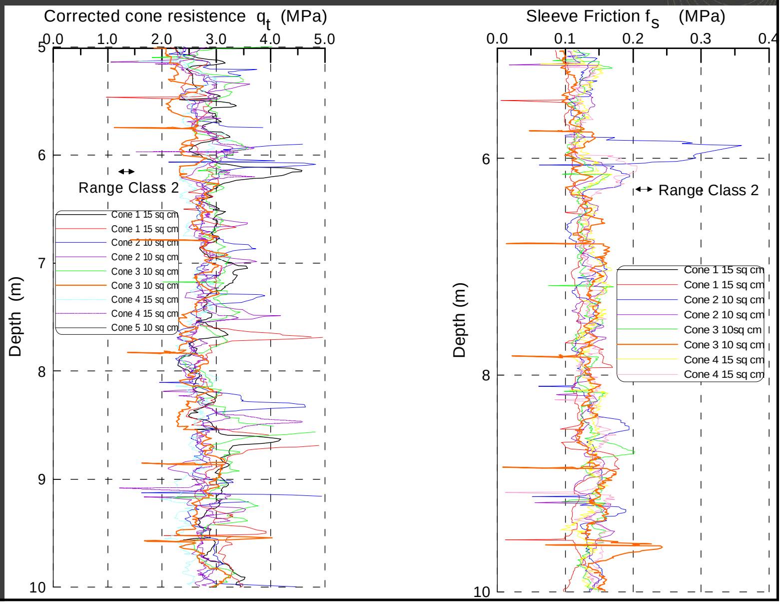
Canons Park expanded

100 kPa 5%
200 kPa 3%



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. Shall be recorded

- ***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.
- (or shift???) should always be checked! And be within Application class range!

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Temperature effects

With any mechanical device containing load cells or sensors, temperature changes can affect the measurements.

In addition to careful temperature compensation of the load cells, there are basically two ways that temperature zero shifts may be avoided or corrected for:

- **Make sure that zero readings are taken at the beginning and end of a test at the same temperature as the ground.**
- **Mount a temperature sensor in the cone and correct the measured results based on laboratory calibrations.**

Tom later

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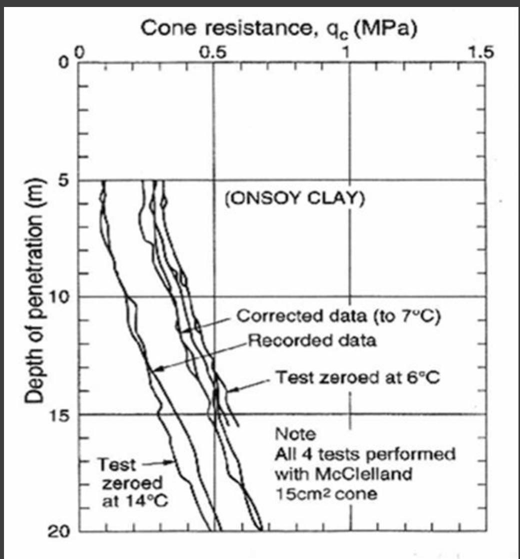
Example :Effect of temperature on field measurements



Onsøy clay

Air temperature = 14 °C

Ground temp. = 7 ° C

From Lunne et al (1997)

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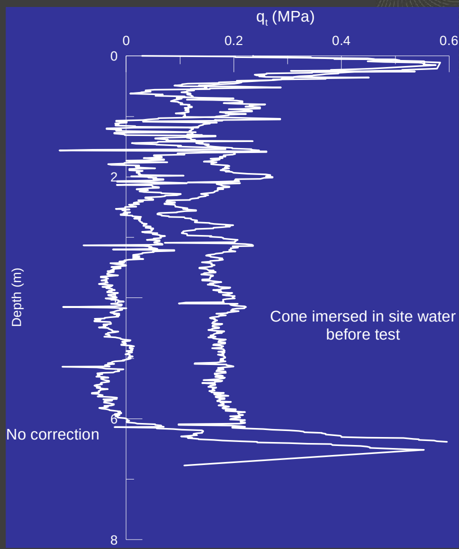
A2 research site, The Netherlands; peat

