Report on answers:

Example 2.2 Pad foundation with inclined eccentric load on boulder clay

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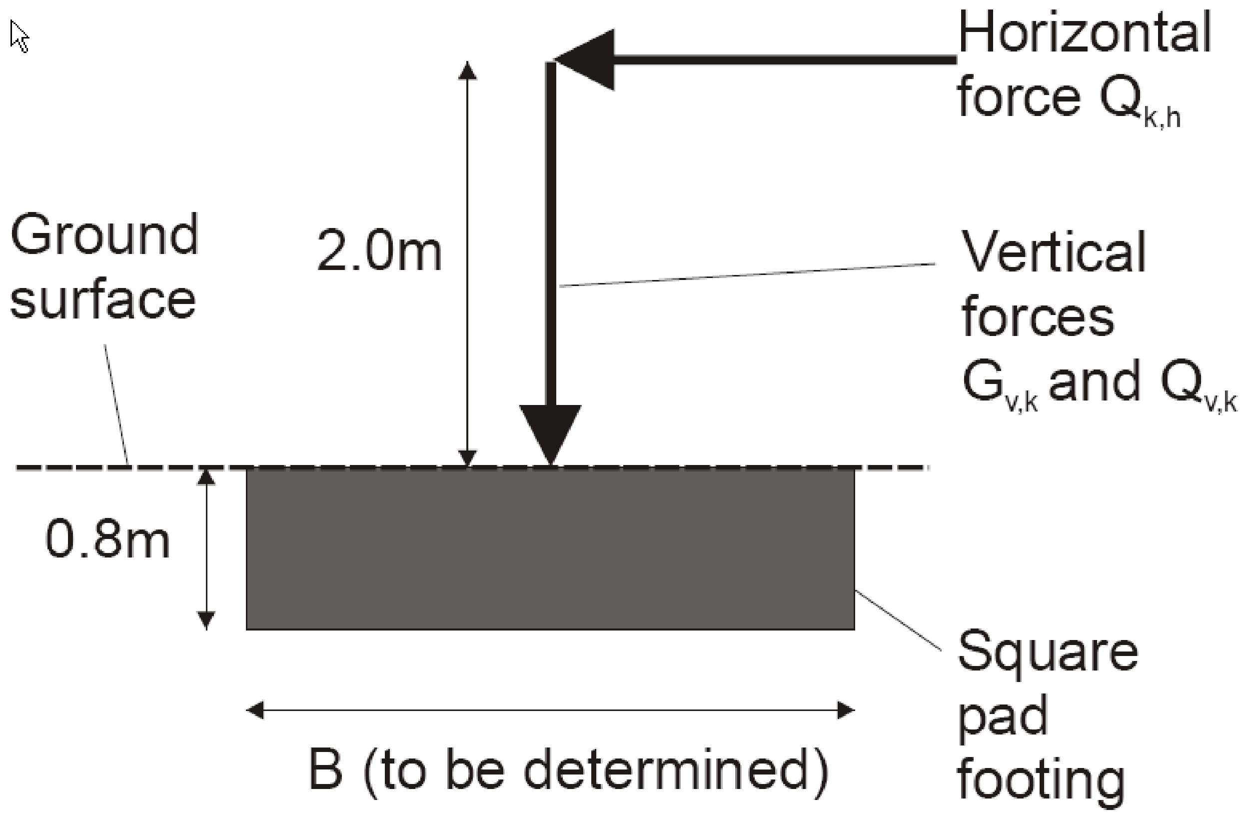
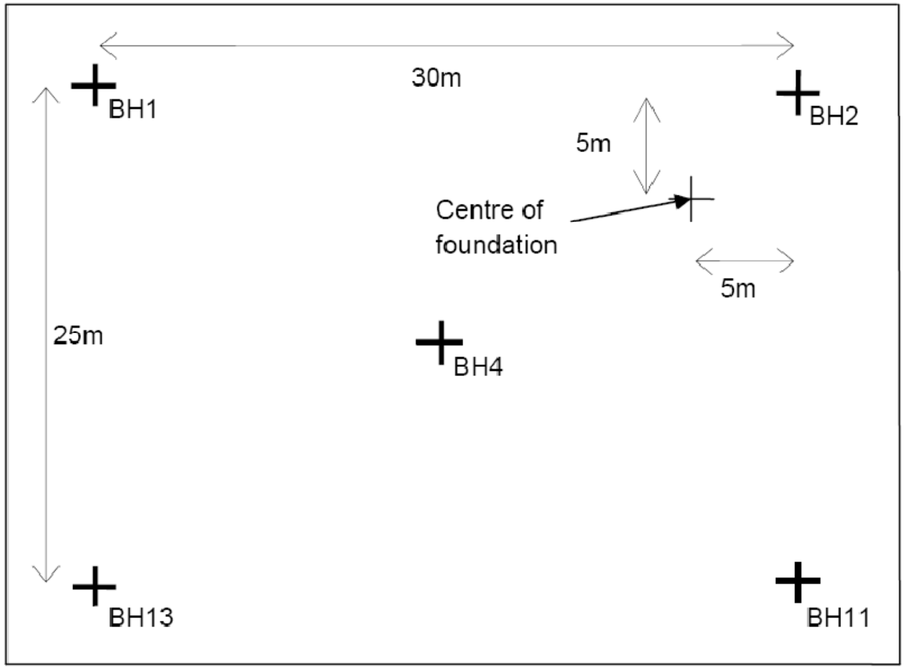


Permanent:	Vertical	$G_{v,k}$ = 1000 kN, excluding weight of foundation
	Horizontal	$G_{h,k}$ = 0
Variable:	Vertical	$Q_{v,k}$ = 750 kN
	Horizontal	$Q_{h,k}$ = 500 kN, at 2m above the top of the foundation
Concrete weight density		γ_c = 25 kN/m^3

The soil consists of boulder clay. A site plan showing the location of the foundation and the locations where five SPT tests were carried out is given in Figure 2.2b.
N values obtained from SPT tests are plotted in Figure 2.2c,
the water contents and index tests determined from samples are presented in Figure 2.2d.
The soil has a bulk weight density of 21.4 kN/m3 and the ground water level is 1.0 m below the ground level. The width of the foundation when designed to Eurocode 7 is to be determined, assuming the foundation is for a conventional concrete framed structure. There is no need to consider any effects due to frost or vegetation. The foundations' design working life is 50 years.



borehole
log 1

Description	Scale Depth	Legend	Samples & S.P.T. Ref. No.	Type	Depth	N
TOP SOIL	0.30					
Very stiff brown sandy gravelly CLAY with cobbles (Boulder Clay)			9998	U	1.00	
			9351	D	1.50	
			9905	D	2.00 (1.80)	27
			9352	D	2.50	
	2.90		9997	D	3.00	
					(3.30)	40
Very stiff black silty sandy gravelly CLAY with cobbles and boulders (Boulder Clay)					(4.80)	38
			9920	D	5.00	
			9923	D	6.00	
					(6.30)	45
			9921	D	7.50	
					(7.80)	47
	8.00		9924	D	8.00	

Code : U—Undisturbed Sample D—Large Disturbed Sample J—Jar Sample W—Water Sample

2.2e: Borehole Log 1

borehole
log 11

Water Strikes		Water Levels Recorded During Boring							
1. 2.80	Hole Depth	6.30	8.50	8.50					
2.	Casing Depth	6.30	7.30	--					
3.	Water Level	Nil	Nil	3.50					

