ENGINEERING GROUP OF THE GEOLOGICAL SOCIETY

Where Are We Now And What Is The Future?

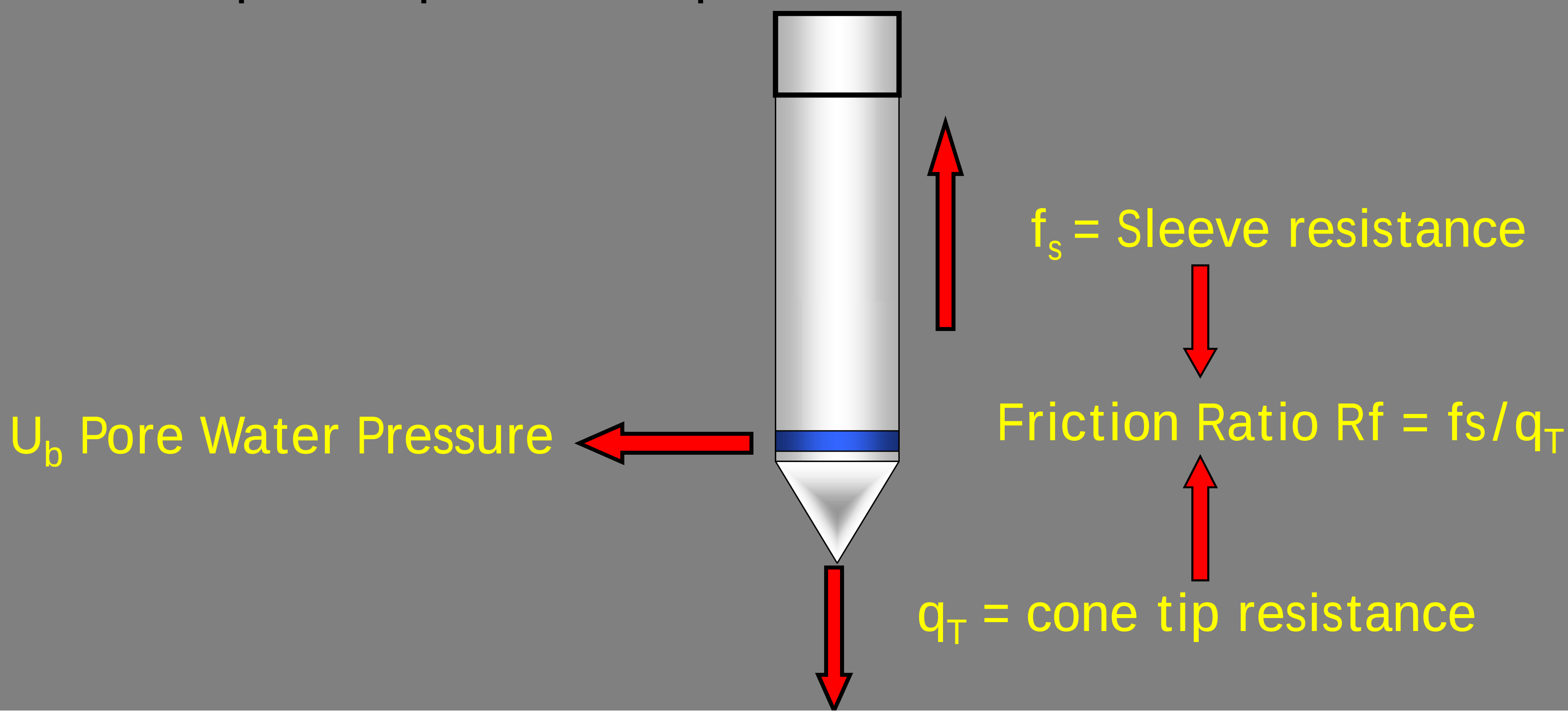
What Is Cone Penetration Testing?

- The Cone penetrometer is an instrumented probe that is pushed into the ground with a 20 Tonne hydraulic ram set and a thrust machine

- Comprises two main sections:
  1. The cone tip (60^0)
  2. A friction sleeve

  } Friction cone

  3. Optional pore water pressure transducer - Piezocone



Eurocode 7

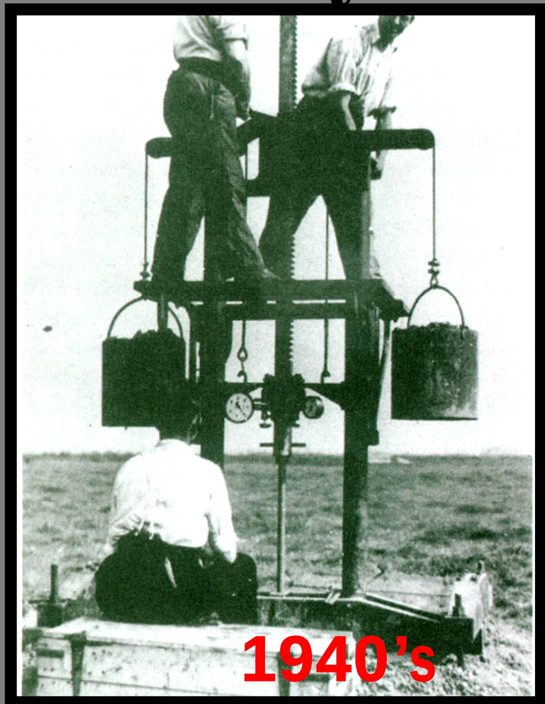
- Implementation 2010 and allows
- For Rapid Site Characterisation
- Design Parameters - ‘‘the derived value’’ of a geotechnical parameter is defined in Eurocode 7 as

‘*’the value……obtained by theory, correlation or empiricism from the test’’*

The CPT readily lends itself to these requirements.

