GEOTECHNICS FOR THE STRUCTURAL ENGINEER

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The Development of Foundation limit State Design

- Before World War II codes of practice for foundation engineering were used only in a small number of countries.
- In 1956 Brinch Hansen used for the first time the words “limit design” in a geotechnical context.
- Brinch linked the limit design concept closely to the concept of partial safety factors, and he introduced these two concepts in Danish foundation of engineering practice.

Basis Behind Eurocode 7

The Limit state concept is today widely accepted as a basis for codes of practice in structural engineering. From the very beginning of the work on the Eurocodes it was a foregone conclusion that the Eurocodes should be written in the limit state design format and that partial factors of safety should be used.

Consequently it was decided that also those parts of the Eurocodes which will be dealing with geotechnical aspects of design should be written in the limit state format with the use of partial factors of safety

Geotechnical Categories & Geotechnical Risk Higher Categories satisfied by greater attention to the quality of the geotechnical investigations and the design

Table 1-Geotechnical Categories related to geotechnical hazard and vulnerability levels

Factors to be considered	Geotechnical Categories		
	GC1	GC2	GC3
Geotechnical hazards /vulnerability /risk	Low	Moderate	High
Ground conditions	Known from comparable experience to be straightforward. Not involving soft, loose or compressible soil, loose fill or sloping ground.	Ground conditions and properties can be determined from routine investigations and tests.	Unusual or exceptionally difficult ground conditions requiring non-routine investigations and tests.
Regional seismicity	Areas with no or very low earthquake hazard	Moderate earthquake hazard where seismic design code (EC8 Part V) may be used	Areas of high earthquake hazard
Surroundings	Negligible risk of damage to or from neighbouring structures or services and negligible risk for life	Possible risk of damage to neighbouring structures or services due, for example, to excavations or piling	High risk of damage to neighbouring structures or services

Table 1 (cont.)

	Geotechnical Categories		
	GC1	GC2	GC3
Expertise required	Person with appropriate comparable experience	Experienced qualified person – Civil Engineer	Experienced geotechnical specialist
Design procedures	Prescriptive measures and simplified design procedures e.g. design bearing pressures based on experience or published presumed bearing pressures. Stability of deformation calculations may not be necessary	Routine calculations for stability and deformations based on design procedures in EC7	More sophisticated analyses
Examples of structures	- Simple 1 & 2 storey structures and agricultural buildings having maximum design column load of 250kN and maximum design wall load of 100kN/m - Retaining walls and excavation supports where ground level difference does not exceed 2m	Conventional: - Spread and pile foundations - Walls and other retaining structures - Bridge piers and abutments Embankments and earthworks	- Very large buildings - Large bridges - Deep excavations - Embankments on soft ground Tunnels in soft or highly permeable ground

Ultimate Limite State (ULS) partial factors (persistant & transiet situations)

Table 2- Partial factors for ultimate limit states in persistent and transient situations

Parameter	Factor	Case A	Case B	Case C	Case C2	Case C3
Partial load factors (γ_F)		(UPL)	(STR)	(GEO)	(EQU)	(HYD)
Permanent unfavourable action	γ_G	1.00	1.35	1.00	1.35	1.00
Variable unfvaourable action	γ_Q	1.50	1.50	1.30	1.50	1.20
Permanent fvourable action	γ_G	0.95	1.00	1.00	1.00	1.00
Variable favourable action	γ_Q	0	0	0	0	0
Accidental action	γ_A	1.00	1.00	1.00	1.00	1.00

- Values in red are partial factors either given or implied in ENV version of EC7
- Values in green are partial not in the ENV that may be in the EN version

Table 2 (Cont.)