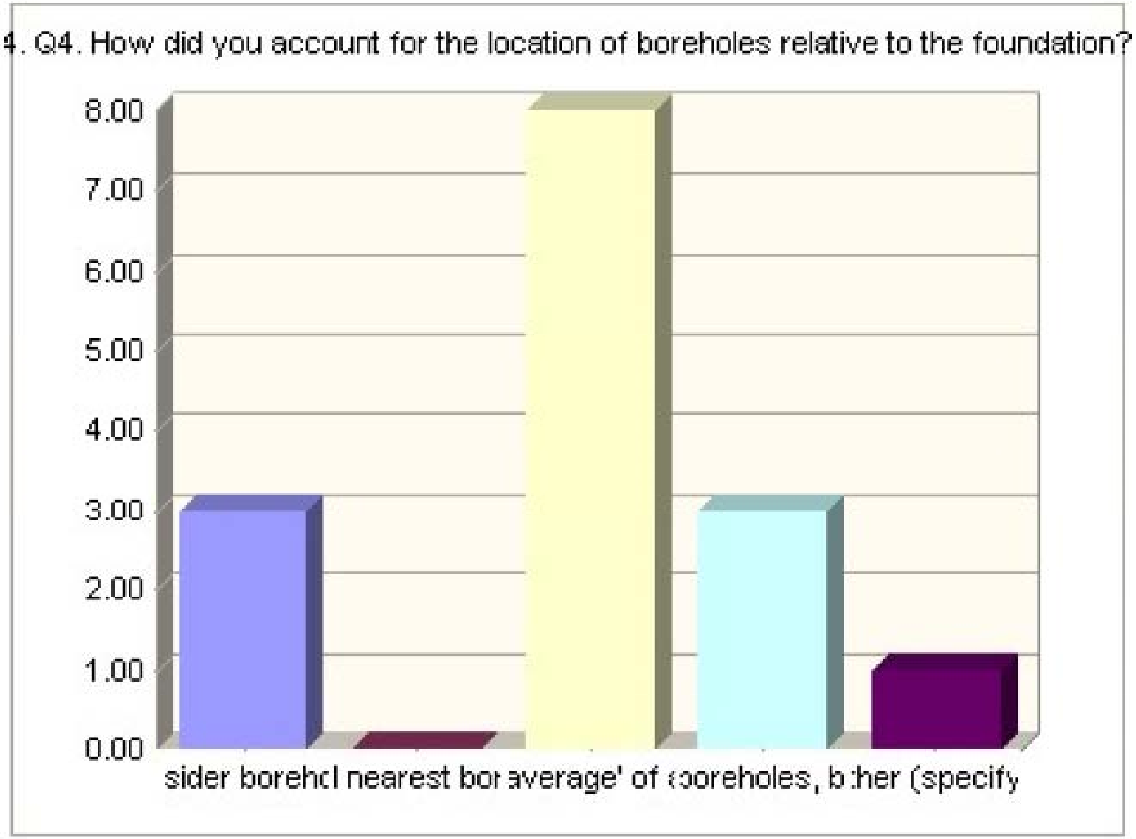
Remarks Total - 3 hrs. chiselling
PVC pipe installed.

Description	Scale Depth	Legend	Samples & S.P.T. Ref. No.	Type	Depth	N
TOPSOIL	0.30					
Stiff brown silty very stony CLAY, some cobbles			10096	U	0.50	
			10097	D	0.50	
	1.00				(1.00)	43
Stiff brown sandy gravelly CLAY with cobbles (Boulder Clay)			10098	D	1.50	
				U	1.50 (Abortive)	
					(2.00)	41
	3.00		10099	D	3.00 (3.00)	64
Very stiff black sandy ~~silty~~ gravelly CLAY, cobbles and some boulders (Boulder Clay)						
			10100	D	4.50 (4.50)	67
					(6.00)	97
			10101	D	6.50	
					(7.50)	70
			10102	D	7.80	
Borehole completed at	9.00				(8.50)	80

Code: U—Undisturbed Sample D—Large Disturbed Sample J—Jar Sample W—Water Sample

Figure 2.2h: Borehole Log 11

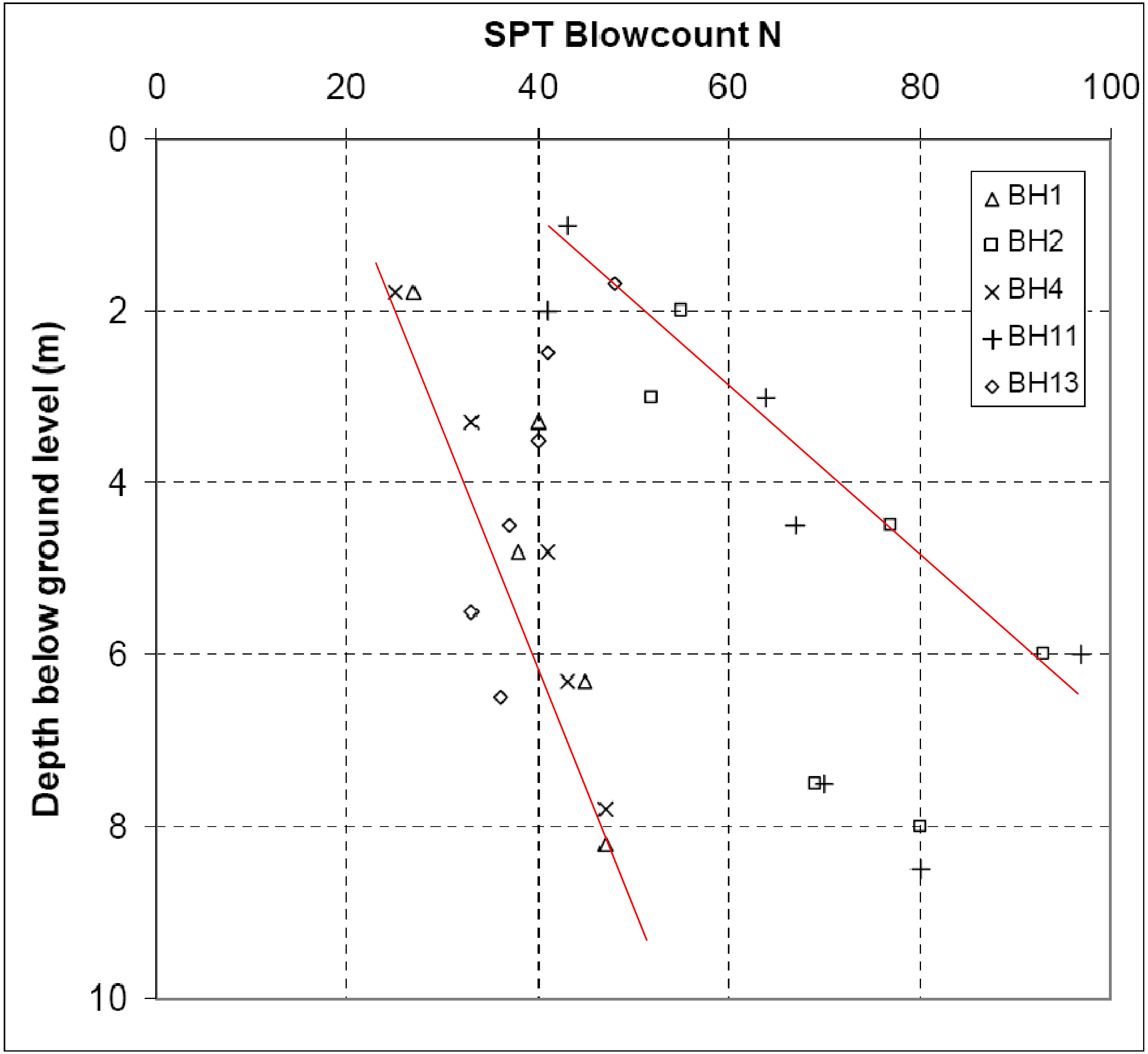
4. Q4. How did you account for the location of boreholes relative to the foundation?



