Pad foundation with vertical central load on dense sand

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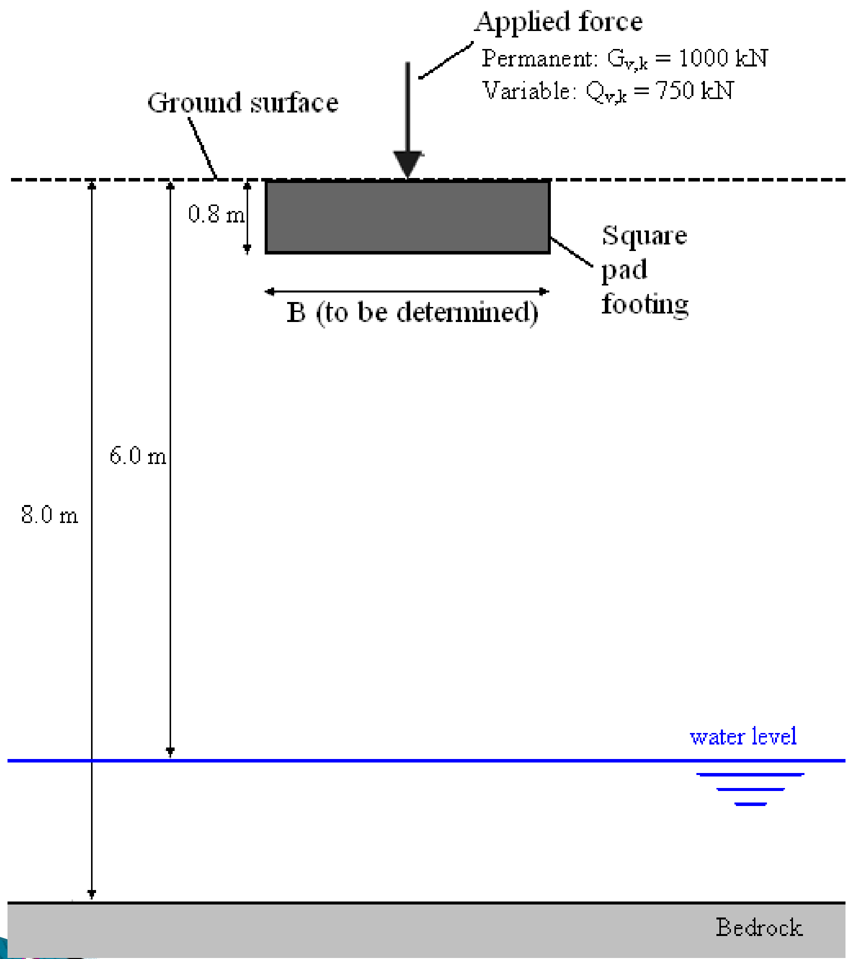
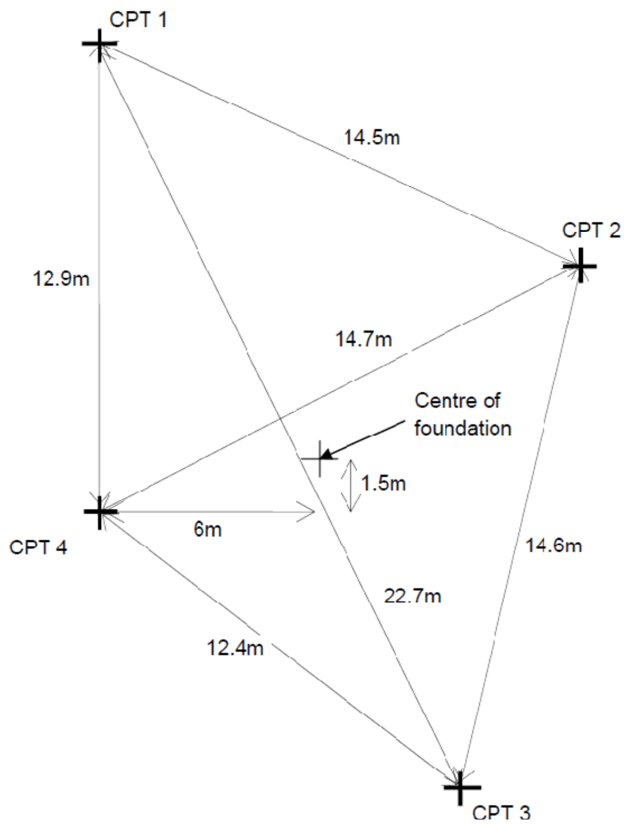
In this example it is asked to design a square pad foundation according to Eurocode 7.