Parameter	Factor	Case A	Case B	Case C	Case C2	Case C3
Partial material factors (γ_m)		(UPL)	(STR)	(GEO)	(EQU)	(HYD)
Tan ϕ'	$\gamma_{\tan\phi'}$	1.10	1.00	1.25	1.00	1.20
Effective cohesion c'	$\gamma_{c'}$	1.30	1.00	1.60	1.00	1.20
Undrained shear strength c_u	γ_{cu}	1.20	1.00	1.40	1.00	1.40
Compressive strength q_u	γ_{qu}	1.20	1.00	1.40	1.00	1.40
Pressuremeter limit pressure p_{lim}	γ_{plim}	1.40	1.00	1.40	1.00	1.40
CPT resistance	γ_{CPT}	1.40	1.00	1.40	1.00	1.40
Unit weight of ground γ	γ_g	1.00	1.00	1.00	1.00	1.00

- Values in red are partial factors either given or implied in ENV version of EC7
- Values in green are partial not in the ENV that may be in the EN version

Table 2 (Cont.)

Parameter	Factor	Case A	Case B	Case C	Case C2	Case C3
Partial resistance factors (γ_R)		(UPL)	(STR)	(GEO)	(EQU)	(HYD)
Bearing resistance	γ_{RV}	-*	1.00	1.00	1.40	1.00
Sliding resistance	γ_{rS}	-*	1.00	1.00	1.10	1.00
Earth resistance	γ_{Re}	-*	1.00	1.00	1.40	1.00
Pile base resistance	γ_b	-*	1.00	1.30	1.30	1.00
Pile shaft resistance	γ_s	-*	1.00	1.30	1.30	1.00
Total pile resistance	γ_t	-*	1.00	1.30	1.30	1.00
Pile Tensile resistance	γ_{st}	1.40	1.00	1.60	1.40	1.00
Anchor pull-out resistance	γ_A	1.30	1.00	1.50	1.20	1.00

- Values in red are partial factors either given or implied in ENV version of EC7
- Values in green are partial not in the ENV that may be in the EN version
- * Partial factors that are not relevant for Case A

Serviceability Limit State Calculations (SLS)

Table 3 – Serviceability limits

Crack width mm	Degree of damage			Effect on structure and building use
	Dwelling	Commercial or public	Industrial	
> 0.1	Insignificant	Insignificant	Insignificant	None
0.1 to 0.3	Very slight	Very slight	Insignificant	none
0.3 to 1	Slight	Slight	Very slight	Aesthetic only
1 to 2	Slight to moderate	Slight to moderate	Very slight	Accelerated weathering to external features
2 to 5	Moderate	Moderate	Slight	Serviceability of the building will be affected, and towards the upper bound, stability may also be at risk
5 to 15	Moderate to severe	Moderate to severe	Moderate	
15 to 25	Severe to very severe	Moderate to severe	Moderate to severe	
>25	Very severe to dangerous	Severe to dangerous	Severe to dangerous	Increasing risk of structure becoming dangerous

LIMIT STATE DESIGN –
CHARACTERISTIC VALUE & DESIGN STRENGTH

CHARACTERISTIC STRENGTH OF A MATERIAL is the strength below which not more than 5% (or 1 in 20) samples will fail.

CHARACTERISTIC STRENGTH =

MEAN VALUE – 1.64 X Standard Deviation

DESIGN STRENGTH =

$$\frac{\text{CHARACTERISTIC STRENGTH}}{\text{MATERIAL FACTOR OF SAFETY}} \qquad \frac{f_u}{\gamma_m}$$

EXAMPLE:

Ten concrete cubes were prepared and tested by crushing in compression at 28 days. The following crushing strengths in N/mm^2 were obtained:

44.5 47.3 42.1 39.6 47.3 46.7 43.8 49.7 45.2 42.7

Mean strength $x_m = \frac{448.9}{10} = 44.9 N/mm^2$

Standard deviation $= \sqrt{[(x-x_m)^2/(n-1)]} = \sqrt{(80/0)}$

$= 2.98 N/mm^2$

Characteristic strength $= 44.9 - (1.64 \times 2.98)$

$= 40.0 N/mm^2$

Design strength $= \frac{40.0}{\gamma_m} = \frac{40.0}{1.5}$

$= 26.7 N/mm^2$

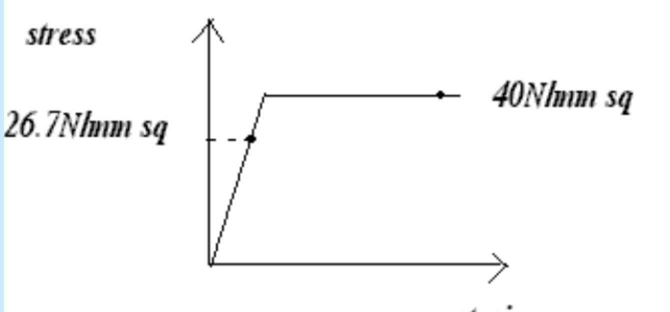

Fig 3

BICC BUILDING INDUSTRY CONSULTATIVE COUNCIL	Project FOUNDATION CPD COURSE	Job ref:
	Part of Structure CHARACTERISTIC VALUE DETERMINATION	
	Drawing Ref: Done by: DHC	Date: 05/02
Ref	Calculations	Output

The Characteristic Value of the angle of shearing resistance $\varnothing'_{K}$ is required for a 10m depth of ground consisting of sand for which the following $\varnothing'_{K}$ values were determined from 10 traxial tests: 33°, 35°, 33.5°, 32.5°, 37.5°, 34.5°,36.0°, 31.5°, 37°, 33.5°

To find the 95% confidence level, for soil properties, as only a small portion of the total volume involved in a design situation is tested, it is not possible to rely on Normal Distribution.

For a small sample size the Student t value for a 95% confidence level may be used to determine that X_K value, given by

$$X_K = X_m \left[1 - \frac{tV}{\sqrt{n}} \right] = X_m - \frac{t\sigma}{\sqrt{n}}$$

Some typical values of V for different soil properties given by

Soil Property	Range of typical V values	Recommended V Value if limited Test results available
$\tan\phi'$	0.05 – 0.15	0.10
c’	0.30 – 0.50	0.40
c_u	0.20 – 0.40	0.30
m_v	0.20 – 0.70	0.40
γ (unit weight)	0.01 – 0.10	0

BICC BUILDING INDUSTRY CONSULTATIVE COUNCIL	Project FOUNDATION CPD COURSE	Job ref:
	Part of Structure CHARACTERISTIC & DESIGN VALUE DETERMINATION	
Drawing Ref:	Done by: DHC	

Ref	Calculations	Output
	Average angle of shearing resistance $\varnothing'_{AV}$ = 34.4° With a Standard Deviation σ = 1.97° Coeff of variation V = 0.057 Student t for a 95% confidence level with 10 test results = 2.26 $\varnothing'_{K} = 34.4 - 1.97 \times 2.26 / \sqrt{10}$ = 33.0° The Design Value $X_D = X_k/\gamma_m$ Applying the γ_m = 1.25 for Case C in Table 2 $\varnothing'_c = \arctan(\tan \varnothing'_K) / 1.25$ = 27.8°	