Air temperature = 12 ° C

Ground temperature = 7 ° C



Boylan et al. (2008)

Possible temperature effect with soft to medium soft clay below dense sand

- Measurements have shown that in very dense sand increase in temperature in cone penetrometer can be up to 30 ° C (Zuidberg, 1988)
- This can cause zero shift – has little relative influence on the measurements in the sand layer
- But if clay with much lower cone resistance below – may have an effect – can be overcome by stopping cone at end of sand layer to let temperature equalize

Zero drift checks especially important in soft clay

1. Check if difference in zero readings before and after test are within acceptable limits. Compare with requirements to accuracy for Application Class 1, new European standard.

2. Even if cone penetrometers are temperature compensated, zero shifts may occur due to different temperature in ground compared to above ground where sensor references (zero readings are taken)

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Calibration of sensors

- The calibration of the CPT/CPTU sensors is fundamental to the successful and reliable use of the devices.
- All calibrations should be done using high quality reference load cells and pressure transducers that are checked at regular intervals.
- Calibrations should be done with all "O"-rings and dirt seals mounted as they are during the CPT.
- The same cable and data acquisition system as normally used in the field should also be incorporated in the calibration in order to test the complete system.

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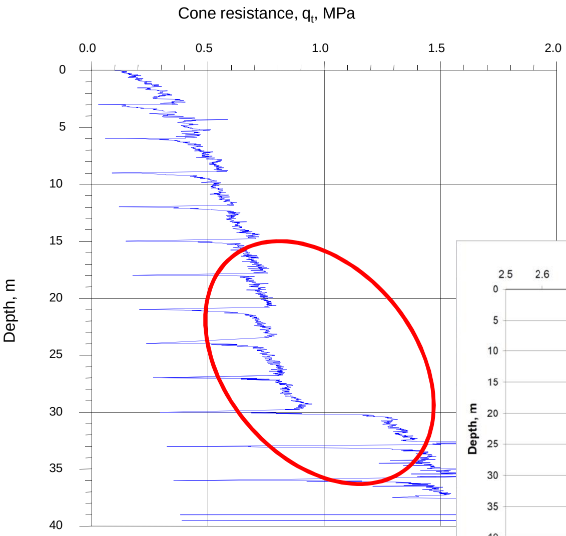
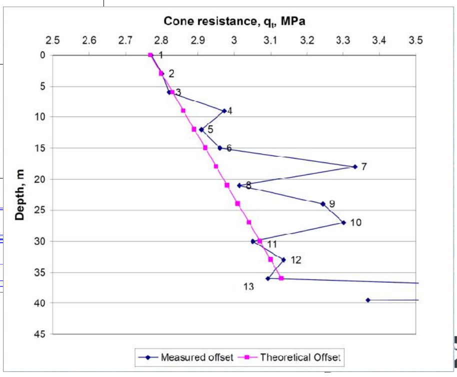
Case history offshore US