CPT DEPLOYMENT SYSTEMS

Early Penetration Testing



1940's

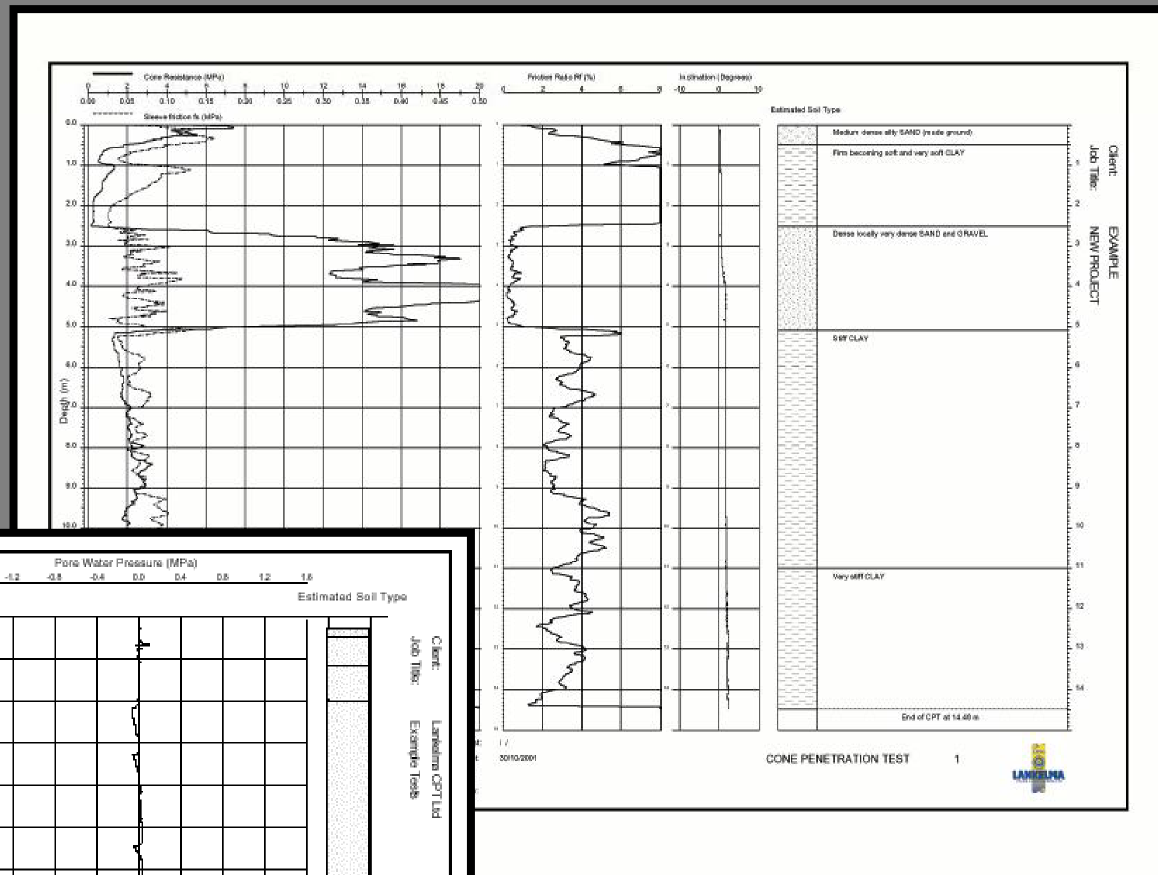
1950's

1960's

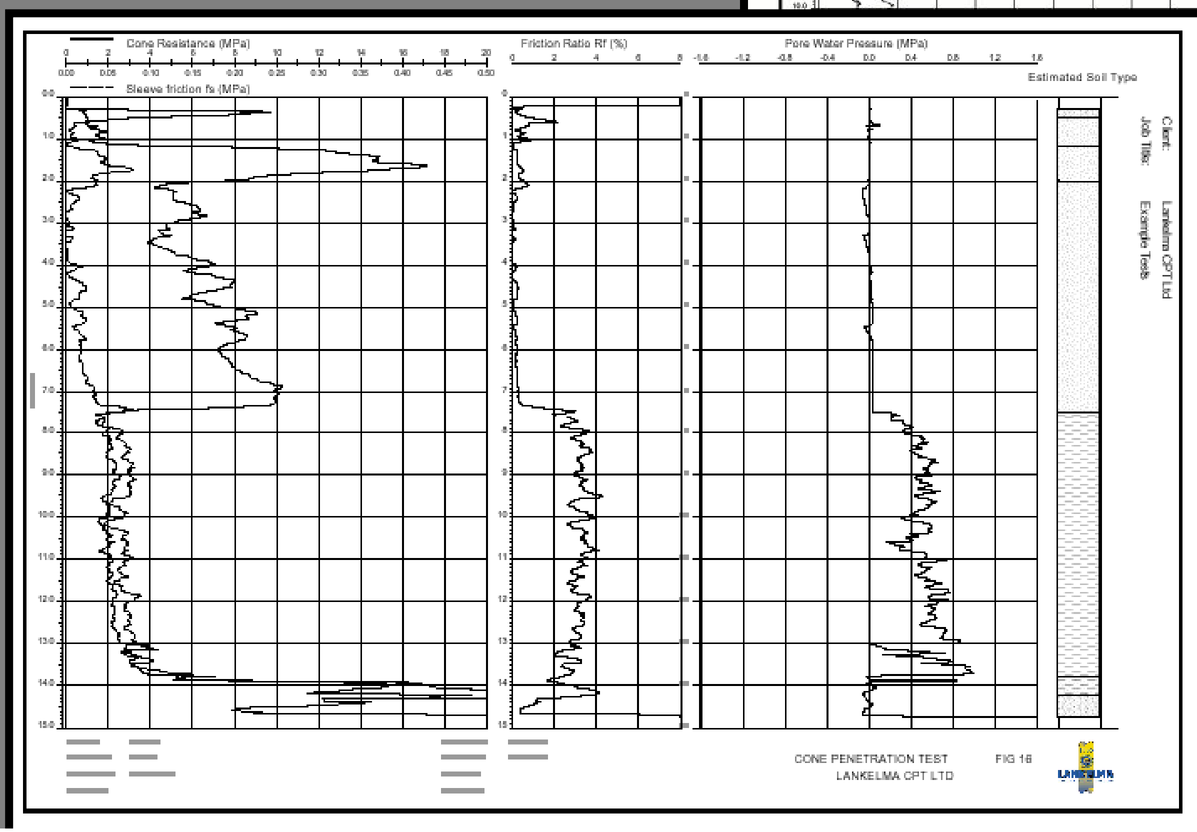
2000

Thrust Machines

Friction Cone



Piezocone



Role of CPT

CPT has three main applications:

- Determine sub-surface stratigraphy and identify materials present,
- Estimate geotechnical parameters
- Provide results for direct geotechnical design

In UK Primary role is soil profiling, but increasingly used for geotechnical properties

Let us now consider getting parameters

Interpretation in fine grained deposits

- CPT/CPTU in fine grained soils is generally undrained.
- Performing CPT/CPTU tests under undrained conditions generate pore pressures and the measurement of pore pressure is extremely useful.
- The pore pressures generated affect measurements of both qc and fs and must be corrected for.
- The measured pore pressures can also be used directly for interpretation in terms of soil design parameters.

Interpretation of CPTU data in clay

Parameters that we can try to estimate from CPTs in fine grained soils are:

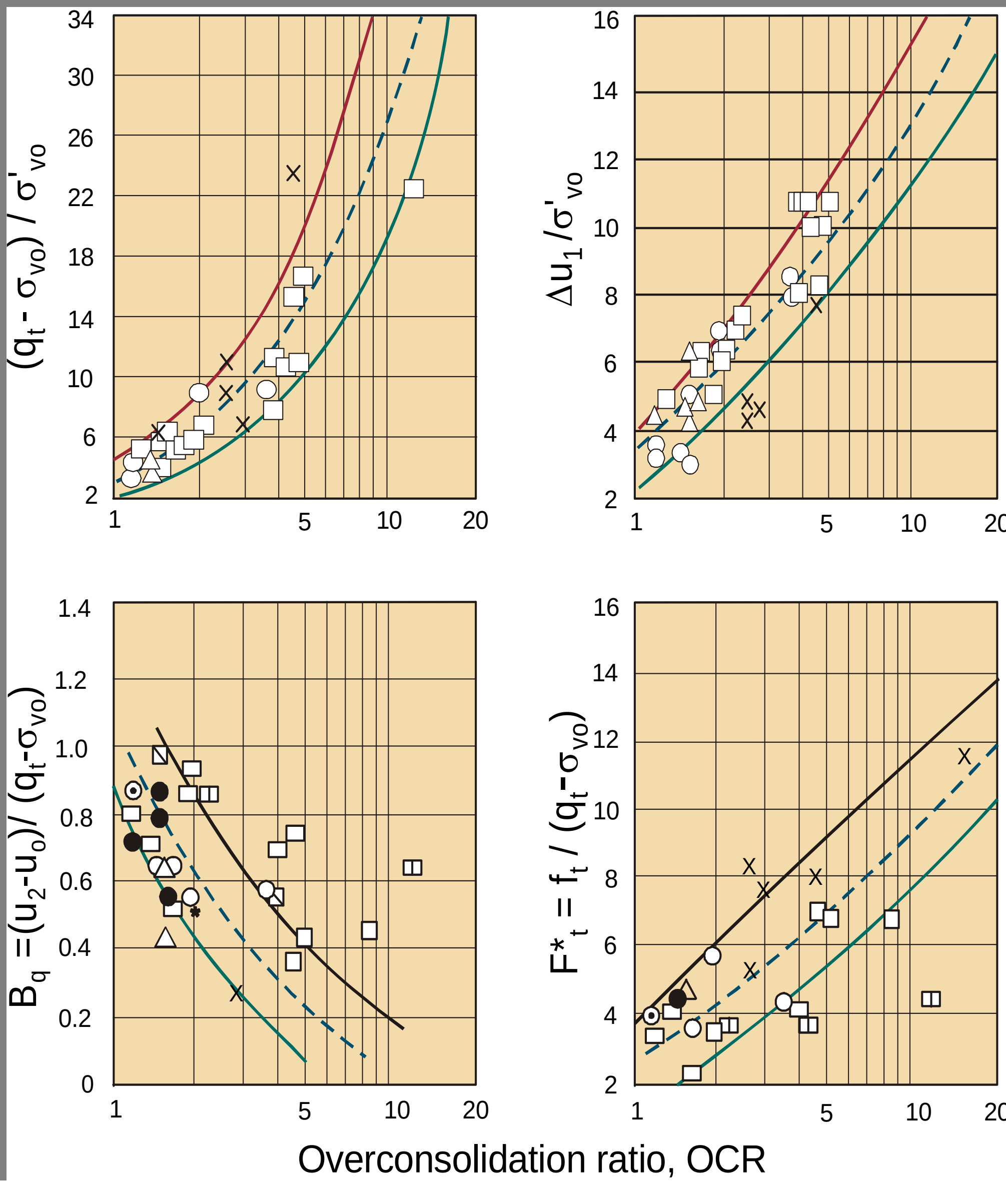
- State characteristics (Unit weight In situ stresses and stress history)
- Strength characteristics
- Deformation characteristics
- Flow and consolidation characteristics
- In situ pore pressure

