Use of Cone Penetration Test (CPT) to derive parameters for shallow foundation design

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Aims:

For vertically loaded footings on dense sands,

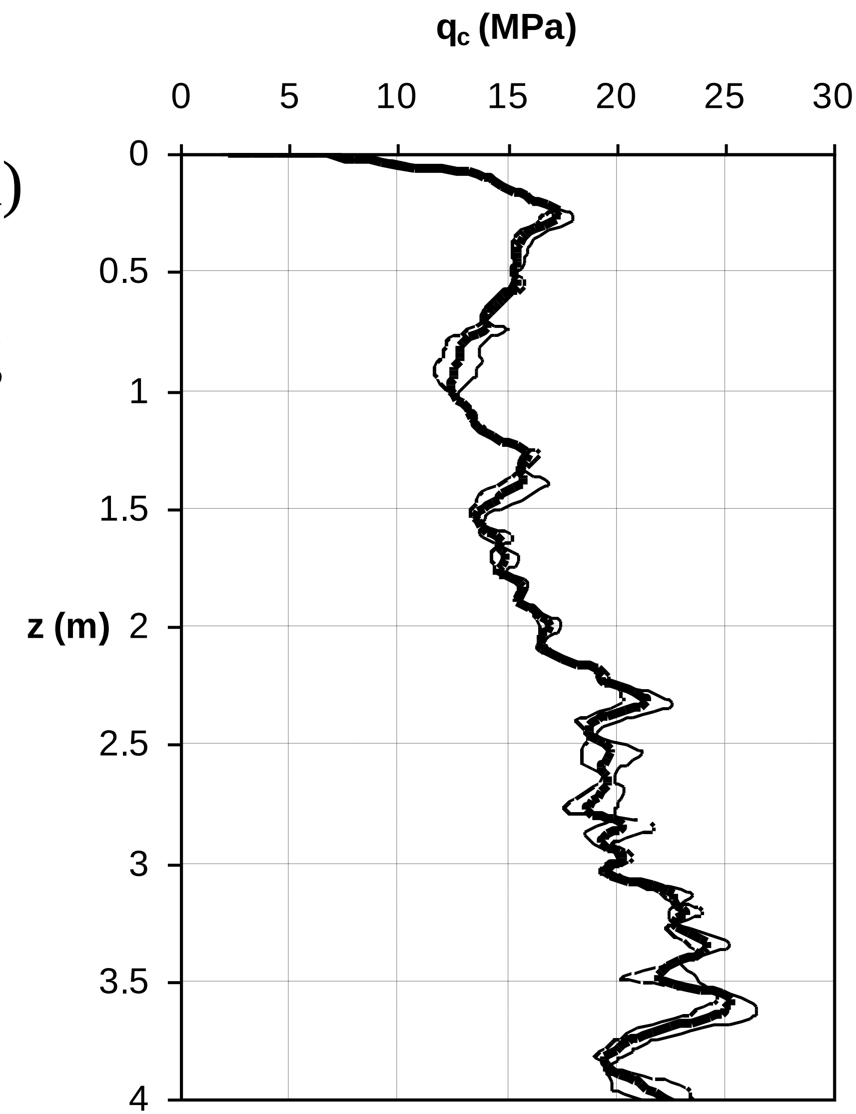
predict using simple techniques and CPT measurements:

- Ultimate bearing capacity (q_{ult})
- Load-displacement response

Designer primarily concerned with estimating settlement (s) of footing under working stress conditions (choice of appropriate Young's modulus)

Test site :

- Glacial sand deposit
- Inter-bedded (D_{50} = 0.1–0.3 mm)
- Water table 5 m below founding level, w ≅ 12 %
- Relative density almost 100 %
- Over consolidated,
  σ'_{vo} = 700–800 kPa
- Peak friction angle = 36–39^o
- q_c = 12–25 MPa



CPT end resistance (q_c) profile

Ultimate bearing capacity

$q_{ult} = 0.5\, B\gamma N_\gamma S_\gamma + \gamma D N_q S_q$ (uncemented sand)