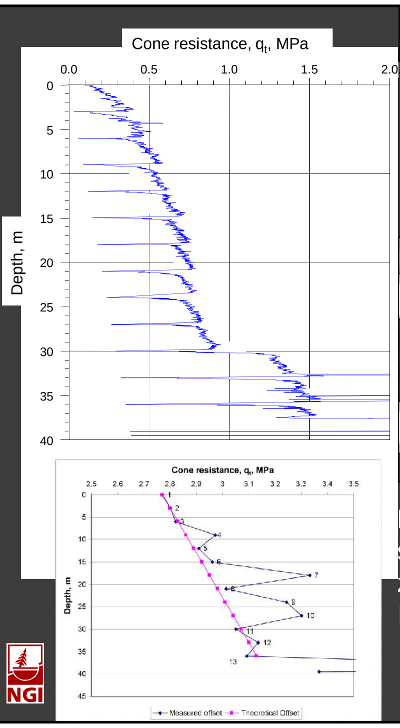
Results as received at NGI

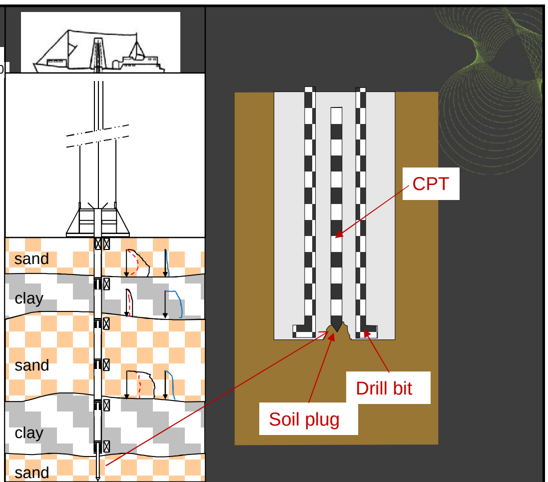
Shape of q_t curve did not fit with results of field lab measurements

Readings in bottom of borehole was requested



CPT'10





Explanation: not proper cleaning of hole; soil plug formed; load on cone when taking zero reference readings

Results could be corrected

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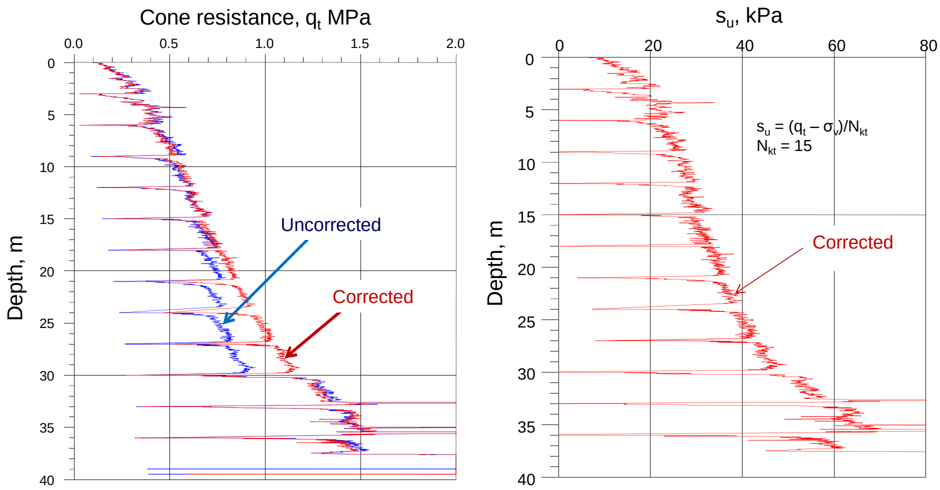
Corrected results

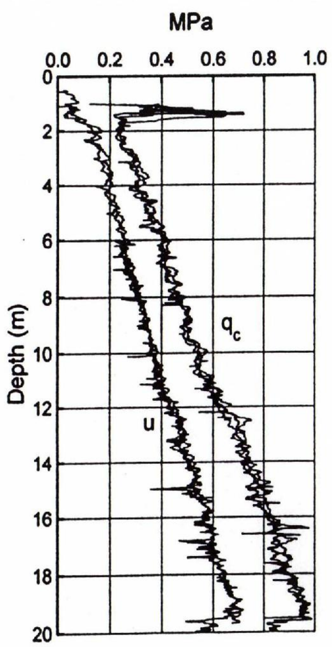


Cases like this still occurs. Can easily be avoided by proper quality control

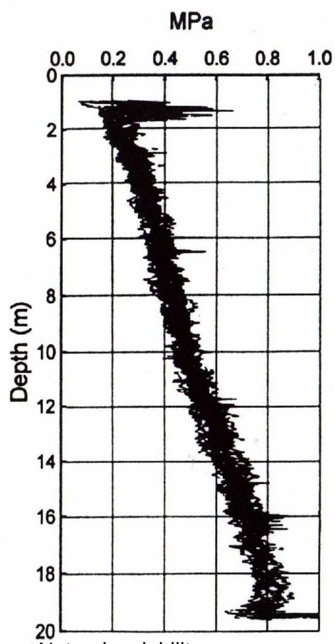
Choice of capacity of load cells

It is generally preferable that the measured loads should represent as high a proportion of the load capacity of the load cells as possible.