Overconsolidation Ratio

Interpretation of CPTU data can use methods based on:

- the undrained shear strength
- the shape of the CPTU profile
- directly on CPTU data

Correlations to OCR – continual improvements

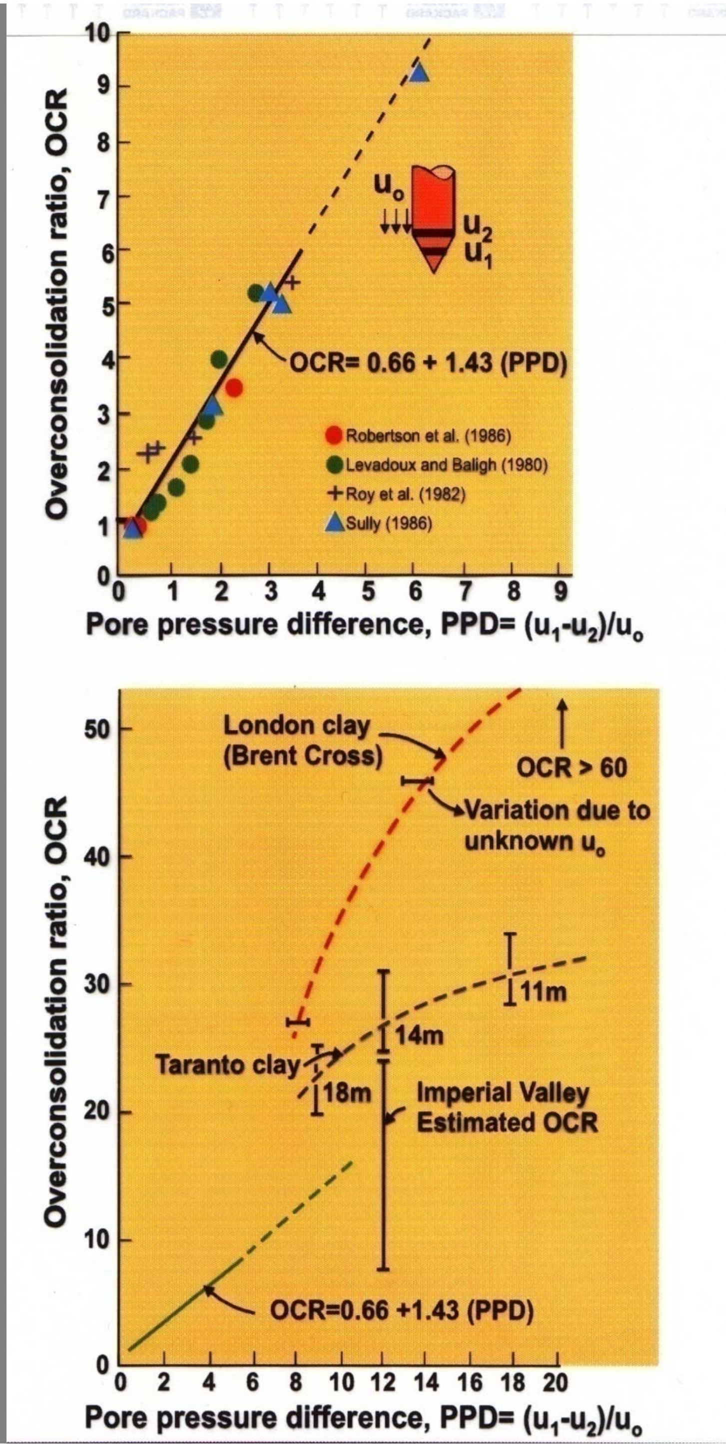


Following recommendations by Prof. P.Wroth 1984 Rankine lecture

Legend:

- △ Troll
- ○ Brage
- □ Haltenbanken
- Haga
- ✱ Rio
- ⊖ Vancouver
- X Cowden
- ▽ Brent Cross
- ▭ Onsøy
- Emmerstad
- ⊙ Drammen lean clay
- ● Drammen plastic clay

PPD


Overconsolidation ratio, OCR
Pore pressure difference, PPD= (u1-u2)/uo
OCR= 0.66 + 1.43 (PPD)
uo
u2
u1
Robertson et al. (1986)
Levadoux and Baligh (1980)
Roy et al. (1982)
Sully (1986)
London clay
(Brent Cross)
OCR > 60
Variation due to
unknown uo
11m
14m
18m
Taranto clay
Imperial Valley
Estimated OCR
OCR=0.66 +1.43 (PPD)

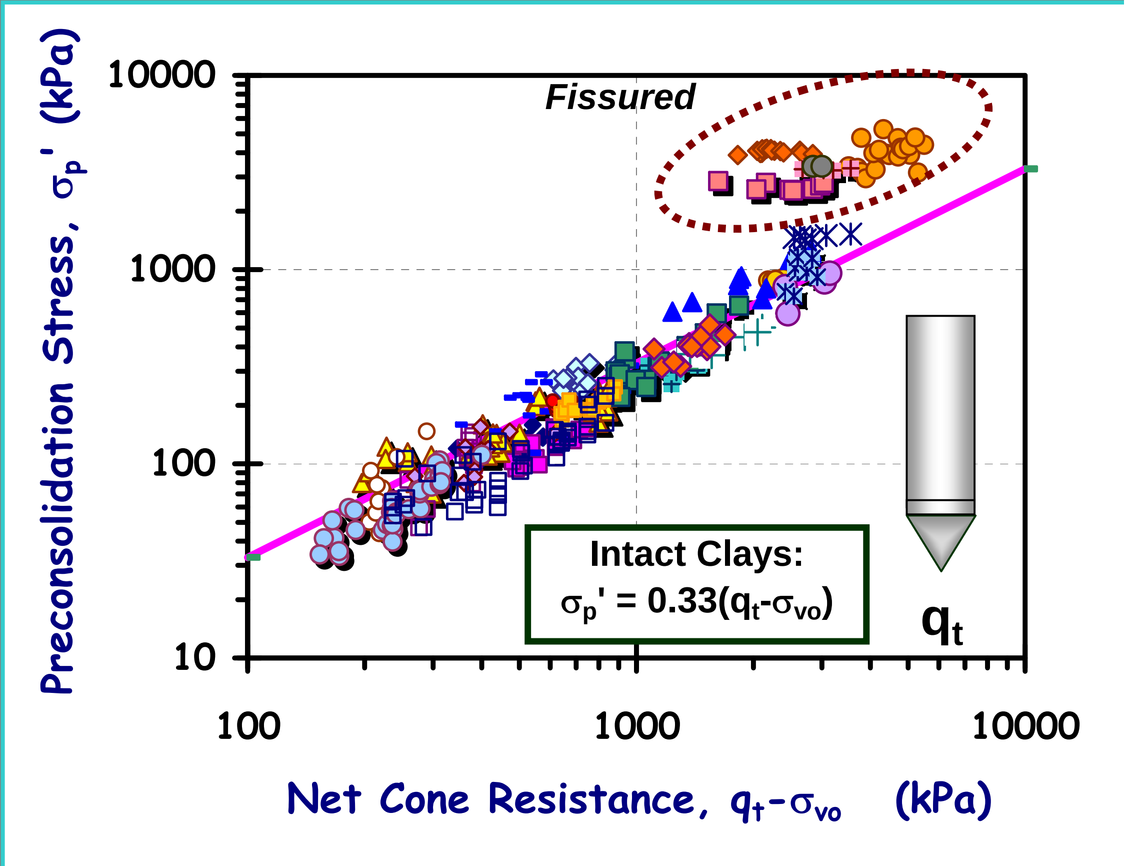
Direct Evaluation of σ_p' in Clays from CPTu