– but main uncertainty lies in choice of friction angle to determine bearing capacity factors N_γ, N_q

$\Rightarrow$ Use CPT to determine friction angle

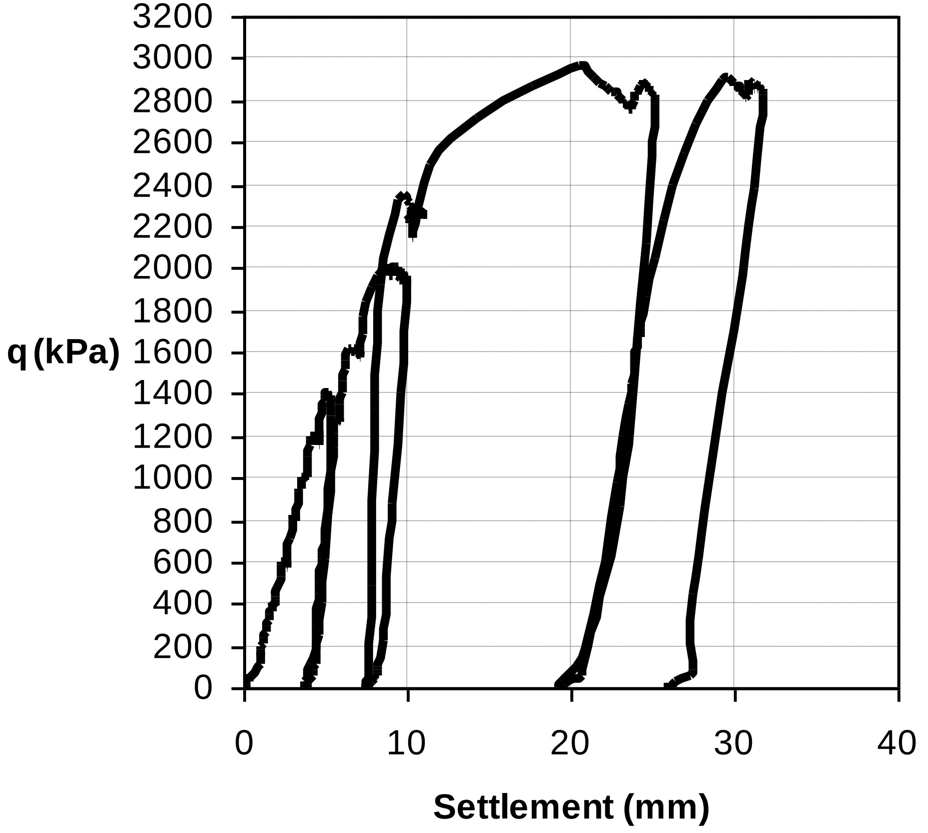
– Bearing pressure (q) normalized by CPT end resistance (q_c), after Randolph et al. (2003)

q/q_c = 0.09–0.16, s = 5 % foundation diameter

q/q_c = 0.13-0.21, s = 10 % foundation diameter

Plate loading tests

- 0.25 m square, steel plate founded at 0.5 m depth
- Load applied in 25 kN increments
- Unload-reload loops performed at 85, 125, 180 kN