The aim is the evaluation of the foundation width with a maximum allowable settlement of 25 mm.

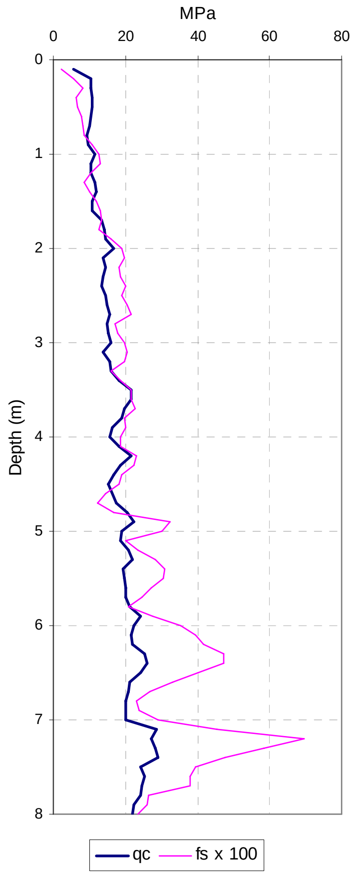
The square pad foundation is made from concrete with a weight density of 25 kN/m^3 and has an embedment depth of 0.8 m. The ground surface shown can be reliably assumed to be below any topsoil and disturbed ground. The design action is vertical with a permanent load of 1000 kN and a variable load of 750 kN.

Problem description

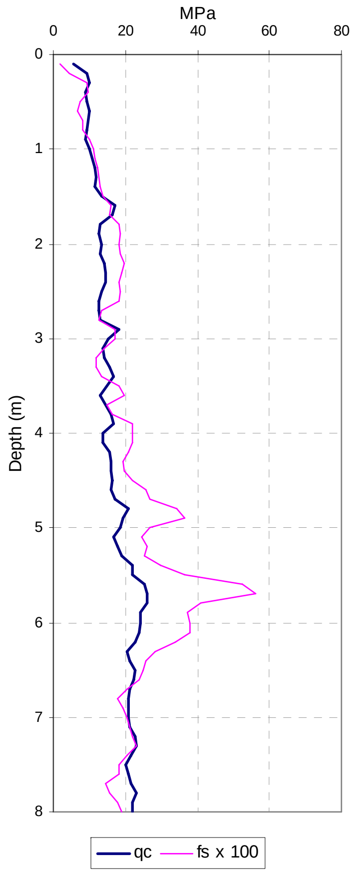




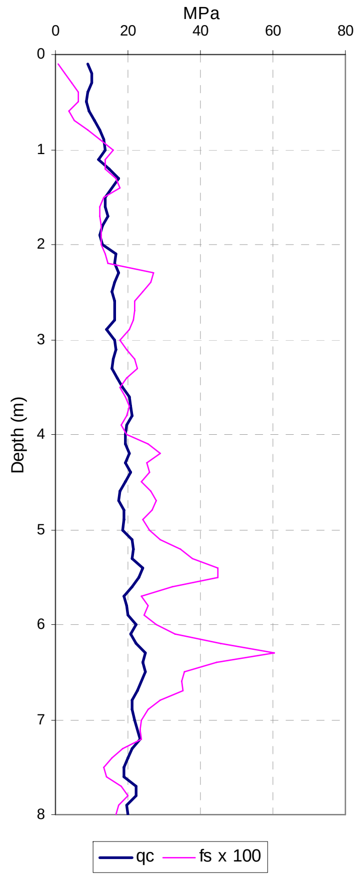
Results of cone penetration tests
(measured values)