$\sigma_p' = 0.33\ (q_t - \sigma_{vo})$

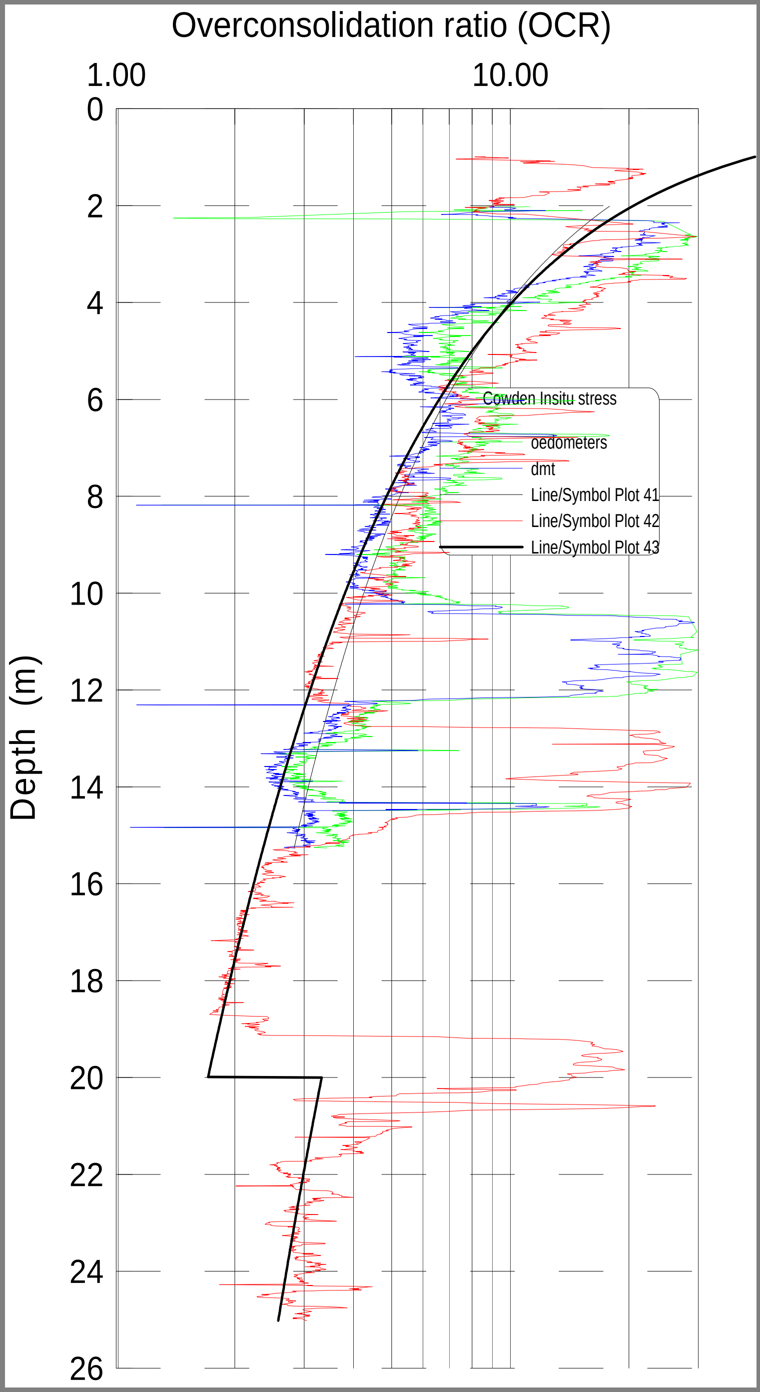
$\sigma_p' = 0.47\ (u_1 - u_0)$

$\sigma_p' = 0.53\ (u_2 - u_0)$

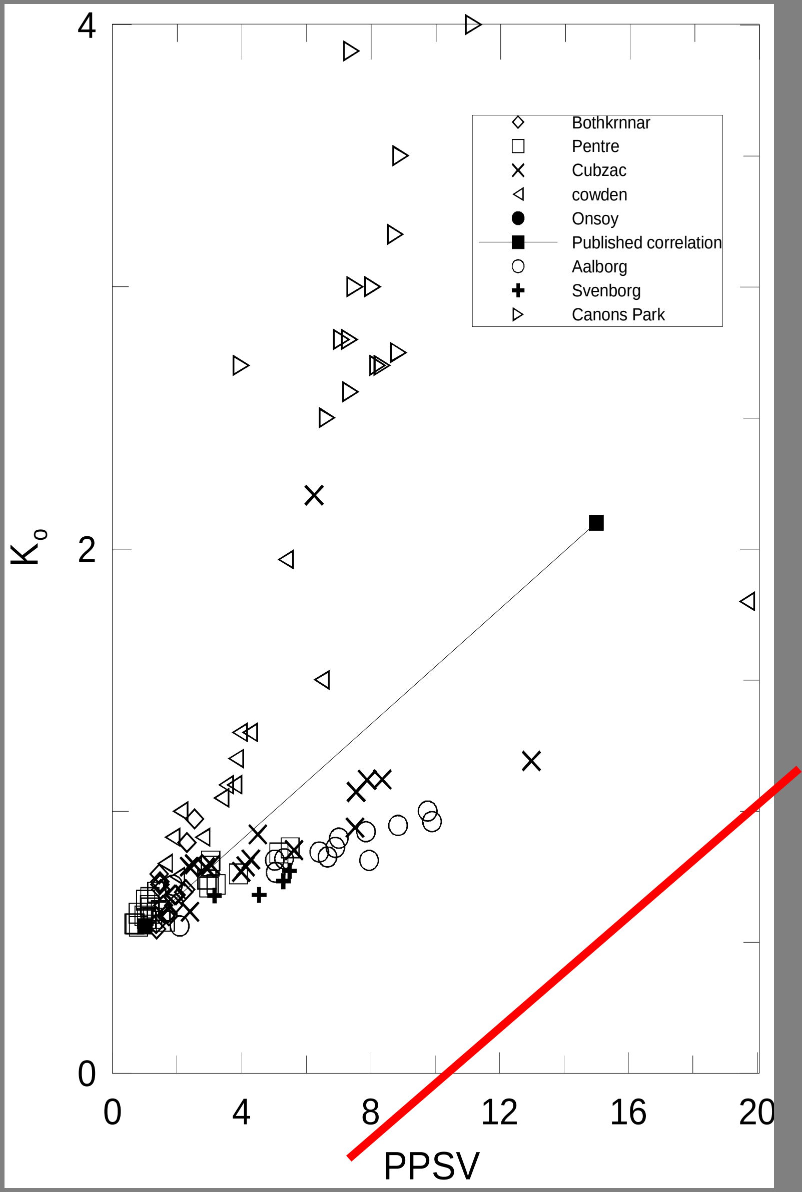
$\sigma_p' = 0.60\ (q_t - u_2)$



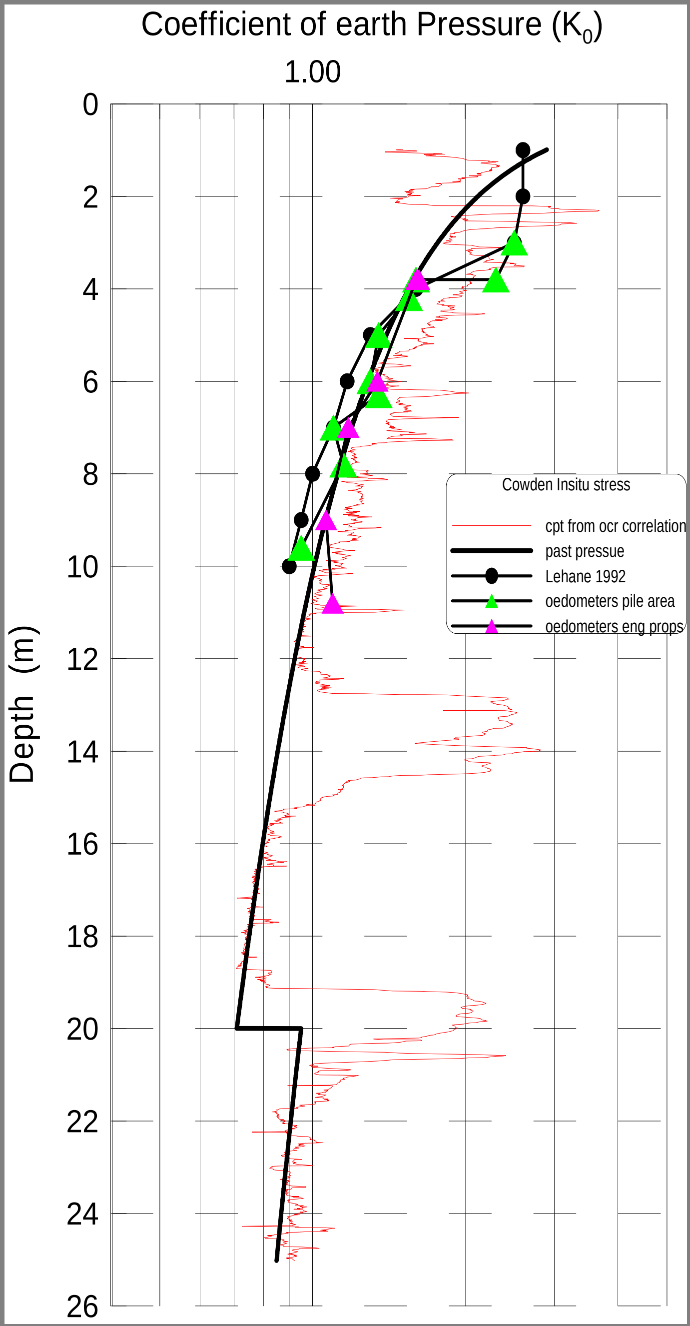
OCR: Cowden



Overconsolidation ratio (OCR)
1.00
10.00
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Cowden Insitu stress
oedometers
dmt
Line/Symbol Plot 41
Line/Symbol Plot 42
Line/Symbol Plot 43