Response	Count	Percent
Did not consider borehole location	3	20.00%
Considered nearest borehole only	0	0.00%
Considered 'average' of all boreholes	8	53.33%
Considered trend of all boreholes, biased towards nearest	3	20.00%
Other (specify)	1	6.67%

5. Q5. Please explain the reasons for your answer to Q4

Response ID	Response
3	Two different trends can be recognized in the boreholes logs; I do not see any particular reason to select one ore the other; considering the dimensions of the problem, the location of the foundation can be only causually closest to the more favourable soil stratigraphy
6	There was a distinct trend, so I increased characteristic value by being biassed by nearest. Value still well below nearest, but higher than the lower ones.
57	The distance of tests location from the centre of foundation is small and doesn't vary between the different tests
60	BH2 shows a firm layer of clay with a relatively low SPT N value at foundation level. As this BH is close to the footing, a lower value of cu was assumed in this location.
44	There are only 5 boreholes and their trend is similar.
65	Picked conservative estimate of conditions on site.
22	Category2, a homogenous ground, the uniform parameters for checking are assumed, for all pad?s foundation
85	I?ve taken into account all boreholes but using weights depending on distance between the borehole and the centre of foundation.
36	I choose the unfavorable soil conditions, because they don't vary that much.
97	The distance of the boreholes has been considered negligible for the final result.
104	Borehole nearest to foundation shows higher SPT values but average values are more conservative
118	No procedure known to determine the soil parameters (drained, undrained shear strength and angle of shearing resistance) from the given borehole test results
110	Experience of this type of soil is that it can vary in an apparantly random manner across a site


SPT Blowcount N
0
20
40
60
80
100
Depth below ground level (m)
0
2
4
6
8
10
BH1
BH2
BH4
BH11
BH13

12. Q11. What is the characteristic value of N at these depths?

Response ID	At 1 m, N_k =	At 2 m, N_k =	At 4 m, N_k =
3	38	40	48
6	30	35	45
60	30	33.3	40
44	41	41	41
65	30	25	35
52	-	39	47
22	35	35	35
85	32	31	45
36	25	25	33
104	40	40	40
110	6	6	6

Phase 2 with benchmark values:
N_k = 30 / 35 / 40

Description: cu = 6N
Author: Stroud and Butler 1978
Title: The standard penetration test and the engineering properties

Eu=400Cu. G=Eu/3.

Description: cu=5N
Author: Stroud
Title: The standard penetration test in insensitive clays and soft

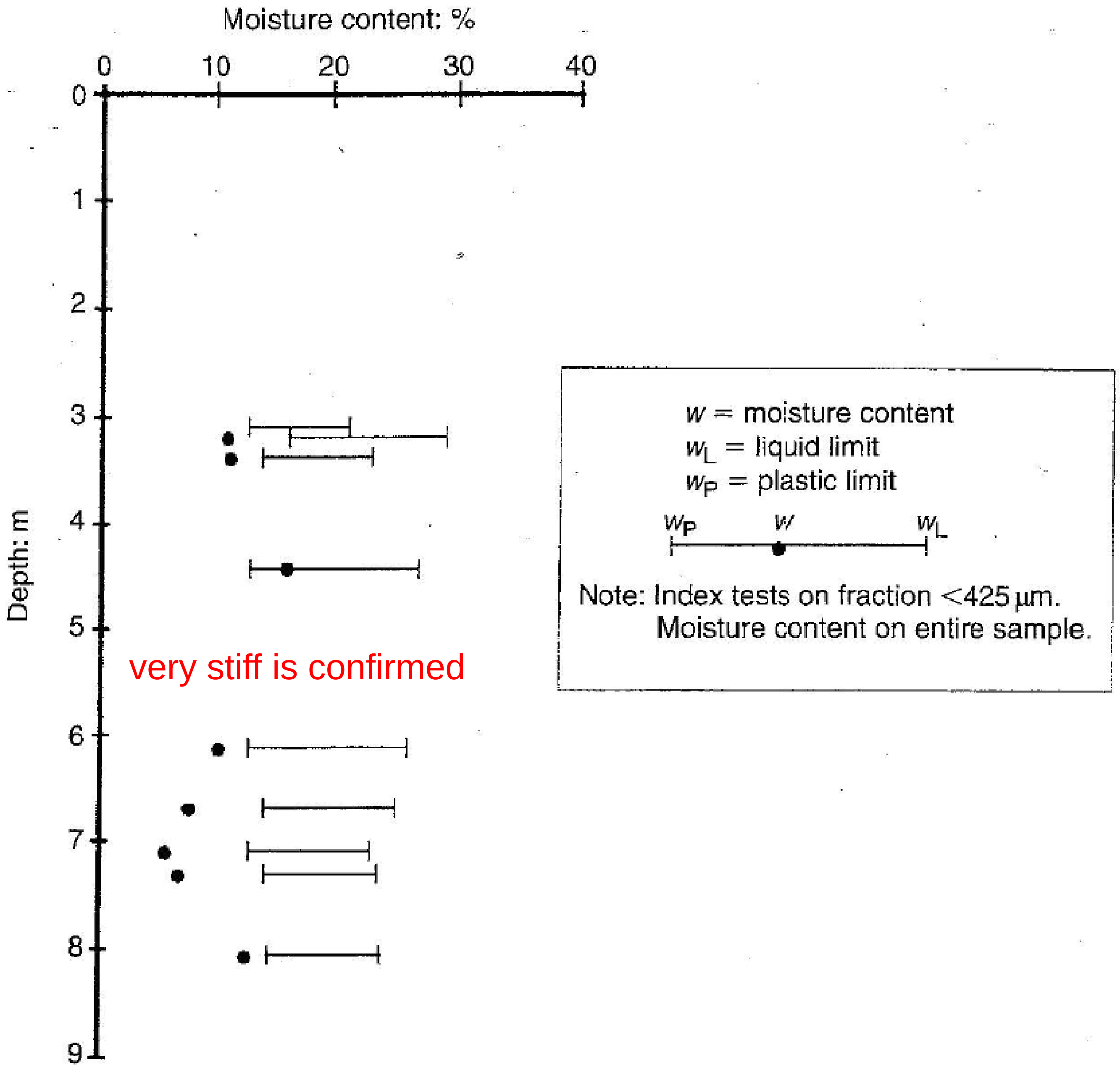
E'=120cu

Eu = 800cu, E' = 1800N

Stroud 1989

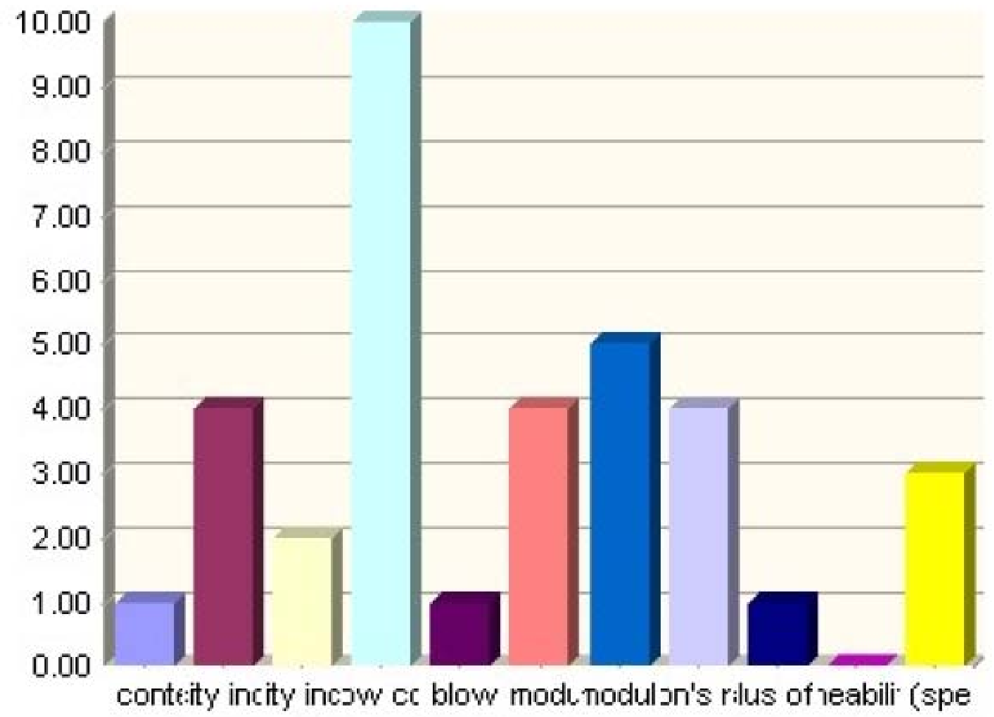
Description: SPT to cu (function of PI)
Author: Stroud (1975)
Title: The SPT in insensitive clays and Rocks, Conf. proc.
Pages: 367-375

Description: cu=4*N Author: Stroud, M.A. (1989) Title: ?The Standard Penetration Test ? Its application and interpretation?.