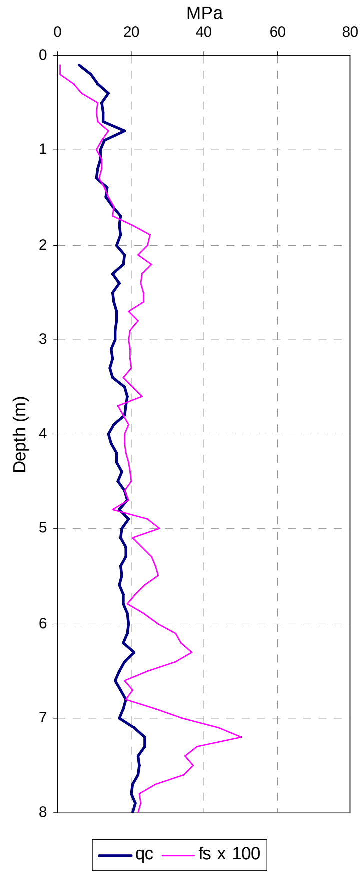
CPT 1



CPT 2

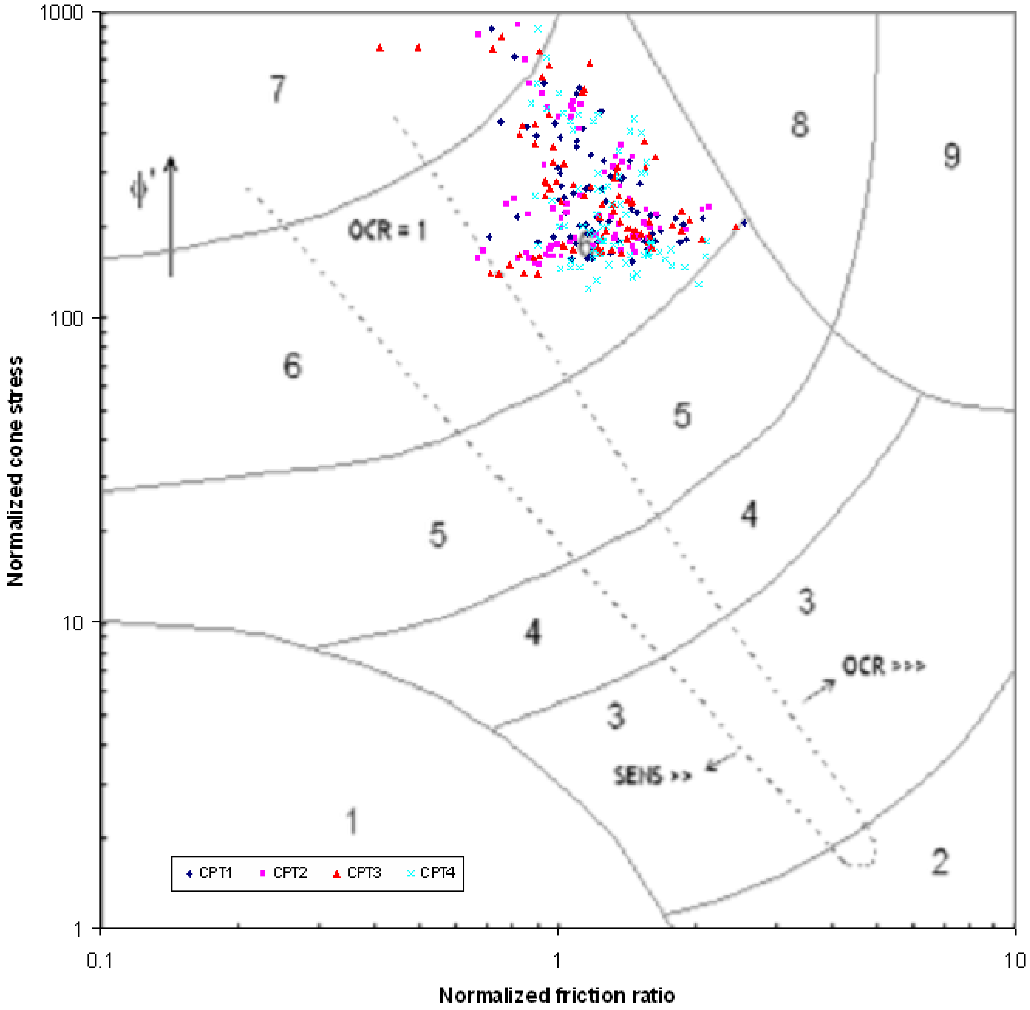


CPT 3



CPT 4

Idealization of the soil
(derived values)



1. Sensitive fine-grained soil
2. Organic soils and peat
3. Clays [clay to silty clay]
4. Silt mixtures [silty clay to clayey silt]
5. Sand mixtures [sandy silt to silty sand]
6.Sand [silty sand to clean sand]
7. Sand to gravelly sand
8. Sand – clayey sand to “very stiff” sand
9. Very stiff, fine-grained, overconsolidated or cemented soil

Derived values

The Young's modulus of elasticity, for calculating the settlement of spread foundations can be determined by the equation proposed on Annex D of EN 1997-2.

$$E' = 2.5 * q_c$$

For the determination of the soil shear resistance angle, from the CPT resistance, it's proposed on Annex D of EN 1997-2:2007 the equation:

$$\phi' = 13.5 * \log_{10}(q_c) + 23$$

Soil characterization

There are two main interdependent tasks to be considered in most of geotechnical design problems:

- a geometrical task, where the soil is idealized into a few of well defined and homogeneous layers;
- a subsequent task, where the geomechanical properties of each layer are assigned.