K_o and PPSV beware of generalisation, site specific possible?



Ko: Cowden

helping to establish history

Strength characteristics

– undrained shear strength
– sensitivity
– effective stress strength parameters

Undrained Shear Strength

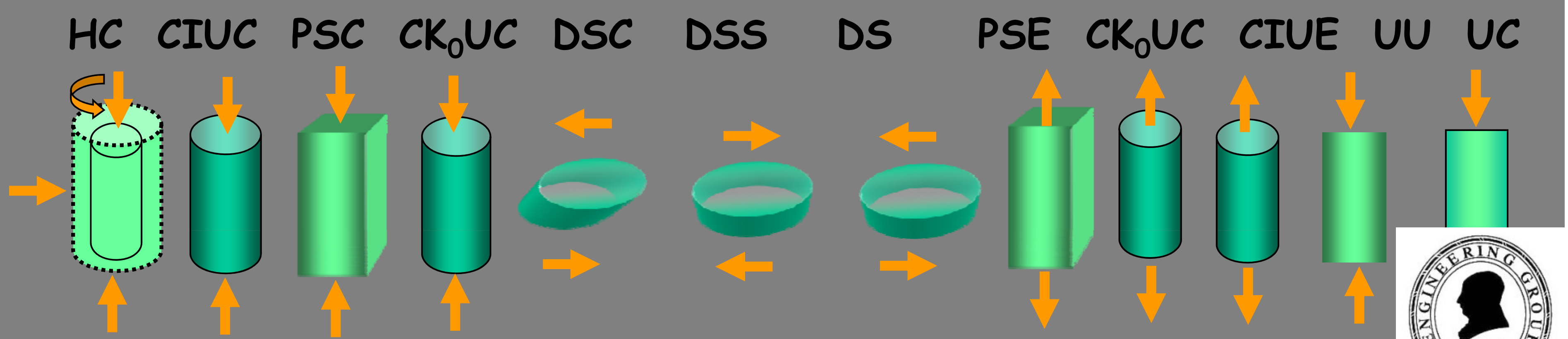
- Classical interpretation from CPT in clays:

  undrained shear strength = s_u

$$s_u = \frac{q_t - \sigma_{vo}}{N_{kt}}$$

  - Which s_u ?

N_k = 15



Undrained Shear Strength from CPTU Data

$s_u = q_{net}/N_{kt} = (q_t - \sigma_{v0})/N_{kt}$

Most Common

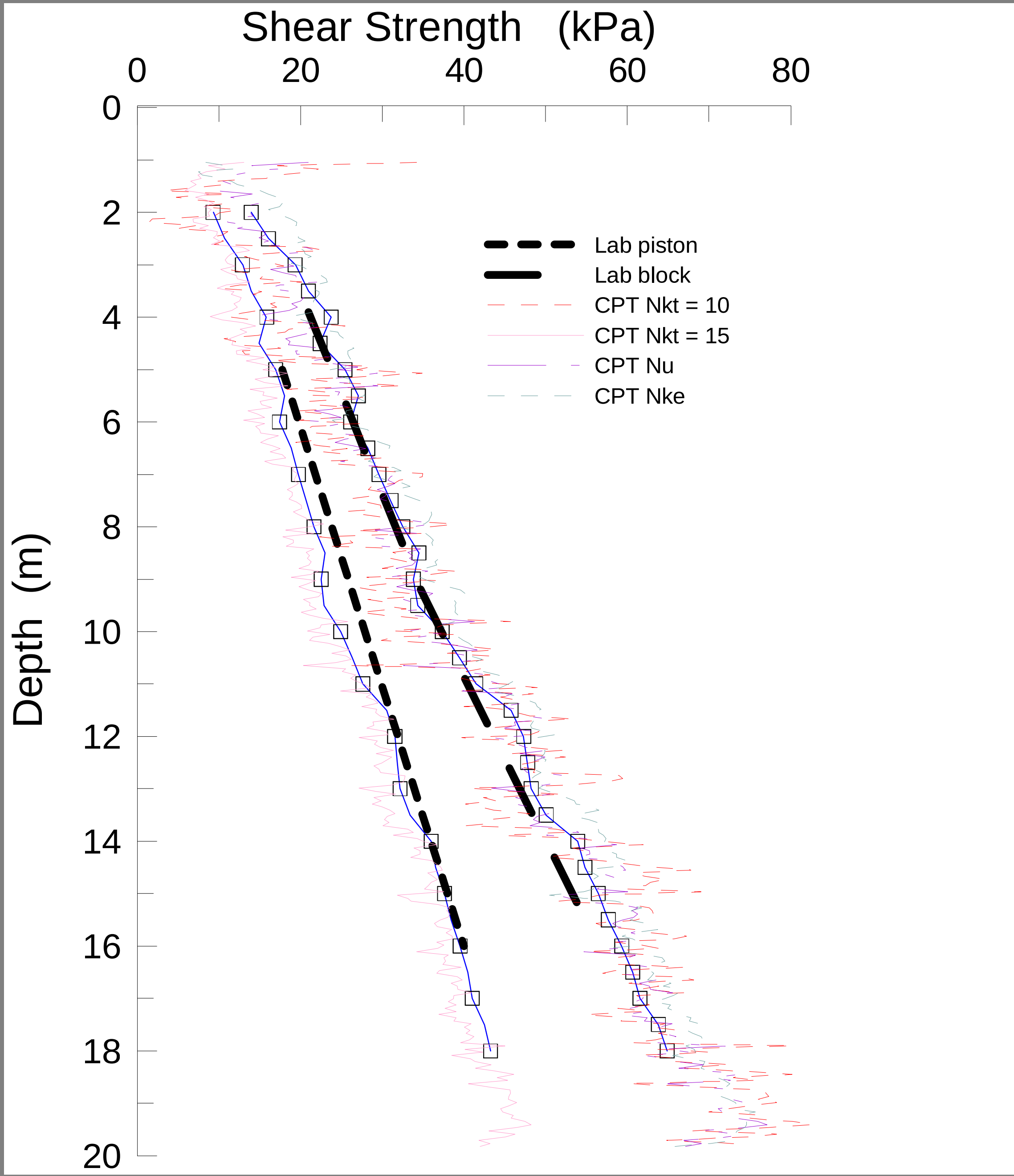
$s_u = \Delta u/N_{\Delta u} = (u_2 - u_0)/N_{\Delta u}$

Often used

$s_u = q_e/N_{ke} = (q_t - u_2)/N_{ke}$

Seldom used

Need empirical correlation factors N_{kt}, $N_{\Delta u}$, or N_{ke} factors to be correlated to a specific measure of undrained shear strength, e.g., s_u(CAUC) or s_u(ave)