(Application classes!)

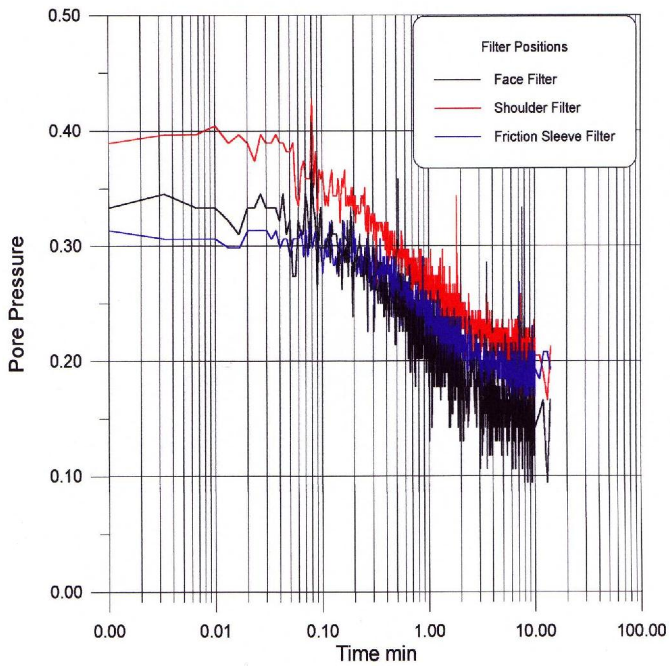


What you can get



Natural variability – no
Resolution issues - yes

Noise or resolution in PWP readings?
(higher frequency helps!)



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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Question	Answer	Note
1. Type of cone penetrometer		Manufacturer, capacity, type
2. Adhering to intern. standard	Ie. 10 cm^2 area	Compare with requirements in IRTP, European standard
3. If answer to 2 is no, what is difference?	X- sect. area	If A= 15 cm^2, α = 60 °, A_{sl} = 202 cm^2, ok
	Cone angle Sleeve area	
4. Location of filter(s) for measuring p.p., type of liquid		
5. Area ratio (a) of cone		Normally in range a = 0.59 – 0.85
6. End areas of friction sleeve		Best if small and equal
7. Is q_c corrected for pp effects?		Compare w formula given in book
8. Is f_s corrected for pp effects?		Compare w formula given in book
9. What is basis for σ_{vo} ?		Assumed? Based on measurements on samples?
10. When were sensors last calibrated?		Compare with requirements in IRTP, European standard
11. Zero readings before and after reported?		Important to check if results appear "non- normal"
12. Where were readings zeroed? (eg. Sea bottom or bottom of borehole)		Important for over water tests
13. Depth of any pre-drilling		Can explain any missing data
14. What is frequency of readings?		Normally should be at least 1 every sec, or every 2 cm
15. For dissipation tests: a) were rods clamped or un-clamped? b) Frequency of readings		How well was initial part of dissipation curve defined?

Lunne et al.(1997)

Checklist when receiving CPTU data

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Maintenance routines (Annex A (normative)

Table 1 — Control scheme for maintenance routines

Checking Routine	Start of test	End of test	Every 6 months
Verticality of thrust machine	x		
Depth sensor			x
Push rods	x		
Wear	x	x	
Gaps and seals	x	x	
Zero value	x	x	
Calibration			x*
Filter element	x	x	
Penetration rate			x
Safety functions			x

* and at intervals during long term testing, see A.2.1

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Test completion

The penetration of the cone penetrometer and the push rods shall be terminated when

- the required penetration length has been reached, or
- the agreed maximum thrust or maximum capacity of the measuring system has been reached.