Bearing pressure resistance vs. settlement

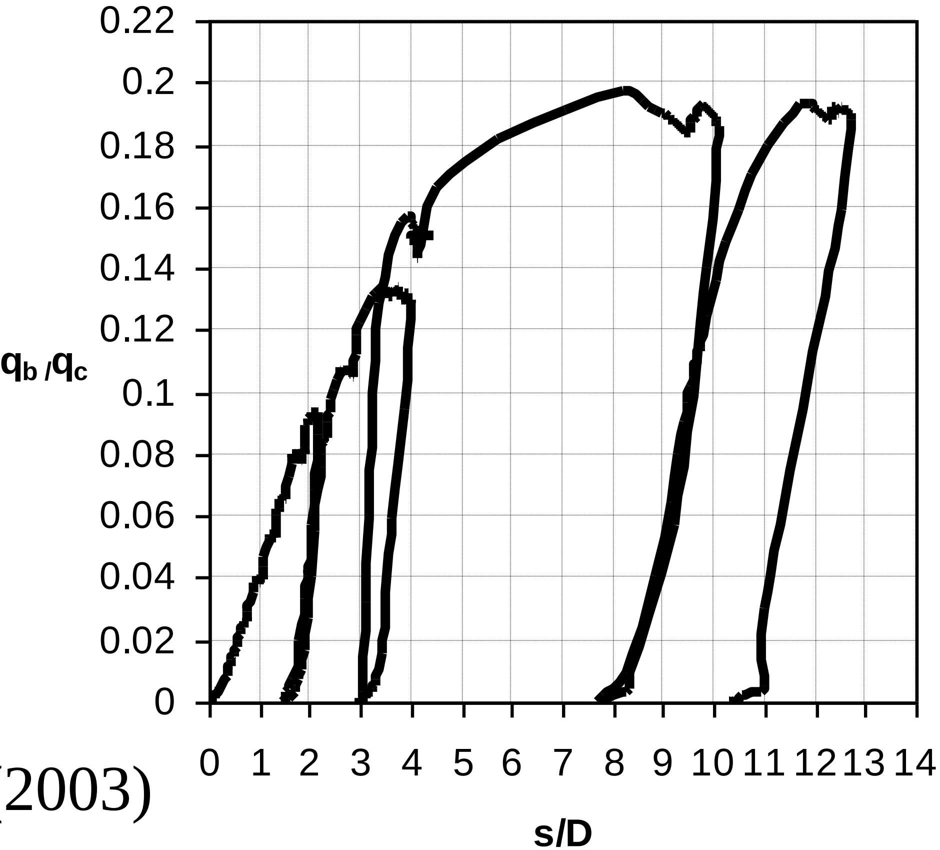
$q_{ult} \cong 2950$ kPa at s = 21 mm

Load–settlement response linear-elastic for $q \leq 1000$ kPa

Bearing pressure normalized by CPT q_c value vs. normalized displacement (s/D)

$q/q_c = 0.17$ at 5 % and
$q/q_c = 0.20$ at 10 %
foundation diameter

$\Rightarrow$ **$q_{ult} = 0.2\ q_c$**



Agrees with Randolph et al. (2003)

Load-displacement response

Choice of appropriate E' value

A) Linear-elastic method

$\mathbf{E'_{initial} = \alpha\, q_c}$ (Lunne & Christoferson, 1985)

with $\alpha = 5$ for over-consolidated soil, $q_c < 50$ MPa

$\Rightarrow E'_{design} = 75$ MPa for this site – using $q_c = 15$Mpa

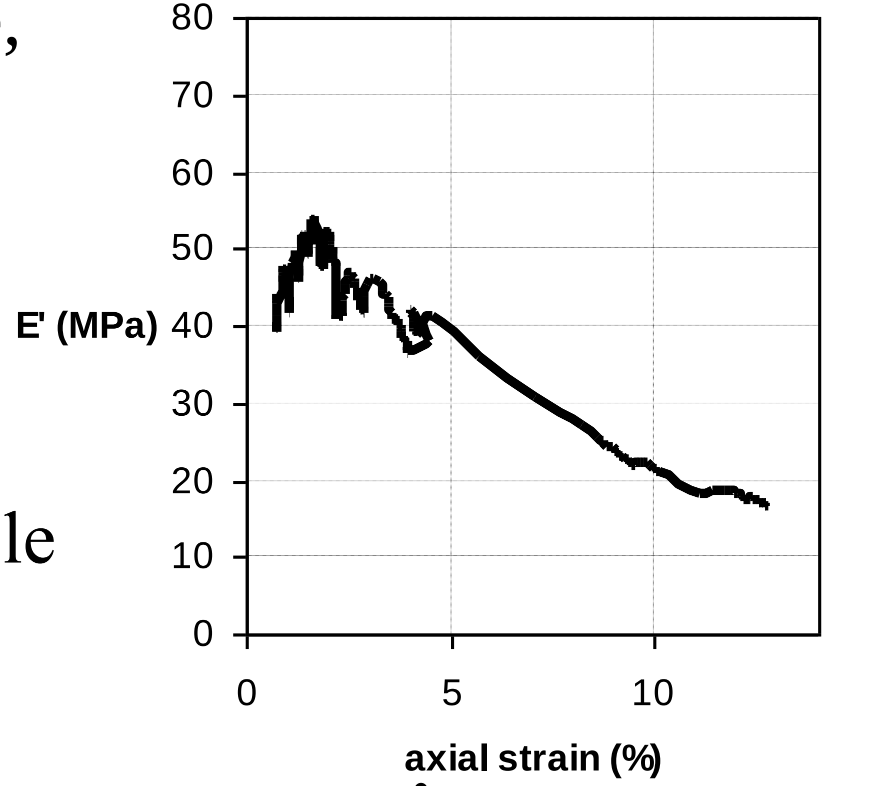
Actual E′ response of test footing derived from measured pressure and settlement response (see figure) using:

$$s = [\pi\, q\, D\, (1-\nu^2)] \,/\, (4E')$$

where q = applied pressure,

ν (poisons ratio) typically 0.2 for drained material,

E’ = Young’s modulus



E’ drops off rapidly, for example 54 MPa at s/D = 1.7 % to 18 MPa at s/D = 12 %

Linear elastic approach unconservative

B) Hyperbolic models:

$$s = \frac{Q \cdot I_{hrv}}{D.E_o\,[1-(Q/Q_{ult})^{0.3}]} \qquad \text{(Mayne 2000)}$$

where Q_{ult} = ultimate capacity,

I_{hrv} = displacement influence factor,

$E_o = 2G_o(1+\nu)$

$Q_{ult} = q_{ult}$ x Footing area, with $q_{ult}/q_c = 0.20$

need to determine G_o values

Measurement of G_o

- **CPT based method**

$G_o = b\ \sqrt[3]{q_c \sigma'_v p_a}$ (Robertson, 1997)

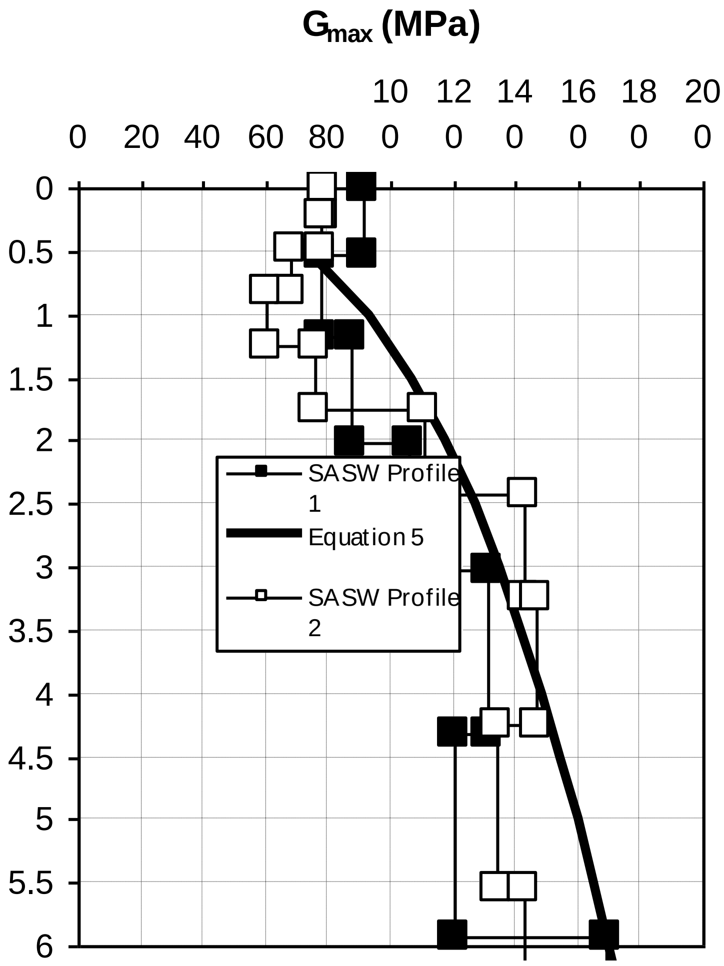
where b varies from 140 to 280, σ'_v = in-situ vertical effective stress, p_a = atmospheric pressure