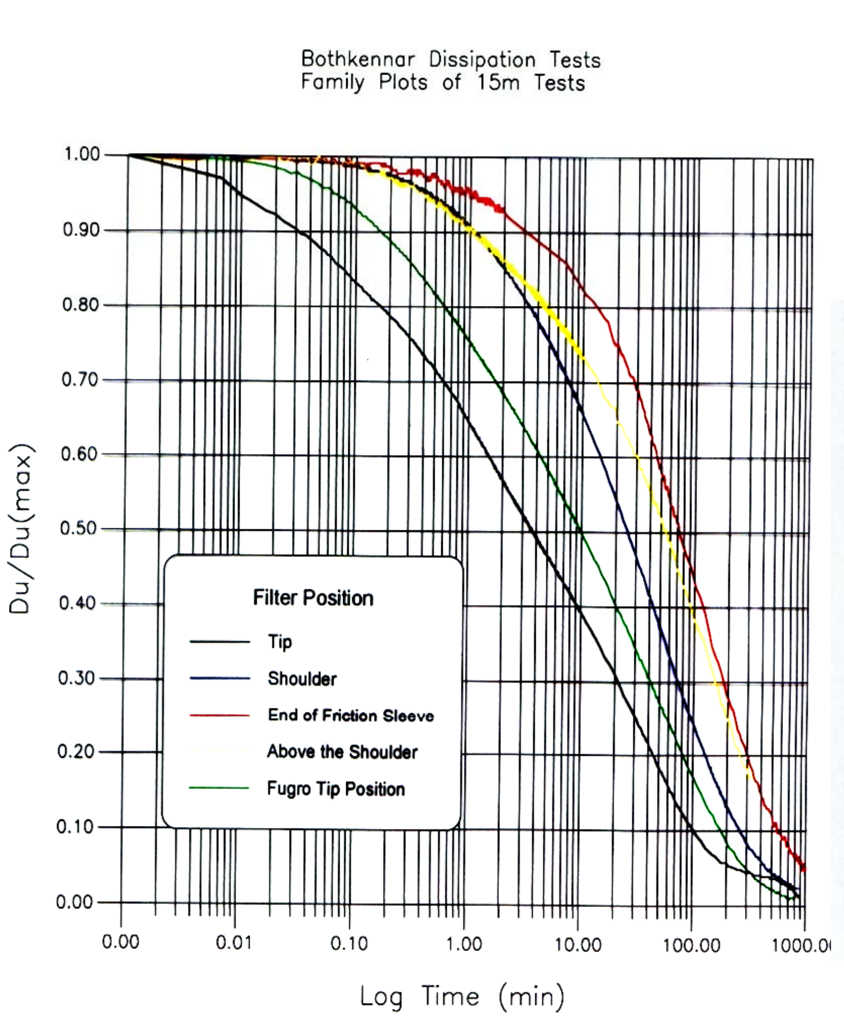
Shear strength - Bothkennar

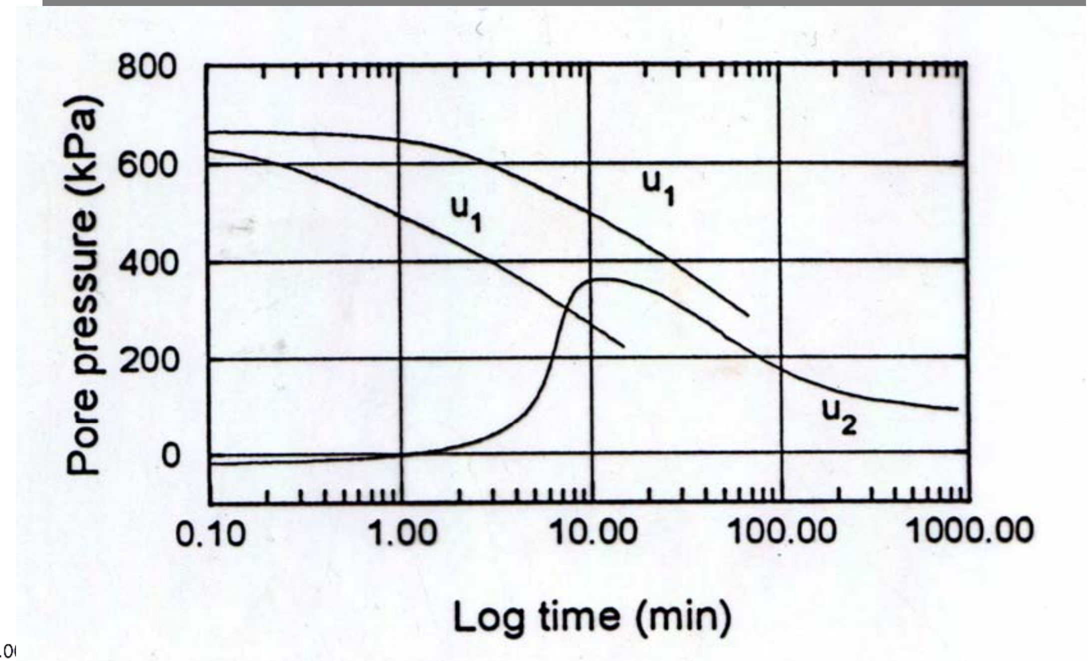
correlation to match source

Flow and consolidation characteristics

- coefficient of consolidation
- coefficient of permeability

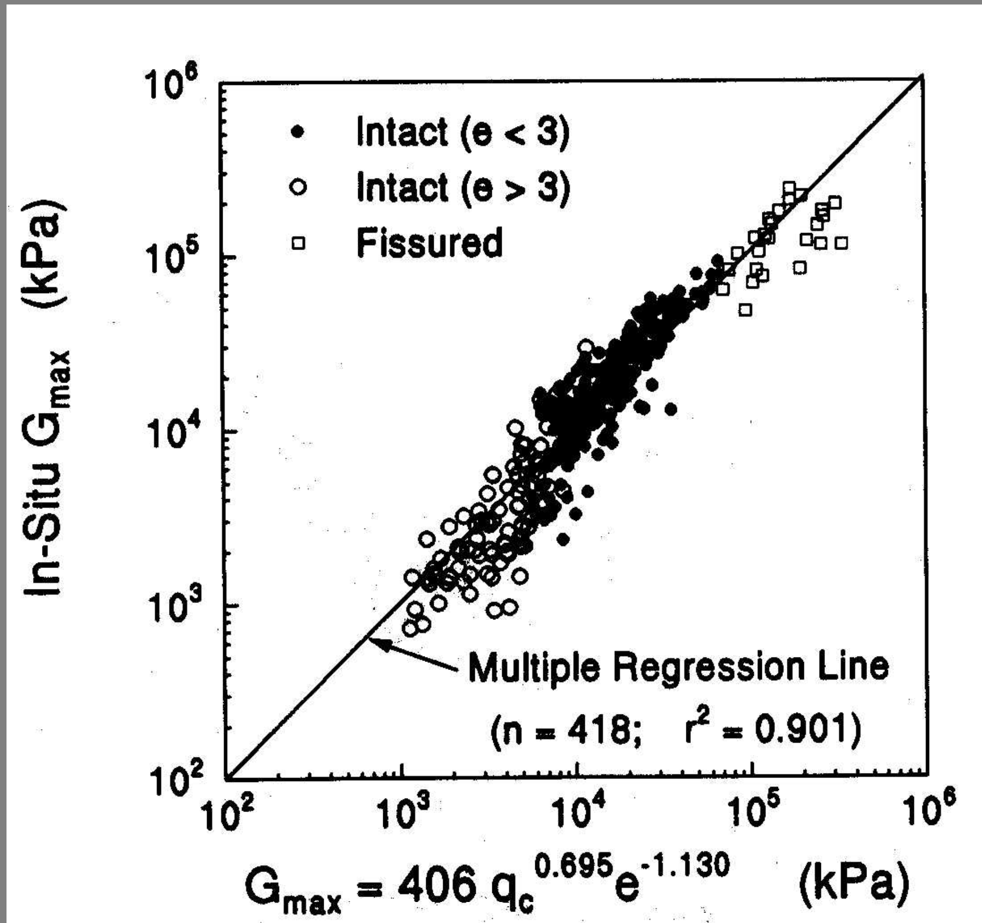
Dissipation Tests





OC Clays (u_2 rising from suctions)

Small strain shear modulus from CPTU data



From Mayne and Rix (1993)