Possible damage to the equipment can also be a valid reason to end the test.

The reference readings of the measured parameters shall be recorded after extraction of the cone penetrometer from the soil and, if necessary, after cleaning of the cone penetrometer. If the zero drift of the measured parameters is larger than the allowable minimum accuracy according to the required application class of Table 2, then the results should be neglected, or the test can be assigned to a lower class. After completion of the test, inspect the cone penetrometer and note any excessive wear or damage.

NOTE The zero drift determined from zero load output before test and after cleaning is a measure of the correct functioning of the equipment and is used to evaluate if the requirements of Table 2 can be fulfilled. The zero load outputs from the uncleaned cone are important for the interpretation of test results.

Measured parameters can be corrected for zero drift, if appropriate.

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Importance of quality control of CPTU data

- In most cases the results are reliable and representative for ground conditions
- However, in some cases results are **not** representative
- Reduce chances of erroneous results by using
  - sound specifications referring to New CEN/ISO standard.
  - Evaluate results in the field
  - Repeat if necessary

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Reporting

- Very detailed reporting of all information related to the testing and test results

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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

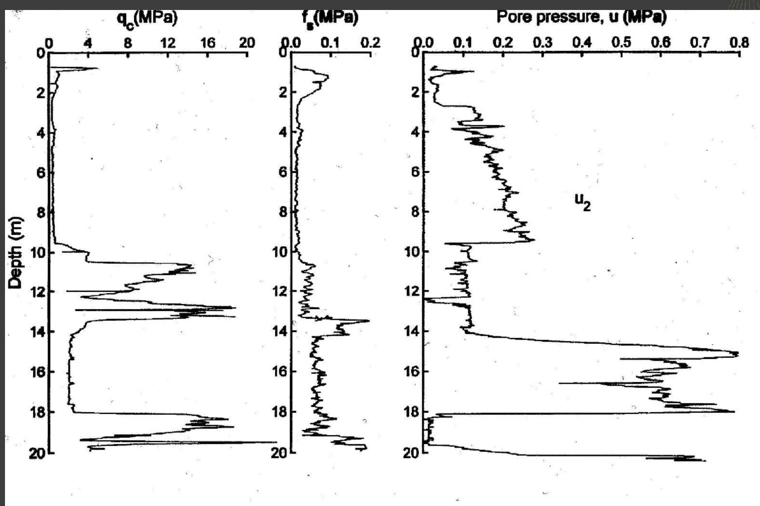
CPT/CPTU ISO/CEN - presentation of results

- 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

CPT/CPTU ISO/CEN - presentation of results

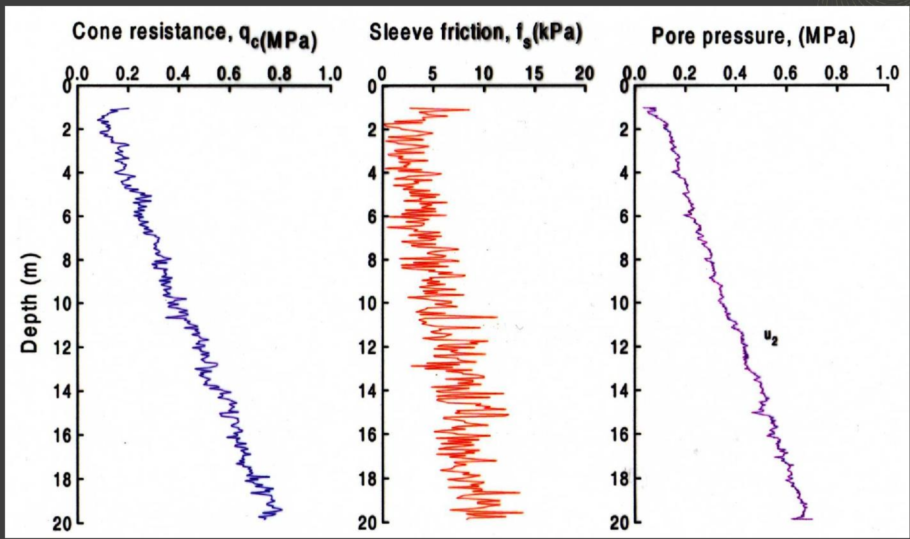
- Parameters
  - Penetration depth 1 scale unit 1m
  - Cone resistance 1 scale unit 2 MPa or 0.5 MPa
  - Sleeve friction 1 scale unit 0.05 MPa
  - Penetration pore pressure 1 scale unit 0.2 MPa or 0.02 MPa
  - Other pore pressures vs. depth u - z
  - Pore pressure ratio 1 scale unit 0.5
  - Friction Ratio 1 scale unit 2%