very stiff is confirmed

6. Q6. Which parameters did you use for the SLS design of the spread foundation?



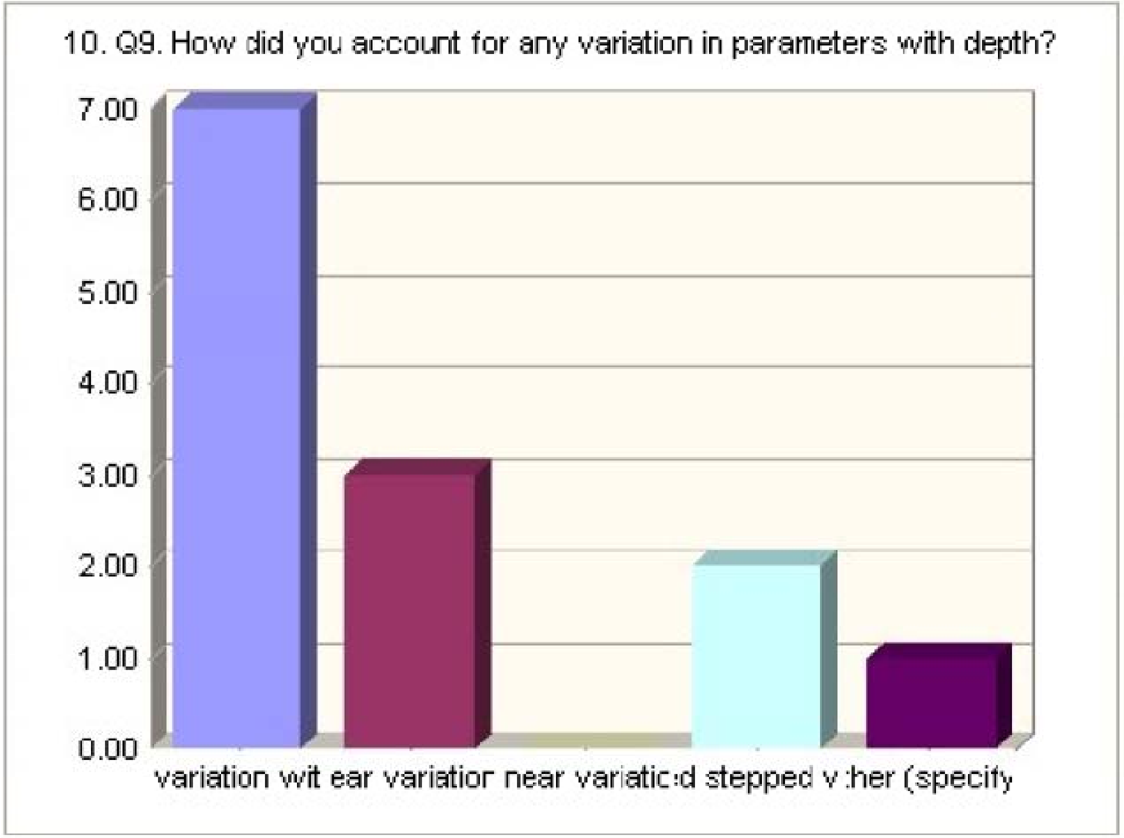
Response	Count	Percent
Water content w	1	6.67%
Plasticity index I_P	4	26.67%
Liquidity index I_L	2	13.33%
SPT blow count N	10	66.67%
Corrected SPT blow count $(N_1)_{60}$	1	6.67%
Undrained Young's modulus of elasticity E_u	4	26.67%
Drained Young's modulus of elasticity E'	5	33.33%
Poisson's ratio n	4	26.67%
Shear modulus of elasticity G	1	6.67%
Permeability k	0	0.00%
Other (specify)	3	20.00%

7. Q7. What correlations did you use to derive soil parameter values (if used) for the SLS verification? If more than one, please list others below.

Response ID	Description	Author	Title	Pages
3	Technical Journal. Geotechnique, 2007,, 57,7	Long M. & Menkiti C.O.	Geotechnical properties of Dublin Boulder Clay	596-611
6	cu=5N	Stroud	The standard penetration test in insensitive clays and soft	Fig 3
57	E'=120cu			
60	N/A			
65	Relationship between plasticity index + mass shear strength	Tomlinson	Fig 1.5	11
22	N → IL and IL →Eoed	PN-B-04452:2002 and PN-81/B-03020		
85	mv=1/f2·N [m2/MN]	Stroud M. A.	The standard penetration test in insensitive clays...	367-375
36	DIN 4094-2	DIN	Baugrund - Felduntersuchungen, Teil 2: Bohrlochrammsondierun	16
104		Stroud	The Standard Penetration Test and the engineering propert...	
110	Eu = 800cu, E' = 1800N	Stroud 1989	The standard penetration test - its application and interpre	

8. Q7a. Any other correlations (please give same info as above)

Response ID	Response
60	N/A
22	no
85	Description: Eu/N60=1,0?1,2 (MPa) Author: Butler F.G. Title: Heavily overconsolidated clays. General report and state-of-the-art review for session. Proc. 3rd Conf. on Settlement of Structures. Pentech Press, London 1975



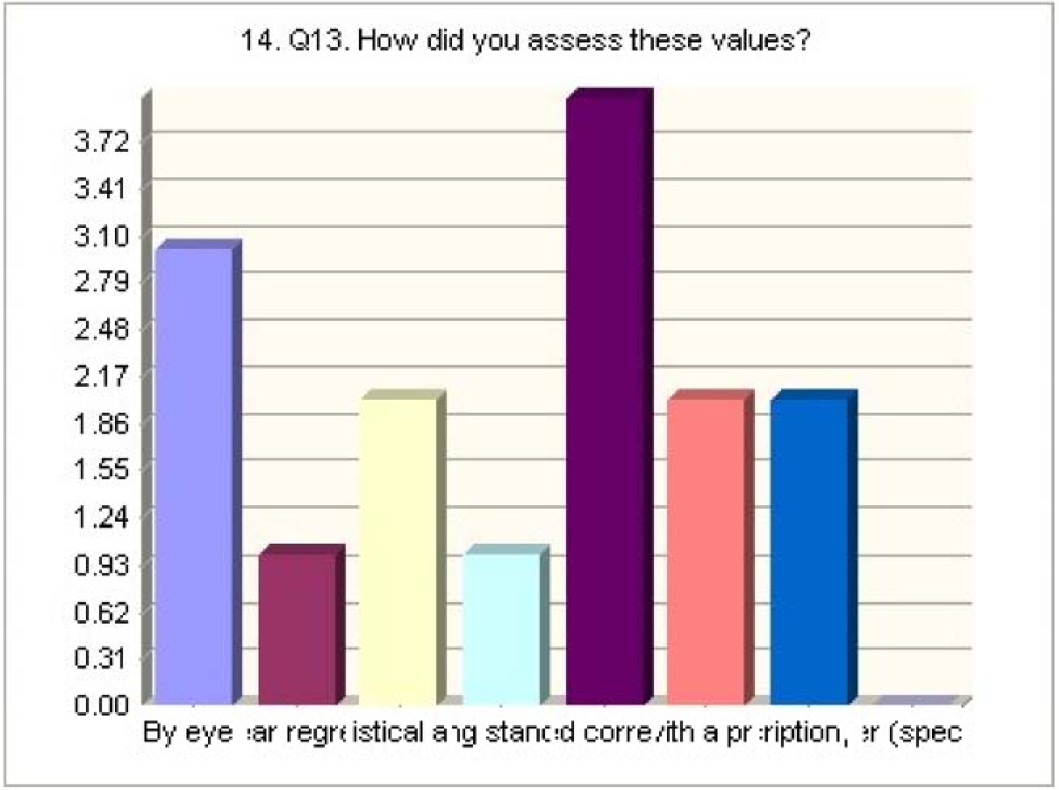
Response	Count	Percent
Ignored variation with depth	7	46.67%
Assumed linear variation with depth	3	20.00%
Assumed bi-linear variation with depth	0	0.00%
Assumed stepped variation	2	13.33%
Other (specify)	1	6.67%

Response ID	Other (specify)
3	select avarage representative values
6	Used values at shallow depth (eg 1m).