The t values are given in Table 4

Level of certainty / Livello di sicurezza

Degrees of freedom (df) / Gradi di libertà (df)	80%	90%	95%	99%	99.9%
1	3.078	6.314	12.706	63.657	636.619
2	1.886	2.920	4.303	9.925	31.598
3	1.638	2.353	3.182	5.841	12.941
4	1.533	2.132	2.776	4.604	8.610
5	1.476	2.015	2.571	4.032	6.859
6	1.440	1.943	2.447	3.707	5.959
7	1.415	1.895	2.365	3.499	5.405
8	1.397	1.860	2.306	3.355	5.041
9	1.383	1.833	2.262	3.250	4.781
10	1.372	1.812	2.228	3.169	4.587
11	1.363	1.796	2.201	3.106	4.437
12	1.356	1.782	2.179	3.055	4.318
13	1.350	1.771	2.160	3.012	4.221
14	1.345	1.761	2.145	2.977	4.140
15	1.341	1.753	2.131	2.947	4.073
16	1.337	1.746	2.120	2.921	4.015
17	1.333	1.740	2.110	2.898	3.965
18	1.330	1.734	2.101	2.878	3.922
19	1.328	1.729	2.093	2.861	3.883
20	1.325	1.725	2.086	2.845	3.850
21	1.323	1.721	2.080	2.831	3.819
22	1.321	1.717	2.074	2.819	3.792
23	1.319	1.714	2.069	2.807	3.767
24	1.318	1.711	2.064	2.797	3.745
25	1.316	1.708	2.060	2.787	3.725
26	1.315	1.706	2.056	2.779	3.707
27	1.314	1.703	2.052	2.771	3.690
28	1.313	1.701	2.048	2.763	3.674
29	1.311	1.699	2.045	2.756	3.659
30	1.310	1.697	2.042	2.750	3.646
40	1.303	1.684	2.021	2.704	3.551
60	1.296	1.671	2.000	2.660	3.460
120	1.289	1.658	1.980	2.617	3.373
∞	1.282	1.645	1.960	2.576	3.291

Basic Cohesive Soil Founding Pressures

Shallow Foundation occurs when founding depth (D) is less than width (B)

D/B < 1 or when d<3m (may not be applicable for rafts)

For undrained conditions, the base resistance q_B per unit area

Shallow foundation $q_B = 5c_u + \gamma_s D$

Deep foundation $q_B = 9c_u + \gamma_s D$

For the general soil type use the EC7 Brinch-Hansen equation.

BICC	Project: Tas-Selfum Apartment Blk.	Job ref:
	Part of Structure: Loadings to Eurocode 1	Sheet No. PO 1/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref.	Calculations	Output

ROOF LOADING

Concrete slab 0.15.24kN/m^3	1.35	=>	4.86kN/m^2
Roofer system 0.15.18kN/m^3	1.35	=>	3.65kN/m^2
LL 1.5kN/m^2	1.5	=>	2.25kN/m^2
			10.75kN/m^2

APARTMENT FLATS

Concrete slab 0.18.24kN/m^3	1.35	=>	5.83kN/m^2
Finish 0.10.18kN/m^3	1.35	=>	2.43kN/m^2
LL 1.5kN/m^2	1.5	=>	2.25kN/m^2
Partitions 4.5kN/m^2	1.35	=>	6.08kN/m^2
			16.60kN/m^2

GARAGE FLOOR

Concrete slab 0.15.24kN/m^3	1.35	=>	4.86kN/m^2
Finish 0.1 .18kN/m^3	1.35	=>	2.43kN/m^2
LL 2.5kN/m^2	1.5	=>	3.75kN/m^2
			11.05kN/m^2

DOMESTIC STORAGE

LL 2.75m.2.4kN/m^2	1.5	=>	9.9kN/m^2

Ultimate characteristic foundation loading
10.75kN/m^2.16.5m + 16.60kN/m^2 (21m + 24m + 25m + 24m)
+ 11.05kN/sqm .27m + 9.9kN/sqm.27m
=> 2303kN/m.6m + (24m.70crs.1.35kN/m/fil x 2 in No.) 1.35
=> 19,942kN