Characteristic values

EN 1990 defines a characteristic material property as follows:

"[EN 1990 §4.2(3)] – where a low value of material or product property is unfavourable, the characteristic value should be defined as the 5% fractile value;

– where a high value of material or product property is unfavourable, the characteristic value should be defined as the 95% fractile value."

Characteristic values

Eurocode 7 redefines the characteristic value as:

"[EN 1997-1 §2.4.5.2 (2)P] The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state."

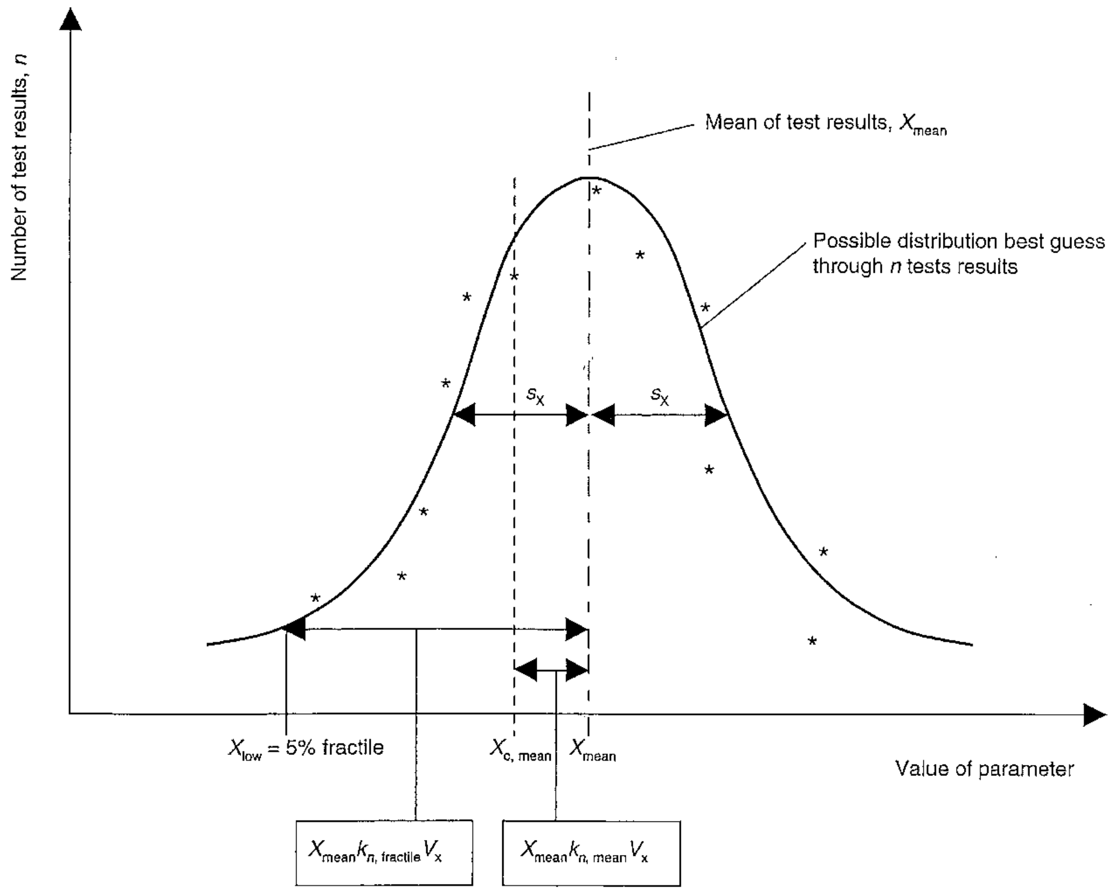
"[EN 1997-1 §2.4.5.2 (11)] If statistical methods are used, the characteristic value should be derived such the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5."