13. Q12. What is the characteristic value of Eu for a linear elastic calculation at these depths?

Response ID	At 1 m, $E_{u,k}$ (MPa) =	At 2 m, $E_{u,k}$ (MPa) =	At 4 m, $E_{u,k}$ (MPa) =
6	60	70	90
57	48	48	48
60	N/a	N/A	N/A
44	22.5	22.5	22.5
52	-	-	-
22	-	-	-
85	29	28	41
36	25	25	25
104	50	50	50
110	168	168	168

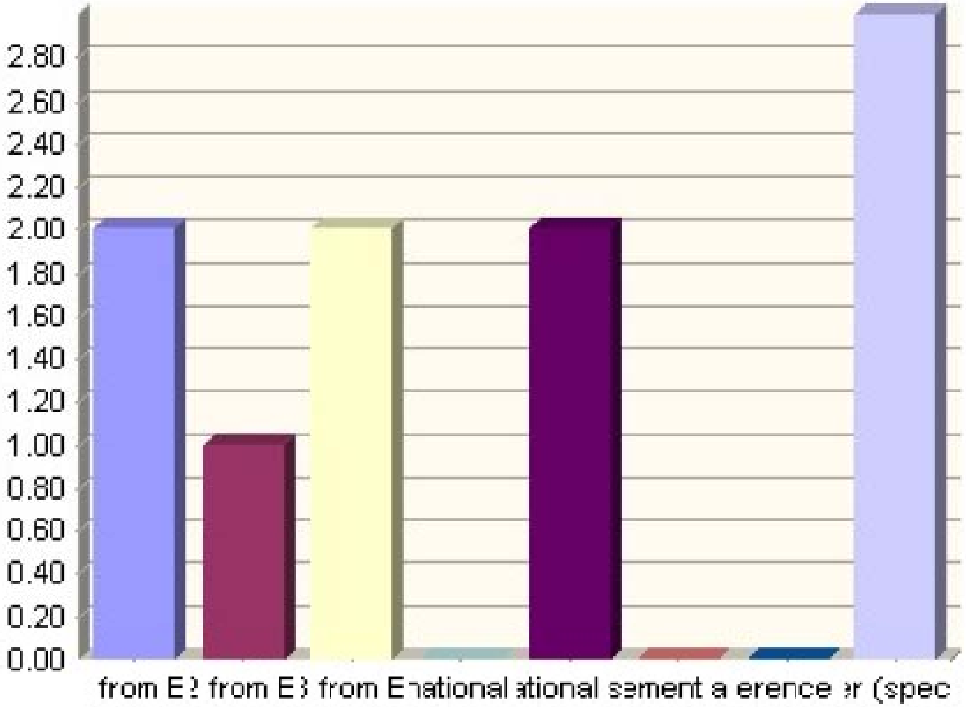
Phase 2 with benchmark values:
$E_{u,k}$ = 150 / 170 / 190 MPa



Response	Count	Percent
By eye	3	20.00%
By linear regression	1	6.67%
By statistical analysis	2	13.33%
From an existing standard (specify)	1	6.67%
From a published correlation (specify)	4	26.67%
Comparison with a previous design	2	13.33%
From the soil description, not using the data	2	13.33%
Other (specify)	0	0.00%

Response ID	From an existing standard (specify)	From a published correlation (specify)
3		Cu = 6 Nspt
36	DIN 4094	
110		Stroud and Butler

Q14. Which calculation model did you use to determine settlement?



Response	Count	Percent
Annex F.1 from EN 1997-1	2	13.33%
Annex F.2 from EN 1997-1	1	6.67%
Annex F.3 from EN 1997-2	2	13.33%
Alternative from national annex (specify)	0	0.00%
Alternative from national standard (specify)	2	13.33%
Finite element analysis	0	0.00%
Finite difference analysis	0	0.00%
Other (specify)	3	20.00%

Other (specify)
Classical solutions of linear elasticity theory
Lambe&Whitman Table15.1. Tilt more critical than settlement.
ULS verified SLS. Clause 6.6.2(16)
Burland and Burridge

Annex F
(informative)
Sample methods for settlement evaluation

F.1 Stress-strain method

(1) The total settlement of a foundation on cohesive or non-cohesive soil may be evaluated using the stress-strain calculation method as follows:

— computing the stress distribution in the ground due to the loading from the foundation; this may be derived on the basis of elasticity theory, generally assuming homogeneous isotropic soil and a linear distribution of bearing pressure;

— computing the strain in the ground from the stresses using stiffness moduli values or other stress-strain relationships determined from laboratory tests (preferably calibrated against field tests), or field tests;

— integrating the vertical strains to find the settlements; to use the stress-strain method a sufficient number of points within the ground beneath the foundation should be selected and the stresses and strains computed at these points.

F.3 Settlements without drainage

(1) The short-term components of settlement of a foundation, which occur without drainage, may be evaluated using either the stress-strain method or the adjusted elasticity method. The values adopted for the stiffness parameters (such as E_m and Poisson's ratio) should in this case represent the undrained behaviour.

F.2 Adjusted elasticity method

(1) The total settlement of a foundation on cohesive or non-cohesive soil may be evaluated using elasticity theory and an equation of the form:

$$s = p \times b \times f / E_m \qquad \text{(F.1)}$$

where:

E_m is the design value of the modulus of elasticity

f is the settlement coefficient

p is the bearing pressure, linearly distributed on the base of the foundation

and the other symbols defined in 1.6

(2) The value of the settlement coefficient f depends on the shape and dimensions of the foundation area, the variation of stiffness with depth, the thickness of the compressible formation, Poisson's ratio, the distribution of the bearing pressure and the point for which the settlement is calculated.

(3) If no useful settlement results, measured on neighbouring similar structures in similar conditions are available, the design drained modulus E_m of the deforming stratum for drained conditions may be estimated from the results of laboratory or in-situ tests.

(4) The adjusted elasticity method should only be used if the stresses in the ground are such that no significant yielding occurs and if the stress-strain behaviour of the ground may be considered to be linear. Great caution is required when using the adjusted elasticity method in the case of non-homogeneous ground.

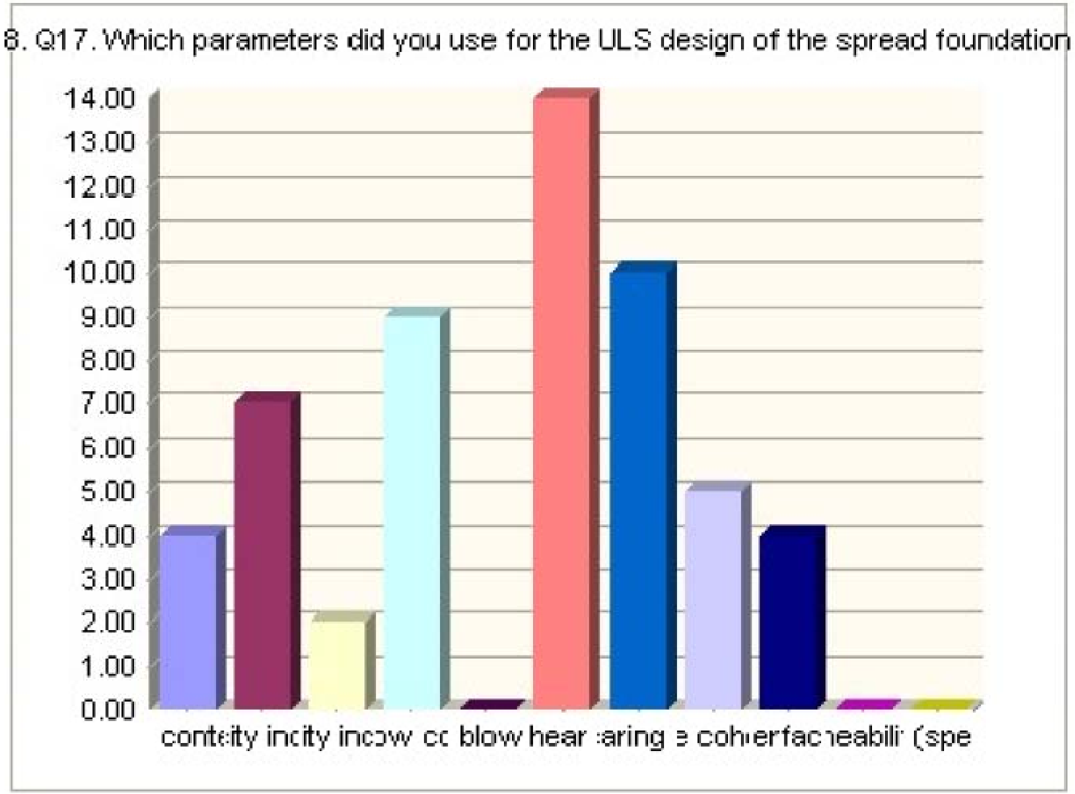
16. Q15. What limiting values of settlement and tilt is appropriate for this foundation?