Seismic Measurements

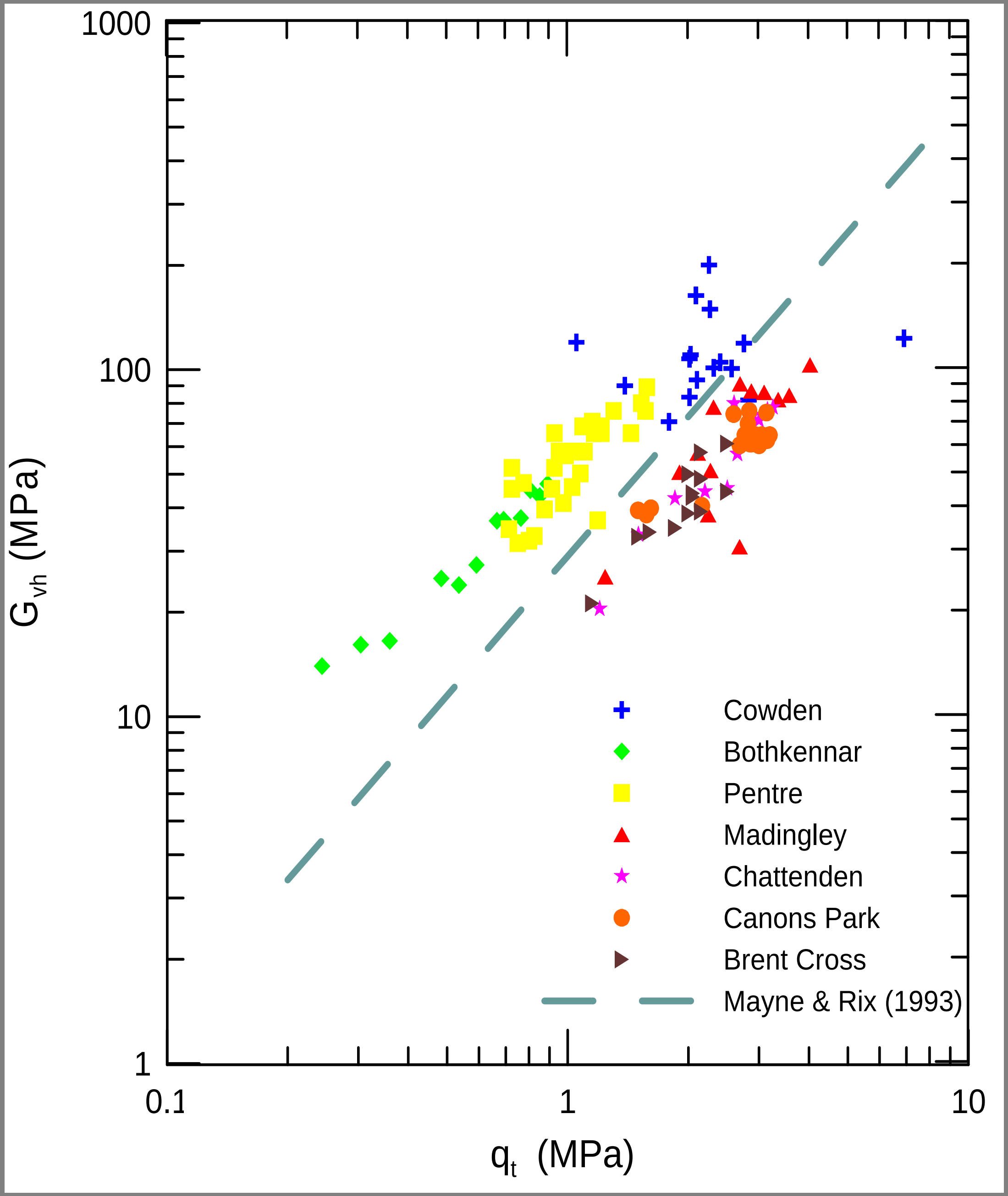
- Elastic theory relates the small strain shear modulus (G_o) using:

$$G_0 = \rho(V_s)^2$$

where ρ is the soil mass density

Measure velocity and calculate stiffness if ρ is known or estimated

G_{VH} in UK soils



INTERPRETATION IN SAND - DRAINED CONDITIONS

- In situ state
  - relative density; porosity
  - in situ stresses, stress history
- Drained shear strength
- Deformation characteristics
  - constrained modulus (M)
  - Young's modulus (E_D)
  - Small strain or maximum shear modulus (G_{max})

Relative density, D_r

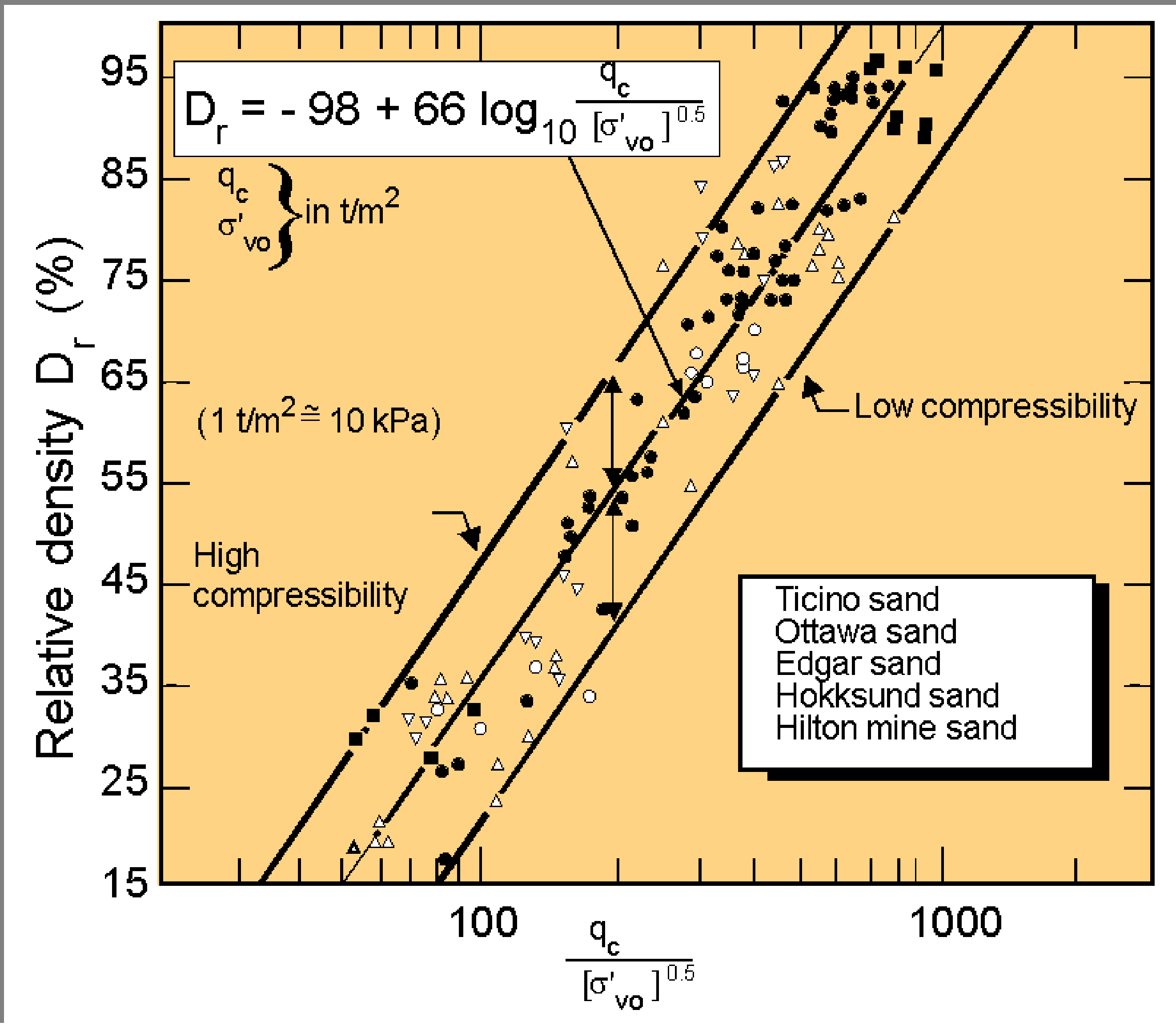
$$D_r(I_D) = \frac{e_{max} - e}{e_{max} - e_{\min}}$$

e = in situ void ratio

e_{max} = max. porosity (loosest state)