- **For comparison, G_o measured in-situ using geophysics**

Shear wave velocity profiles using Multi Channel Analysis Surface Waves (MASW) method (Park et al. 1999) at the test site

$G_{max} = \rho . V_s^2$

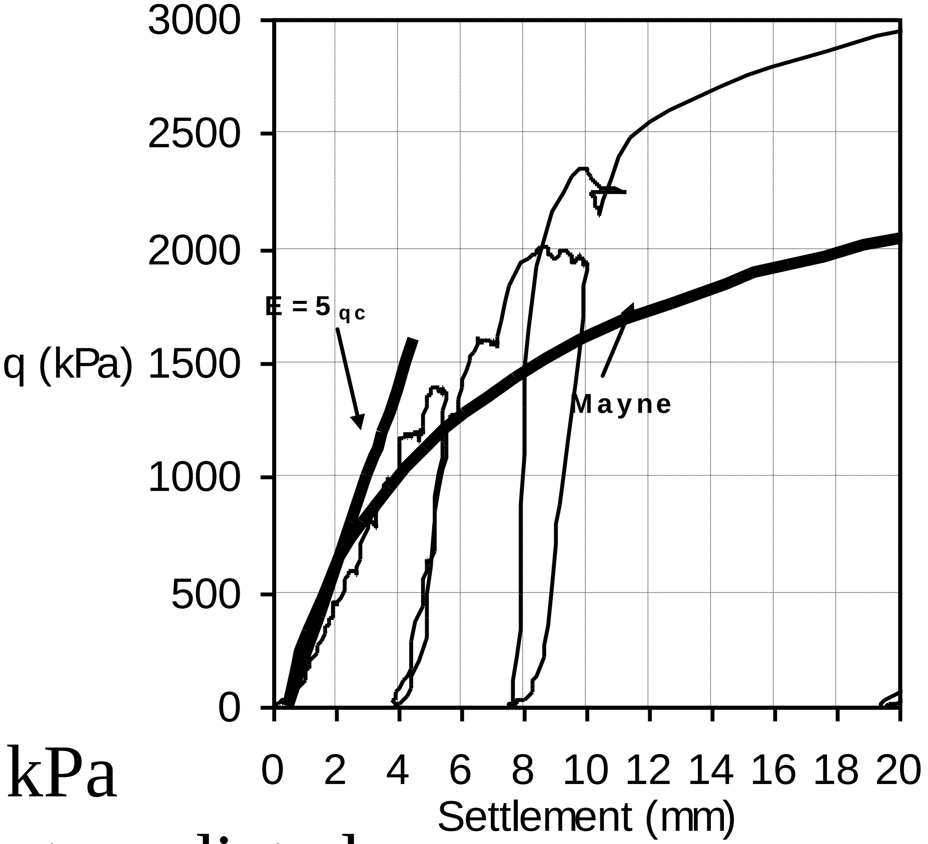
V_s = shear wave velocity (m/s), ρ = density (kg/m^3)



CPT and MASW in agreement, use CPT method in practice

$\Rightarrow G_o \cong 82$ MPa at 0.5 m founding depth

Linear-elastic prediction after Lunne & Christoferson (1985)
Hyperbolic prediction after Mayne (2000)



For a factor of safety = 3,
Safe bearing pressure ≅ 1000 kPa
same as actual 4 mm settlement predicted
by hyperbolic model

Conclusions

For vertically loaded footings in dense sands,

From CPT end resistance (q_c):

- **Ultimate bearing capacity = 0.2 x q_c**
- **Accurate settlement predictions under working stresses** using hyperbolic model (after Mayne 2000) and G_o predictions from measured CPT q_c (after Robertson, 1997)