Characteristic values

Frank et. al (2004) explains that there are two main aspects to consider when selecting the characteristic value, which are:

- *the degree of confidence in the information (which includes the amount of information on the soil characteristics and the variability of results);*
- *the soil volume involved in the limit state considered and the ability of the structure to transfer loads from weak to strong zones of the ground.*

Characteristic values



Difference between cautious estimate of the mean and of the 5% fractile value
(Frank et. al, 2004)

Characteristic values

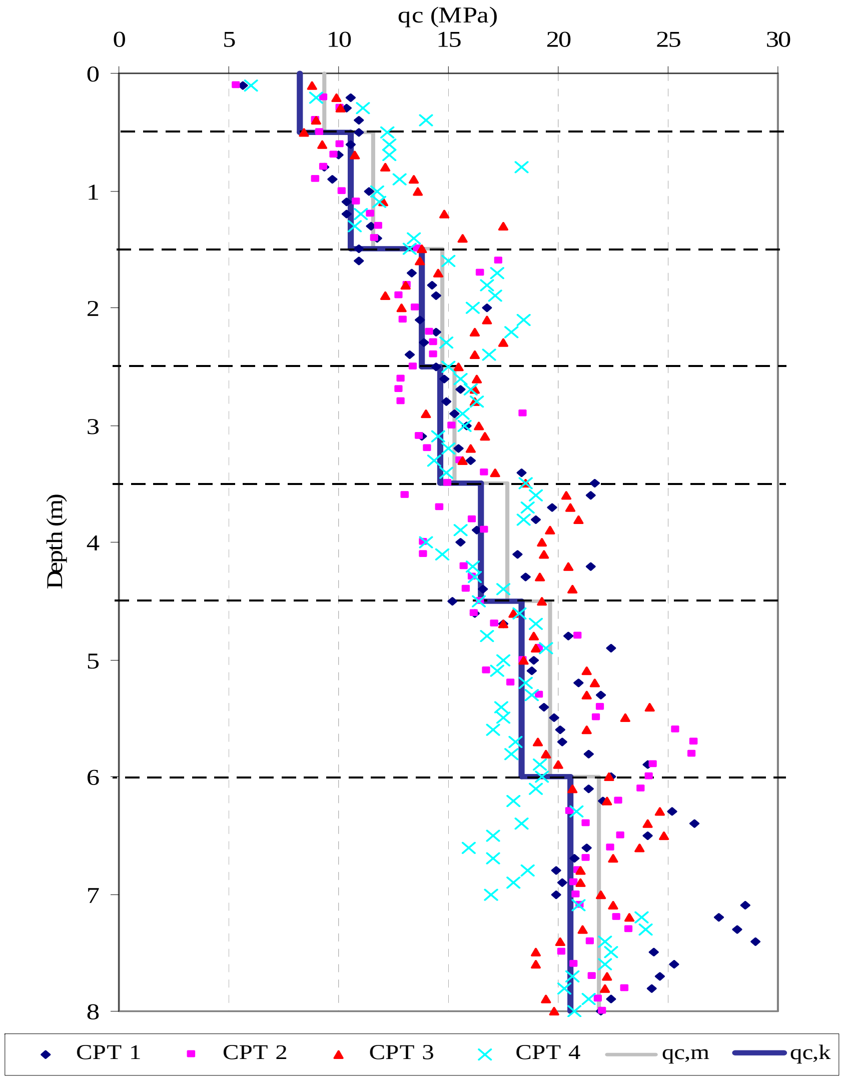
Schneider (1997) defines the characteristic value as the "best estimate of the unknown statistical mean x_m *of a soil layer". By this he means that the characteristic value shall be selected with the aim that the probability of a more adverse (mean) value governing the behaviour of the soil and rock in the ground is not greater than 5%.*

Schneider shows that a suitable equation for the determination of characteristic value for most of soil properties is given by