Response ID	Settlement C_d (in mm) =	Tilt C_d (1 in x) =
3	10-15	
6	25	
57	25	1 in 250
44	50	The EN 1997-1 does not provide any limit
65	25	
52	25	500
22	25	a case: e < 0,3B was not checked
47	not calculated	not calculated
85	50	1/150
36	20	300
104	25	
110	25	2000

17. Q16. What width does the foundation need to avoid a serviceability limit state?

Response ID	B_{SLS} (in m) =	
3	3.5	
6	4	Phase 2 4,0 m ➔ 3,2 m
57	4.5	
44	4.00 (see 27)	
65	4.3	
52	1,2	(tilt was not considered because H is only short time loading)
22	2,4	
47	not calculated	
36	4,10	Phase 2 4,1 m ➔ 3,0 m
97	see Q27	Phase 2 ➔ 2,8 m
104	3.0	
110	3.6	

18. Q17. Which parameters did you use for the ULS design of the spread foundation?



Response	Count	Percent
Water content w	4	26.67%
Plasticity index I_P	7	46.67%
Liquidity index I_L	2	13.33%
SPT blow count N	9	60.00%
Corrected SPT blow count $(N_1)_{60}$	0	0.00%
Undrained shear strength c_u	14	93.33%
Angle of shearing resistance f'	10	66.67%
Effective cohesion c'	5	33.33%
Angle of interface friction d	4	26.67%
Permeability k	0	0.00%
Other (specify)	0	0.00%

19. Q18. What correlations did you use to derive soil parameter values (if used) for the ULS verification? If more than one, please list others below.

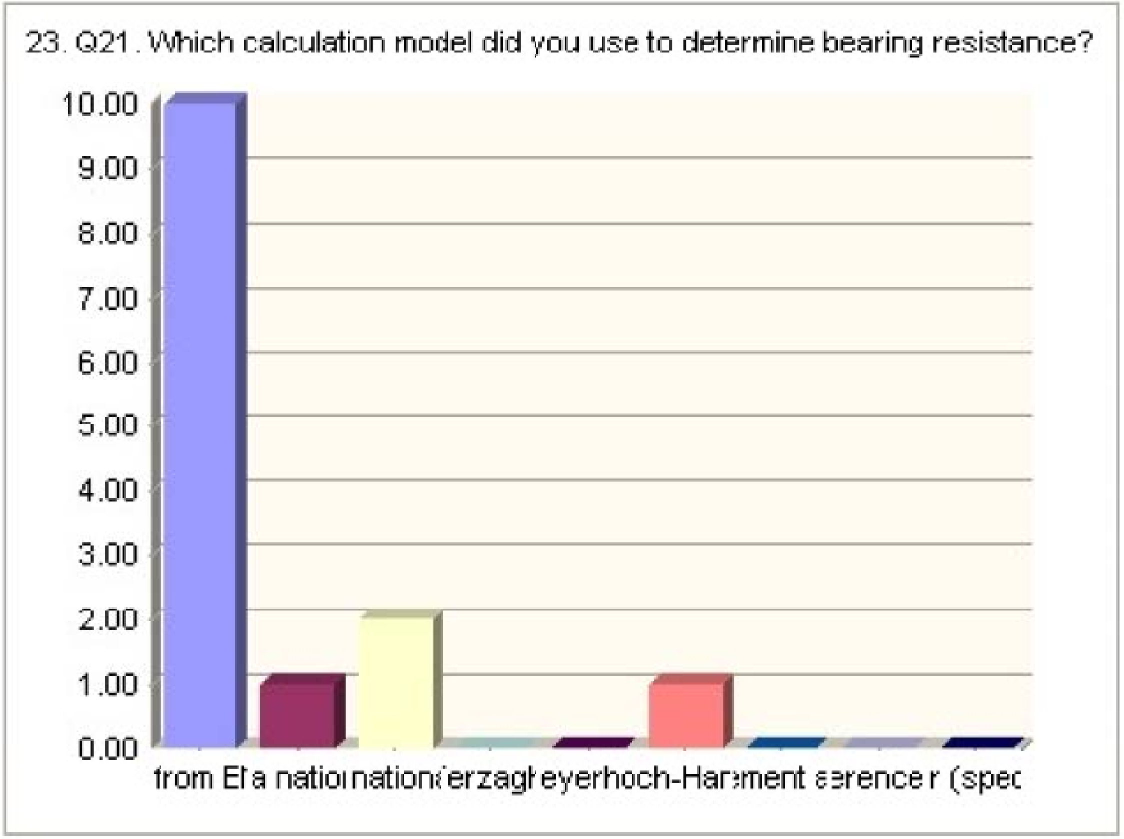
Response ID	Description	Author	Title	Pages
3	friction as a function of dilatancy index Id	Bolton M.D. (1986)	The strength and dilatancy of sands. Geot. 36(1)	65
6	Cu=5N	Stroud	The standard penetration test in insensitive clays and soft	Fig 3
60	SPT to cu (function of PI)	Stroud (1975)	The SPT in insensitive clays and Rocks, Conf. proc.	367-375
44	See question 18a			
52	soil characteristics of clay	Arbeitsausschuss Ufereinfassungen	EAU 1990	10-11
22	N → IL and IL →fi?, c?, cu	PN-B-04452:2002 and PN-81/B-03020		
47	experienced data of value of soil parameters	Arbeitsausschuss \"Ufereinfassungen\" der HTG und DGGT	EAU 2004	12 pp
85	cu = 4,75Nfield	O. Sivrikaya, E. Togrol	Determination of undrained strength of fine-grained soils...	52-69
97		Terzaghi - Peck		
104	Relations between cu, PI and SPT	Stroud	The standard penetration test in intensive clays and soft...	
118		K. Simmer	Grundbau 2, 1987	291
110	cu = 6N	Stroud and Butler 1978	The standard penetration test and the engineering properties	

22. Q20. What is the characteristic value of cu at these depths?

Response ID	At 1 m, $c_{u,k}$ (kPa) =	At 2 m, $c_{u,k}$ (kPa) =	At 4 m, $c_{u,k}$ (kPa) =
3	220	240	280
6	150	175	225
57	120	120	120
60	150	165	250
44	164	164	164
65	130	110	150
52	200	200	200
22	150	150	150
47	150	150	150
85	152	147	214
97	180	200	
104	200	200	200
118	200	200	200
110	210	210	210

Phase 2 with
benchmark values:
c_u = 190 / 210 / 240 kPa

23. Q21. Which calculation model did you use to determine



Alternative given in a national standard (specify)