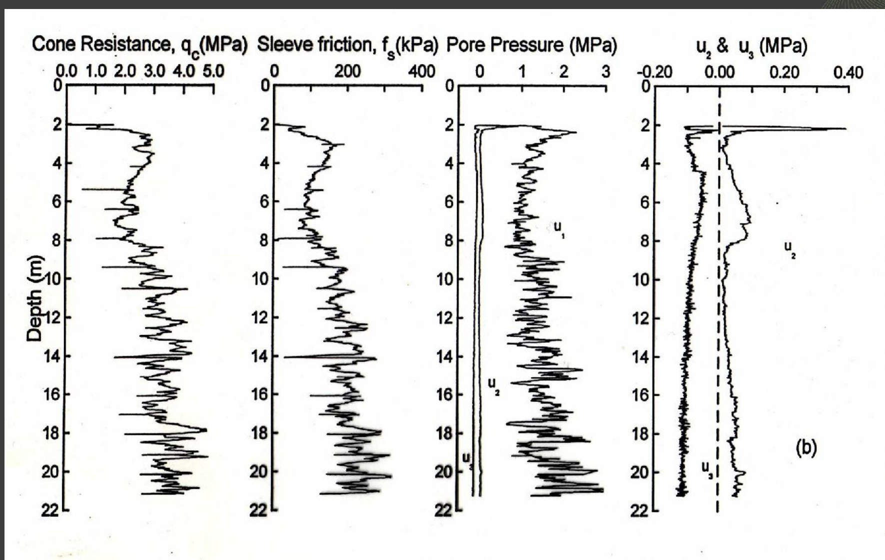
Examples measured CPTU parameters



Example: Measured CPTU Parameters

Plot to best scale to show information





CPT/CPTU IRTP/CEN - 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 — $\underline{R_f = (f_s/q_t)\ .\ 100\%}$
  - Pore pressure ratio — $B_q = (u_2 - u_0)/q_t - \sigma_{vo})$
  - Normalised excess pore pressure — $U = (u_t - u_o)/(u_i - u_o)$

  - <u>Corrected cone resistance shall be presented for Application class 1</u>

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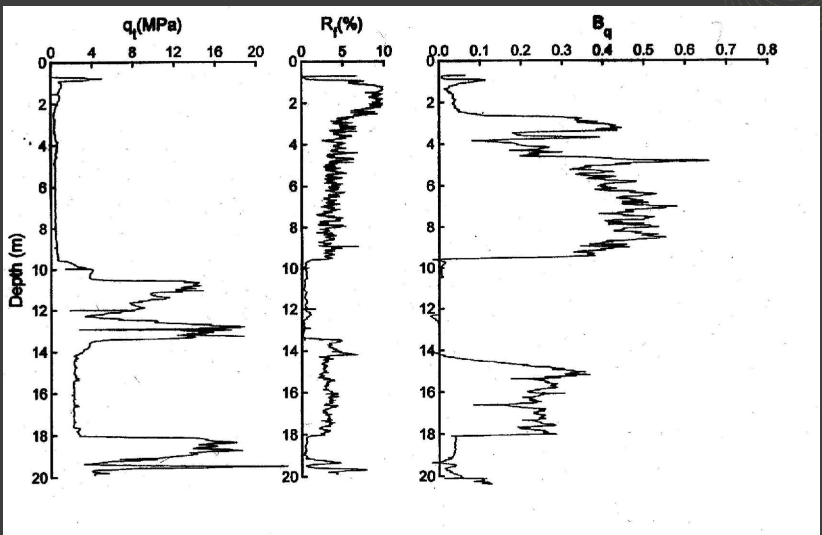
Example derived CPTU parameters