$$x_k = x_m * \left(1 - \frac{V_x}{2}\right)$$

Proposed resolution

Characteristic cone resistance

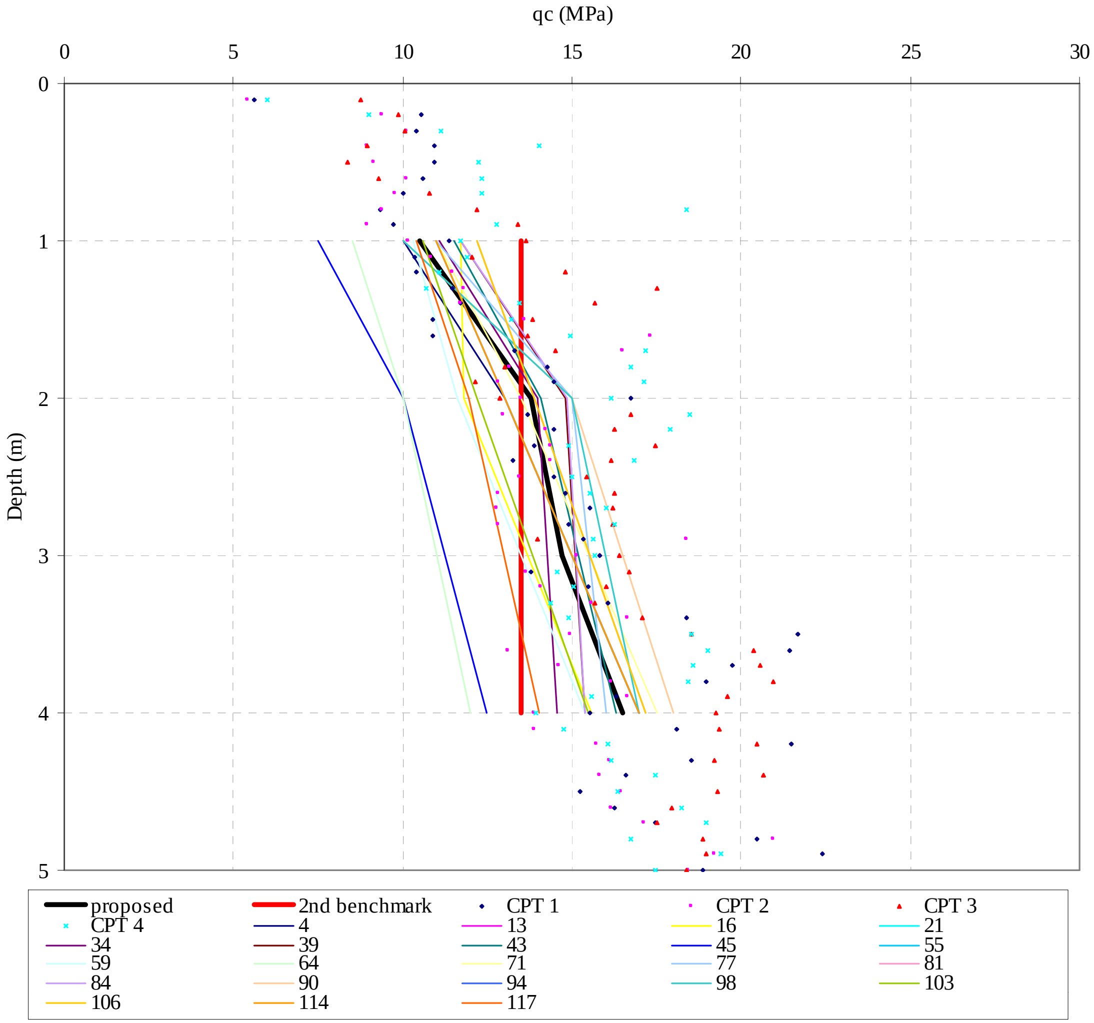


Characteristic design values

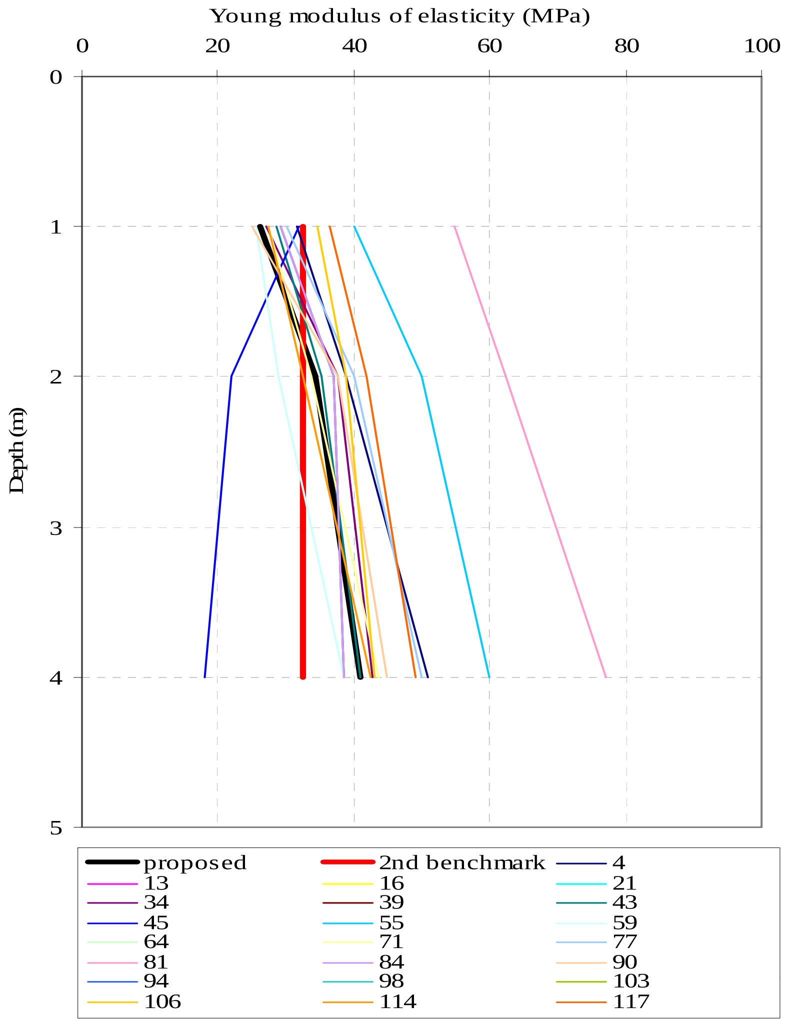
Layer no.	Depth (m)	Mean depth (m)	$q_{c,m}$ (MPa)	$q_{c,k}$ (MPa)	E (MPa)	ϕ (º)
1	[0.0; 0.5]	0.25	9.32	8.22	20.6	35.4
2	[0.5; 1.5]	1.00	11.60	10.52	26.3	36.8
3	[1.5; 2.5]	2.00	14.72	13.77	34.4	38.4
4	[2.5; 3.5]	3.00	15.32	14.67	36.7	38.7
5	[3.5; 4.5]	4.00	17.67	16.45	41.1	39.4
6	[4.5; 6.0]	5.25	19.60	18.33	45.8	40.1
7	[6.0; 8.0]	7.00	21.83	20.58	51.4	40.7