4019:2006-03

DIN 4017

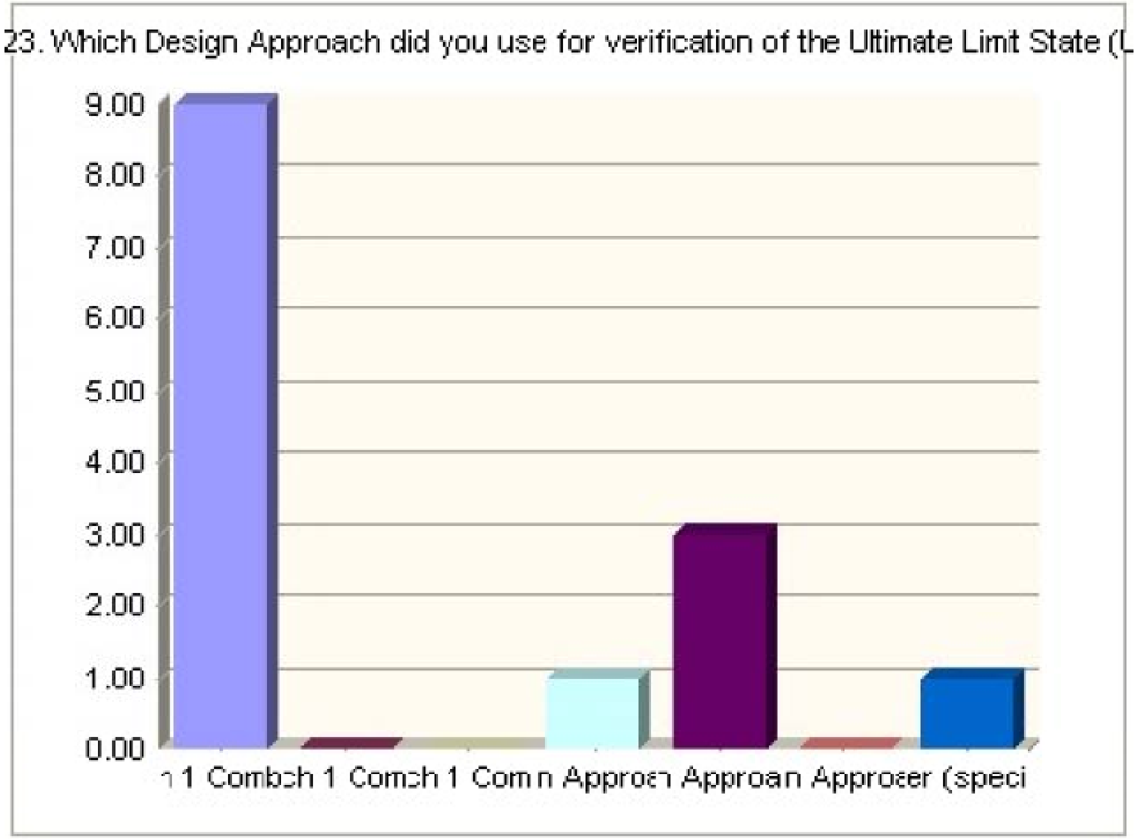
DIN 4017

Response	Count	Percent
Annex D from EN 1997-1	10	66.67%
Alternative given in a national annex (specify)	1	6.67%
Alternative given in a national standard (specify)	2	13.33%
Terzaghi	0	0.00%
Meyerhof	0	0.00%
Brinch-Hansen	1	6.67%
Finite element analysis	0	0.00%
Finite difference analysis	0	0.00%
Other (specify)	0	0.00%

24. Q22. Which country's National Annex did you use to interpret EN 1997-1?

Response ID	Response
3	none
6	UK
57	Italy D.M. 14/01/2008 \"Approvazione delle nuove norme tecniche per le costruzioni\"
60	UK
44	Portugal
65	U.K
22	none
47	germany, NA 005-05-01 AA N349
36	E DIN 1054-101: 2009-02
97	Italian
118	E DIN 1054?101:2009?02 ==> DIN 4017
110	Ireland

25. Q23. Which Design Approach did you use for ve (ULS)?



Response	Count	Percent
Design Approach 1 Combinations 1 and 2	9	60.00%
Design Approach 1 Combination 1 only	0	0.00%
Design Approach 1 Combination 2 only	0	0.00%
Design Approach 2	1	6.67%
Design Approach 2*	3	20.00%
Design Approach 3	0	0.00%
Other (specify)	1	6.67%

Response ID	Other (specify)
52	neglected Qhk

26. Q24. What values of partial factors did you use for this ULS verification?

Response ID	gG	gQ	gf	gc	gcu	gRv	gRh	gRd
3	1	0	1		1			
6	1	1.5 / 0	1	1	1	1	1	1
57	1.0?1.3	0.0?1.5			1.0	1.0	1.0	1.0
60	1	1.3	N/A	N/A	1.4	1	1	1
44	1.35	1.50	1.00	1.00	1.00	1.00	1.00	1.00
65	1.35	1.5	1	1	1	1		
52	1,35	1,5				1,4	1,1	
22	1,35	1,50	1,00	1,00	1,00	1,40	1,10	-
47	1,35	1,5	1	1	1		1,1	1,4
85	1,35	1,5			1			1,4
36	1,35	1,5				1,40	1,10	
97	1.3	1.5	1	1	1	1	1	1
104	1.3	1.5	1	1	1	1	1	
118	1,35	1,5				1,4	1,1	1,4
110	1.0	1.0	1.25		1.4			

27. Q24a. If you used a second combination of partial factors, what values did you use for this second combination?

Response ID	gG	gQ	gf	gc	gcu	gRv	gRh	gRd
3	1	0	1.25		1.4			
6	1	1.3 / 0	1.25	1.4	1.4	1	1	1
57	1.0	0.0?1.3			1.4	1.8	1.1	1.0
60	1.35	1.5	N/A	N/A	1	1	1	1
44	1.00	1.30	1.25	1.25	1.40	1.00	1.00	1.00
65	1	1.3	1.25	1.25	1.4			
22	1,00	1,50	1,00	1,00	1,00	1,40	1,10	-
47	1,35	0	1	1	1		1,1	1,4
97	1	1.3	1.25		1.4	1.4	1.8	1.8
104	1	1.3	1.25	1.25	1.4	1.8	1.1	
110	1.35	1.5	1.0		1.0			

28. Q25. What width does the foundation need to avoid an ultimate limit state?

Response ID	B_{ULS} (in m) =	
3	4.5	
6	4.66	Phase 2 4,66 m → 4,22 m
57	4.5	
60	4.5	
44	4.40	
65	4.3	
52	3,3	
22	3,2 or 4,8	
47	3,5	
85	3,1	
36	4,50	Phase 2 4,5 m → 3,5 m
97	4.40 x 4.40	Phase 2 no change
104	3.5	
118	4,63	Phase 2 no change
110	4.23	

29. Q26. What are the structural forces (at its centreline) that the foundation must be designed for according to Eurocode 2?

Response ID	Design bending moment, M_{Ed} (in kNm) =	Design shear force, V_{Ed} (in kN) =
6	1980	1992
57	2100	750
44	614 kNm/m	503 kN/m
65	N/A	N/A
52	1400	1644
22	1858 for Buls =4,8	2753 for Buls=4,8
47	not calculated	not calculated
85	1500	2735
36	2753	2223
97	see Q32	see Q32
104	1500	2425
118	2100	3053,8
110	2694	2538