BICC	Project: Tas-Sellum Apartment Blk.	Job ref:
	Part of Structure: Founding Pressures to Eurocode VII	Sheet No. PO 2/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref:	Calculations	Output

f_b => 19,942kN / 6m.27m => 123kN/m^2

for a stiff to very stiff clay

characteristic c_u => 150kN/m^2

$$q_{char} = \frac{5C_u}{1.4} + \gamma d$$

Class B (STR)

$$= \frac{5.150}{1.4} + 20.1.5m$$

=> 565kN/sqm > 123kN/sqm

Foundation Settlement due to the adjusted elasticity method

Eurocode VII Appendix F

$S = pBf / E_m$

P => f_f/1.4 => 123kN/m^2 / 1.4 => 87.85kN/m^2

E_m / c_u => 300

E_m => 300 x 150kN/m^2 => 45,000kN/m^2

f= 0.86 (for a square rigid foundation)

& Poisonn's ratio => 0.3

S => 87.85, 6.0.86 / 45,000 => 10mm

Which settlement is less than allowable

at 50mm, although total allowance

settlements in clay at 75 - 125mm also quoted

MALTESE CLAYS CHARACTERISTICS

Referring to Mr. A. Cassar A&CE, from various insitu tests carried out using SPT and laboratory tests on recovered samples, Maltese clays may be described as stiff to very stiff in its natural state, having an average C value of 100KN/m^2, with a lower limit of 50 and an upper limit of 200.

Also the plastic limit (PL) of clay is given at 23%, with the liquid limit (LL) at 70% (Bonello 1988).

The plasticity index (PI) is thus given by

PI = LL – PL = 47%

MALTESE CLAYS CHARACTERISTICS - continued

- From the Casagrande plasticity chart this is classified as an inorganic clay of high plasticity.
- From BS 8004 table 1, stiff clays have a presumed alloweable bearing value of 150 to 300KN/m^2, whilst very stiff clays have values varying from 300 to 600 KN/m^2.
- For a PL at 23% and a high clay content, the shrinkage and swelling potential of Maltese clays is classified at high, usually showing cracks on drying.

Blue Clay Formation Mineralogic Composition

Clay type	Water Content (%)	Undrained shear str kPa	Liquid limit %	Placticity limit %	Illite %	Kaolinite %	Chlorite %	Smectite %
Blue Clay	36.0	137	78	31	13.0	30	0	57
Lon-don clay	29.0	345	89	32	31.5	24.5	3	41

Maximum burial depth: Blue clay: c 400m London Clay: c500m

Source: Saviour Scerri - geologist

Blue Clay – Geotechnical characteristics

Sample Depth m	Moisture Content	LL	PL	PI	LI	Soil Class	Bulk Weight	Dry Weight	Lateral Press	C_u – KN/m^2
4.00	36	77	29	48	0.15	CV	1.90	1.40	80	243
8.50	33	71	26	45	0.16	CV	1.91	1.44	170	251
5.20	33	74	25	49	0.16	CV	1.92	1.44	104	266
8.80	34	74	28	46	0.13	CV	1.92	1.45	176	334
1.00	32	72	27	45	0.11	CV	1.91	1.45	20	285
5.50	33	76	27	49	0.12	CV	1.90	1.43	110	305
1.00	30	69	27	42	0.07	CH	1.95	1.49	20	415
5.50	33	74	26	48	0.15	CV	1.91	1.46	110	342

Source: Saviour Scerri -geologist

Blue Clay Formation

- Blue Clay has a high clay content
- Shrinkage due to desiccation is high and may reach 3m in depth
- Deep cracks are produced
- Clay loses all its cohesion
- Subsequent saturation produces clay slips

Source: Saviour Scerri - geologist

Preparing A Clay Founding Layer

- In order to eliminate seasonal ground movement (heave or shrinkage) a min. foundation depth of 0.9m is suggested
- When constructing foundations in very dry weather, care must be taken to ensure superstructure loads are applied as soon as possible
- Foundations are to be placed at a sufficient distance from trees. To reduce above damage due to subsidence or heave, foundations should be placed at a distance away of 0.5H, being the mature tree height.
- For trees such as the poplar, oak, elm, willow and eucalyptus the distance should be doubled to H