Participants answers

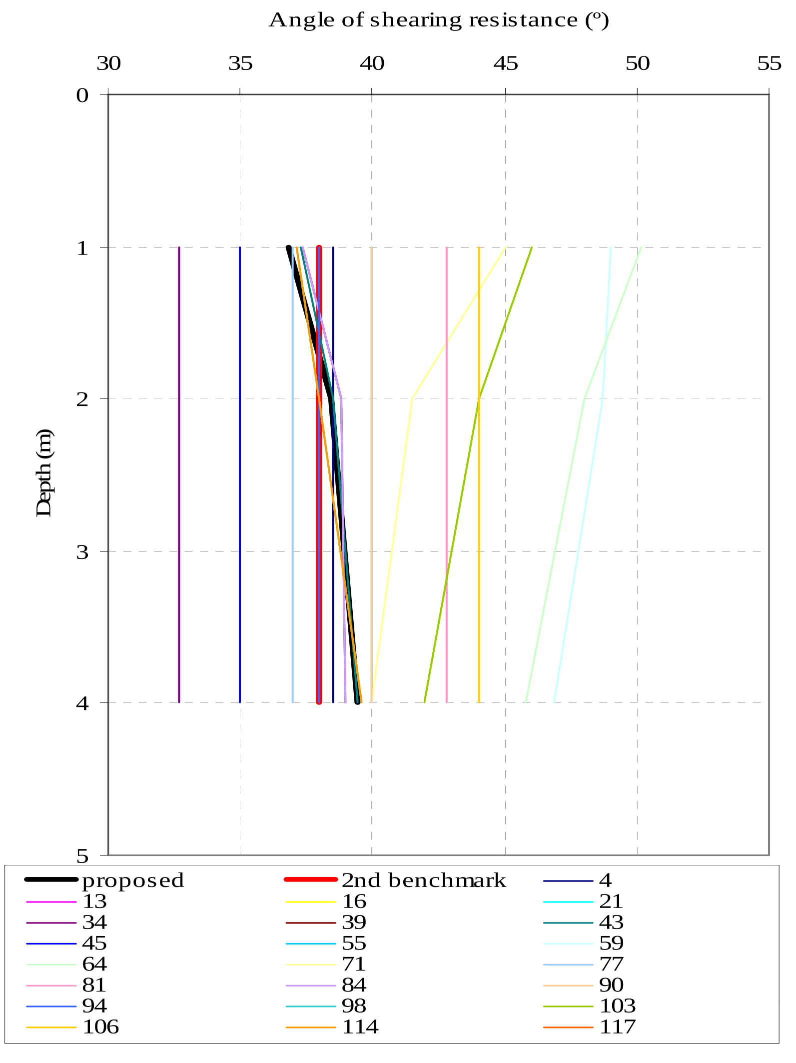
Characteristic cone resistance



Characteristic Young modulus of elasticity



Characteristic angle of shearing resistance



Design approches
National choices

DA 1 com 1 and 2	GB, IT, PT
DA 2	GR, FR, DE, PL, IE
DA 3	DK, NL

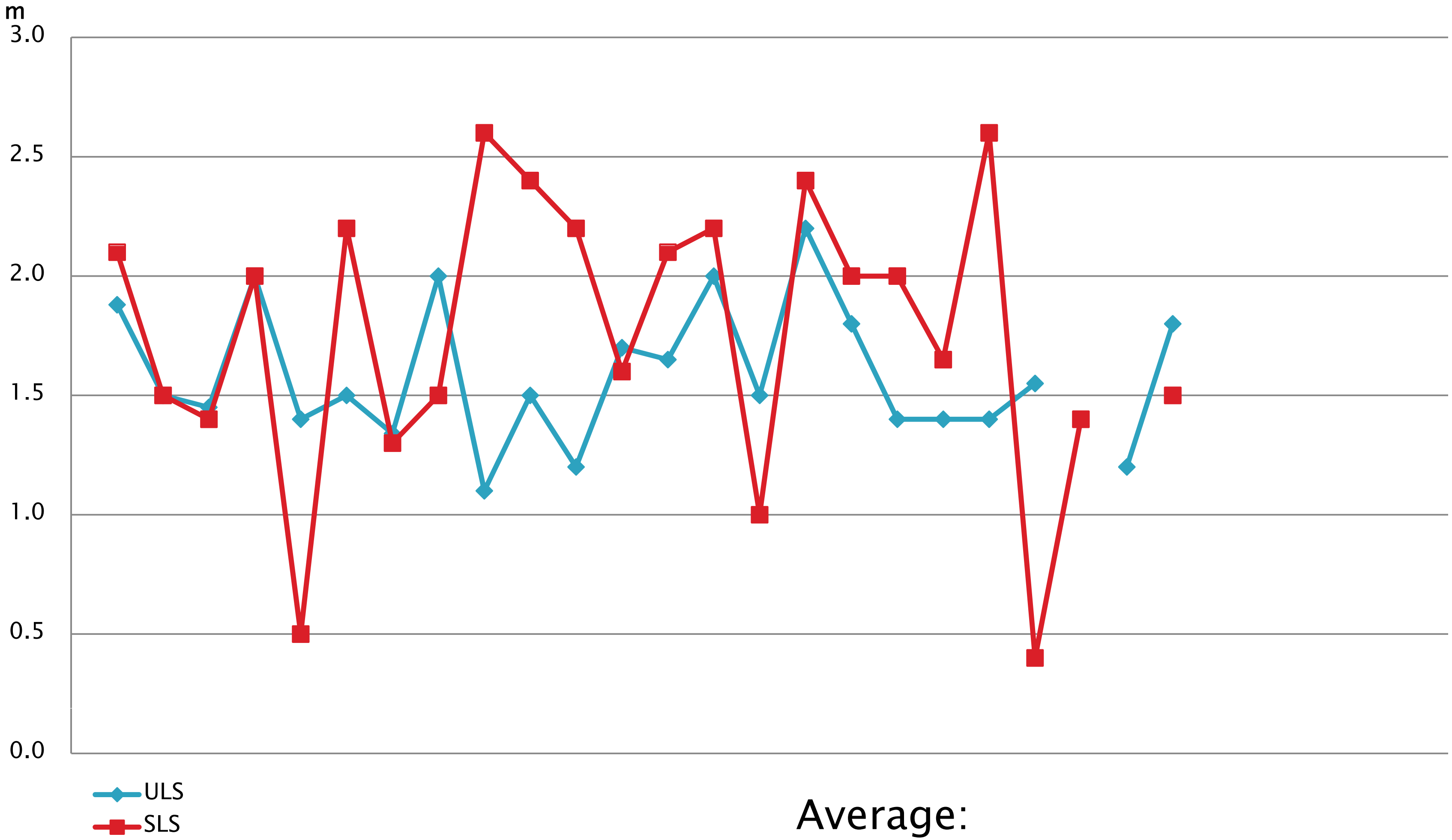
Method used (ULS)

Annex D	10 answers
National annexes	5 answers
Brinch Hansen	4 answers
Terzaghi	1 answer
Highway bridges (Japan)	1 answer

Method used (SLS)

Annex D.3 EN 1997-1	9 answers
Annex F.1 EN 1997-2	5 answers
National annexes and different methods as Schmertmann, Tomlinson, Burland & Bridge	10 answers

Width of pad (conclusion)



Average:
ULS 1.6 m and SLS 1.8 m

Comparison of foundation width and tan(ϕ)