Example: Derived CPTU Parameters

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CPT/CPTU IRTP/CEN - presentation

- Ensure all information is supplied to allow full evaluation of data quality
- Follow the standards

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Important elements of new CEN/ISO on CPT/CPTU

Application Classes

- 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**
- **EC7 may force this forward in Europe**

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Conclusions/thoughts

- The challenge is still there to get reliable data that can be trusted, is repeatable and accurate, especially in soft soils.
- How do we ensure adherence to standards and quality of maintenance and operation?
- We need to also maximise the amount and value of data gathered by add-on devices.

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Use of CPT/CPTU in Geotechnical Soil Investigations

Summary

- If we don't have confidence in the base data then we won't have confidence in the derived parameters
- Equipment and procedures should/shall be standardised
- Reliable results can be obtained

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WG10 / RG7 – TP1

Marine soil investigations standard (19901-8)

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NORSOK and ISO standards

- NORSOK G-001 (Geotechnology) - Marine soil investigations, see http://www.standard.no/en/sectors/Petroleum/
- NORSOK G-001 is a NATIONAL standard
- ISO 19901-8 is an INTERNATIONAL standard. The goal is:
  - Common understanding and terminology worldwide
  - Common requirements and test methods worldwide
  - Will get equal quality worldwide
  - Will get equal test results worldwide

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Objective of 19901-8

The primary objectives of this part of ISO 19901 is to provide requirements and guidance for how the most important aspects of a marine soil investigation shall be performed to obtain reliable soil parameters based on documented methods.

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List of Contents – NORSOK and ISO standards

NORSOK G-001

- *Chapter 4, General objectives and planning*
- *Chapter 5, General requirements*
- *Chapter 6, Drilling and logging*
- *Chapter 7, Sampling*
- *Chapter 8, In situ testing*
- *Chapter 9, Laboratory testing*
- *Chapter 10, Reporting*

ISO 19901-8

- Chapter 5, *General objectives, planning and requirements*
- Chapter 6, *Deployment of investigation equipment*
- Chapter 7, *Drilling and logging*
- Chapter 8, *In situ testing*
- Chapter 9, *Sampling*
- Chapter 10, *Laboratory testing*
- Chapter 11, *Reporting*

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To be given in «Project specifications»

The extent of and what is to be included in a marine soil investigation, such as field programme, equipment to be used, laboratory testing programme, soil parameters to be established (measured, derived, representative) and reporting should be defined in project specifications based on important factors such as type of structures involved, type of soil conditions expected, regional or site-specific investigation, preliminary or final soil investigation.

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CPT testing – Sec. 8.3.3

Seafloor CPT systems generally provide thrust perpendicular to the seafloor, with no opportunity for correcting the pushing force to vertical. In drilling mode, verticality of the downhole CPTU/CPT system depends on verticality of the drill string. A vertical pushing force is normally assumed for the calculation of the penetration depth.

NOTE The difference between accuracy and uncertainty is described in Clause 3.

Table 2 — Accuracy of CPT/CPTU parameter values for application classes

Application Class	Test type[a]	Measured parameter	Allowable minimum accuracy[a]
1	CPTU	Cone resistance	35 kPa or 5 %
		Sleeve friction	5 kPa or 10 %
		Pore pressure	25 kPa or 5 %
2	CPT or CPTU	Cone resistance	100 kPa or 5 %
		Sleeve friction	15 kPa or 15 %
		Pore pressure[b]	50 kPa or 5 %
3	CPT or CPTU	Cone resistance	200 kPa or 5 %
		Sleeve friction	25 kPa or 15 %
		Pore pressure[b]	100 kPa or 5 %

[a] The allowable minimum accuracy of the measured parameter is the larger value of the two quoted The relative accuracy applies to the measured value and not the measuring range.