differences supposed to depend on the weight of the footings

30. Q27. What other assumptions did you need to make to complete your design?

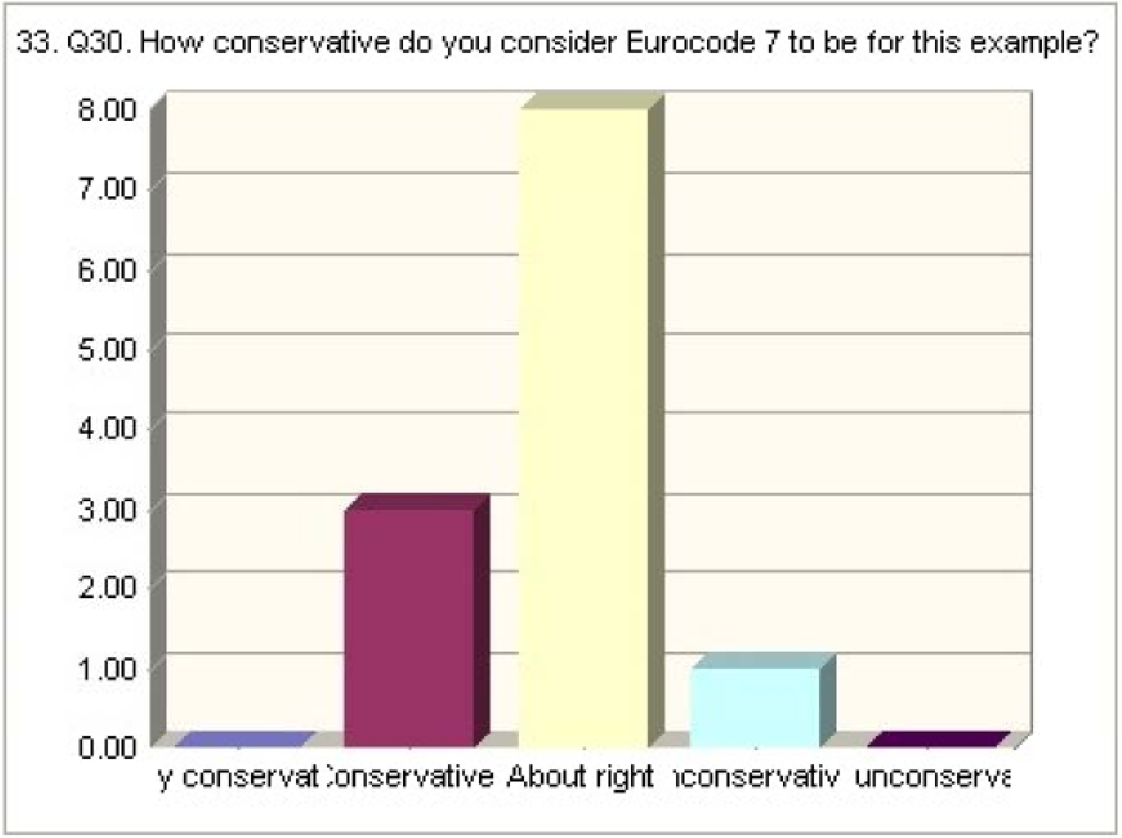
Response ID	Response
6	Q27: The column width is not specified, so I gave results at the CL. Calculated as though water table at underside of footing. Checked for both drained and undrained states with full range of variable loading.
60	The e
44	For the decision on the final value of BSLS, it was also considered the limiting values on Tomlinson?s book for foundations on boulder clays for a long term settlement less than 50 mm. The structural forces were determined with B=4.4 m and assuming a column with 0.5*0.5 m2 (flexible footing)
22	Independence of variable action are assumed.
36	soil parameters
97	As the kind of the structure above the foundation is not known, the limit of the settlement cannot be found. This the reason why such calculation has been neglected.
110	None
44	The SPT is not a good test for clays. So, and attending to the lack of experience on this soils in Portugal, would be good to have information from Borehole Pressure meter and triaxial tests in large samples.
22	There is no specify about Qh i Qv and their?s conjunction.
47	geotechnical interpretative report with detailed informations about soil parameters
97	Water level at ground level.
118	drained, undrained shear strength and angle of shearing resistance or a standard procedure to determine these parameters from the given borehole test results

31. Q28. Please specify any other data that you would have liked to have had to design this type of foundation

Response ID	Response
3	- more soil data: for example why the soil grading is not given ? this can be very useful to assess geotechncial parameters from SPT data - undisturbed samples are indicated in the bore logs, but no data from testing are given - column dimensions are needed for structural design of the foundation
6	Q7. Also Eu=400Cu. G=Eu/3.
57	Tilt and settlement limiting values (Q15) could be modified on the basis of the building type
60	Supplementary GI data. Perhaps field vane tests on U100 samples, or CPT data.

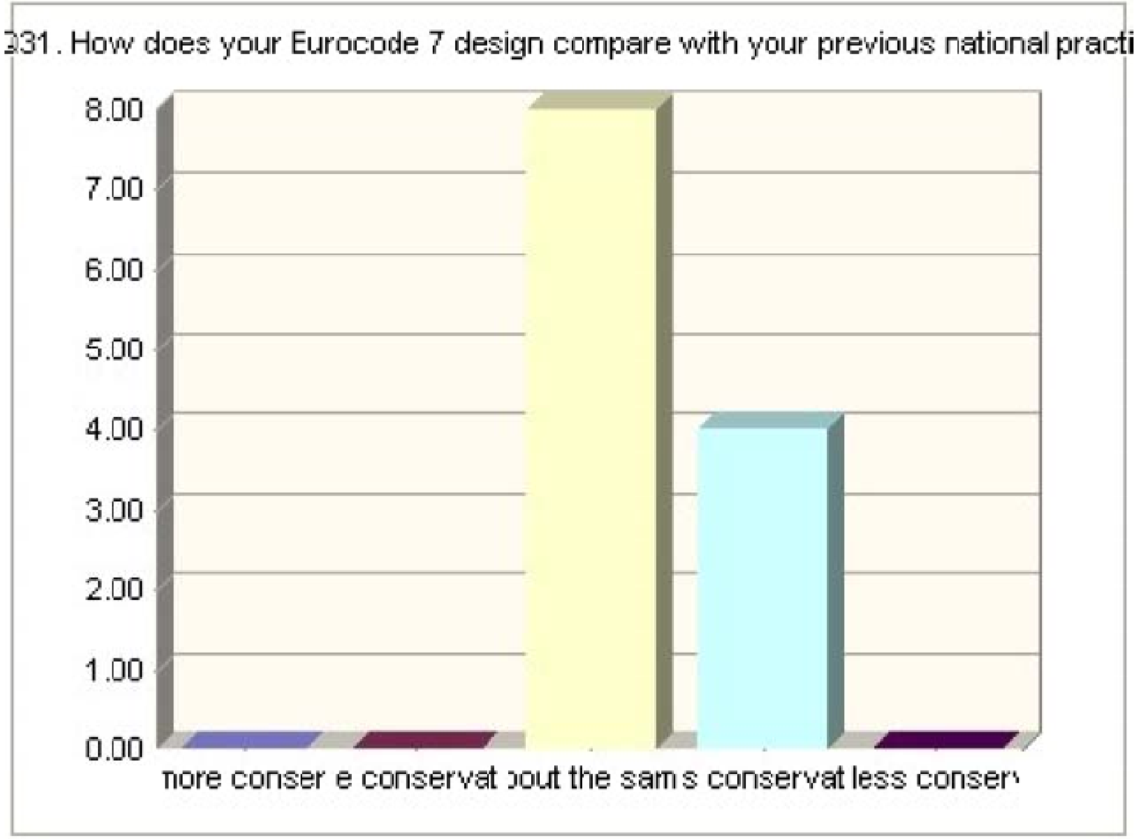
32. Q29. How conservative do you consider your previous national practice to be for this design example?

Response	Count	Percent
Very conservative	0	0.00%
Conservative	5	33.33%
About right	7	46.67%
Unconservative	0	0.00%
Very unconservative	0	0.00%



Response	Count	Percent
Very conservative	0	0.00%
Conservative	3	20.00%
About right	8	53.33%
Unconservative	1	6.67%
Very unconservative	0	0.00%

34. Q31. How does your Eurocode 7 design compare with your previous national practice?



Response	Count	Percent
Much more conservative	0	0.00%
More conservative	0	0.00%
About the same	8	53.33%
Less conservative	4	26.67%
Much less conservative	0	0.00%

Phase 2: verifications with benchmark characteristic values

Please assume the following benchmark characteristic values apply:

Characteristic SPT blow count N_k = 30 at 1m depth; 35 at 2m; 40 at 4m

Characteristic undrained strength* $c_{u,k}$ = 190 kPa at 1m; 210 kPa at 2m; 240 kPa at 4m

Characteristic undrained Young's modulus* $E_{u,k}$ = 150 MPa at 1m; 170 MPa at 2m; 190 MPa at 4m

(*OR, if a single value is adopted, please use $c_{u,k}$ = 210 kPa and $E_{u,k}$ = 170 MPa constant with depth)

Characteristic drained strength $\varphi_k = 30°$ and c'_k = 25 kPa (constant with depth)

Characteristic drained Young's modulus $E_{s,k}$ = 50 MPa (constant with depth)

Assume the limiting value of settlement is 25 mm and of tilt is 1/500.

The width of the foundation when designed to Eurocode 7 is to be determined, assuming the foundation is for a conventional concrete framed structure. There is no need to consider any effects due to frost or vegetation. The foundations' design working life is 50 years.