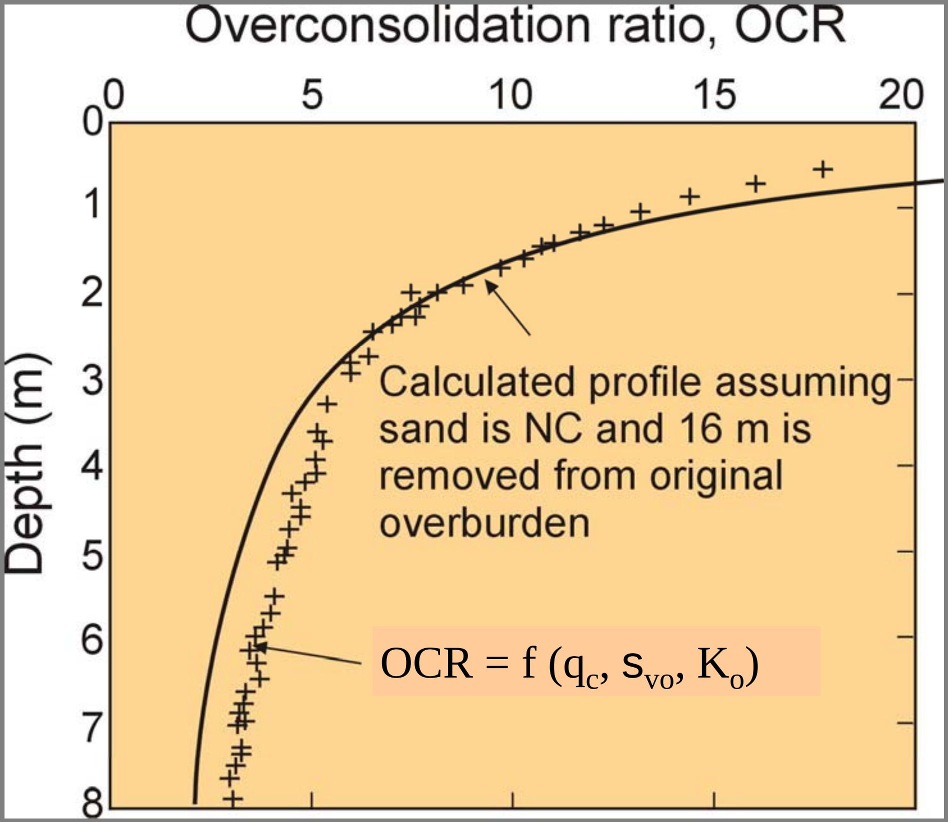
e_{min} = min. porosity (denses state)

Influence of compressibilty on NC, uncemented, unaged, predominantly quartz sands



After Jamiolkowski et al., 1985

Example of K_o and OCR interpretation after Mayne (1991)



Stockholm sand

DRAINED SHEAR STRENGTH, f_D', FROM CPT

<u>Three most common methods:</u>

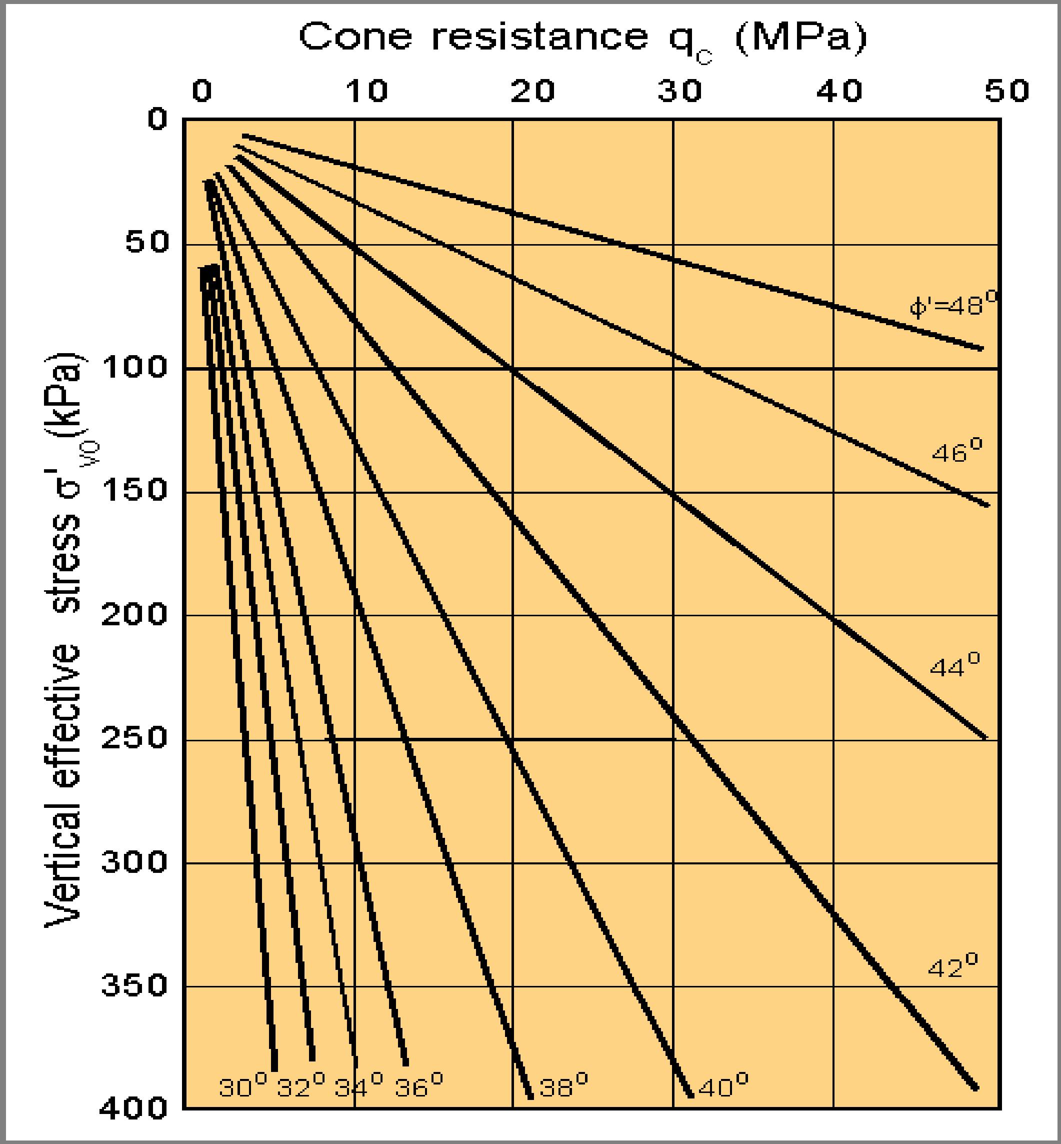
1 Empirical D_r approach

- use estimated D_r and then correlation $(\phi_D'/D_r)/\sigma_{v0}'$
- or carry out triaxial tests reconstituted to D_r from CPT

2 Empirical calibration chamber correlation

3 Bearing capacity method

σ_v',q_c, ϕ' relationships



Based on Calibration Chamber Data

From Robertson and Campanella(1983)

CORRELATIONS BETWEEN CONE RESISTANCE AND CONSTRAINED MODULUS, M FOR SANDS

Rough estimate from calibration chamber tests:

NC sands: $M_0 = 4\ q_c$ $\qquad q_c < 10$ MPa

$M_0 = 2\ q_c + 20$ (MPa) for $10 \text{ MPa} < q_c < 50$ MPa

$M_0 = 120$ MPa $\qquad q_c > 50$ MPa

OC sands: $M_0 = 5\ q_c$ $\qquad q_c < 50$ MPa

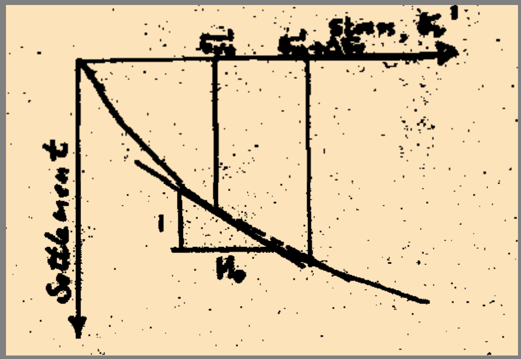
$M_0 = 250$ MPa $\qquad q_c > 50$ MPa

Ref. Lunne and Christophersen (1983)

M_0 is tangent modulus at in situ stress conditions, σ_{v0}'.

Tangent modulus applicable for stress range $\sigma_{v0}' + \Delta\sigma_v'$ is given as:

$$M = M_0 \sqrt{\frac{\left(\sigma_{v0}' + \Delta\sigma_{v0}'/2\right)}{\sigma_{v0}'}}$$



Ref. Modulus concept by Janbu(1969)