[b] Pore pressure can only be measured if CPTU is used.

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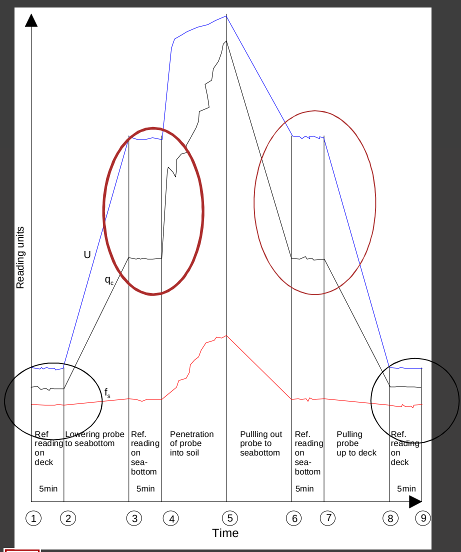
Recommended evaluation of in situ tests where accurate readings in soft soil is a particular requirement



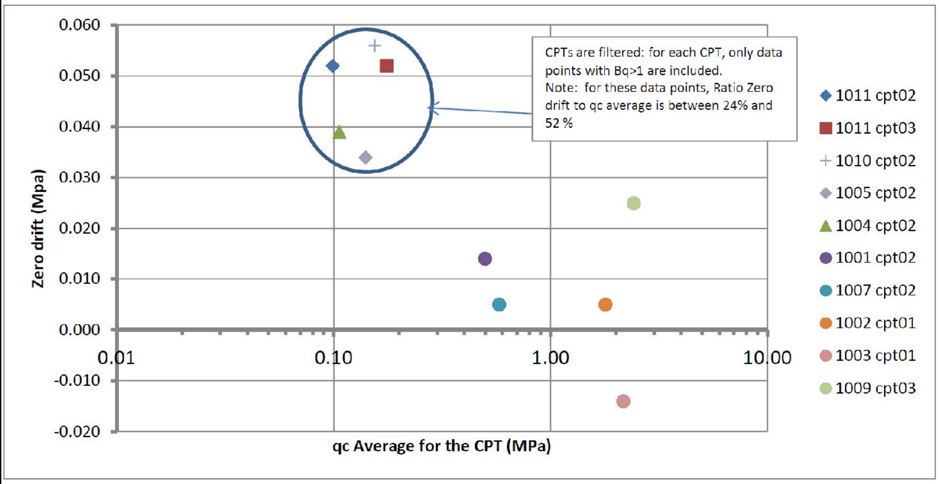
If difference(s) in reading(s) at 7 and 4 or 9 and 2 exceeds limiting values, assign test to be of lower quality:

Measured parameter	Allowable min. accuracy**
q_c	35 kPa or 5%*
f_s	5 kPa or 10 %
u	10 kPa or 2 %
$q_{T\text{-}bar}$ or q_{ball}	10 kPa or 5 %

* % of max. reading in layer

** The largest of the two values

For CPTU values are taken from new European standard



Statoil use of ISO 19901-4

APPENDIX E

SPECIFICATIONS

2.5 ISO

Document No.	Document Title
ISO 9001	Quality management systems – Requirements
ISO 19901-6	Marine operations
ISO 19901-8	Marine soil investigations (when published as a draft ISO document)

2.8.2 General geotechnical requirements

- Cone penetrometer testing (CPT):

All CPTU testing shall be Application Class 1 unless otherwise agreed;

2.8.3 Additional requirements for vessel-mounted drilling systems

- If not otherwise specified by Company a depth accuracy of 0.5 m shall apply (reference to class Z2 in the planned ISO document 19901-8).

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