BICC Building Industry Consultative Council	Project: Tas-Sellum Apartment Blk.	Job ref:
	Part of Structure: Raft design to Eurocode II	Sheet No. PO 3/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref:	Calculations	Output
	BM => $(123kN/m^2 - 9.9kN/m^2).6^2/8$	
	=> 509kN - m/m	h => 250 + 40 + 10 => 300mm
	span/d => 24 d => 6000/24 => 250mm	
	y => $M/bd^2.f_{ck}$ - use concrete C25/30	d => 450 - 40 - 10 => 400mm
	=> $509 / 1.400^2.25$ => 0.127 (μ_{lim} => 0.167)	
	W => $\frac{A_s}{bd} . \frac{f_{yk}}{f_{cu}}$ => 0.168 (W_{lim} => 0.2336)	
	A_s => 3,652 mm^2/m	
	The Shear Resistance with no axial load	
	V_{Rd1} => $\tau_{Rd}k\ (1.2 + 40\rho_t)\ bd$	
	τ_{RD} => $0.3N/mm^2$ k => 1.6 - d => 1.2 ≮ 1	
	ρ_t => 3,652 / 1.400 => 0.00091	
	V_{Rd1} => 0.3 x 1.2 (1.2 + 40.0 x 0091) 1.400	
	=> 225 kN/m	
	V => $(123kN/m^2 - 9.9kN/m^2)\ (\frac{6m}{2} - 0.25m)$	
	=> 311kN/m (shear links to be provided)	

Project: Tas-Sellum Apartment Blk.	Job ref:
Part of Structure: Raft design to BS 8110	Sheet No. PO 4/2
Drawing ref: Done by: DHC Chkd By:	Date 03/05

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Ref:	Calculations	Output

BM => 509kNm/m x 1.45 / 1.4 => 527kNm/m

k => $M/bd^2.f_{cu}$ => $527 / 1.400^2.30$ => 0.11

a_1 => Z / d => 0.86 Z => 0.86 x 400 => 344mm

A_s => $M/(0.87f_y)$ Z => 527/(0.87 x 460 x 344) => 3,828mm^2/m

v => $(123kN/m^2 - 9.9kN/m^2) \times \frac{1.45}{1.4} \times (\frac{6m}{2} - 0.25m)$

=> 322kN/m

v => 322 / 1.400 => 0.8N/mm^2

ρ => 3,828 / 1.400 => 0.96%

v_c => 0.67N/mm^2

so increase ρ to 1.75% V_c => 0.8N/mm^2

As_{req} => 7000mm^2/m (Y32 @ 115mm centreline)

Commentary :-

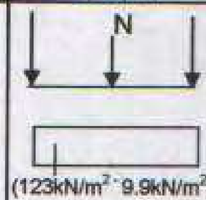
Thus EC2 is more economical on tensile steel (3,652mm^2/m as against 3,828mm^2/m), however, shear links are to be included as per EC2, whilst BS 8110 has the possibility of increasing steel area to 7,000mm^2/m and providing no shear links.

BICC BUILDING INDUSTRY CONSULTATIVE COUNCIL	Project: Tas-Sellum Apartment Blk.	Job ref:
	Part of Structure: Raft design under central walling	Sheet No. PO 5/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref:	Calculations	Output

CENTRAL POINT LOAD CREATED BY CENTRAL WALLING

N => 3m (11.05kN/m^2 + 16.6kN/m^2) + (22crs x 1.35kN/m/fil) 1.35
=> 123kN/m



BM at centre at raft

(123kN/m^2 - 9.9kN/m^2) x 6^2/8 - 123 x 6/4
=> 324kN - m / m

V => (123kN/m^2 - 9.9kN/m^2) x 2.6m - 123kN/m/2
=> 232kN/m

v => 232kN/m/400mm => 0.58N/mm^2

for V_c => 0.58N/mm^2 ρ => 0.7% (2,800mm^2/m)

k => M/bd^2.f_{cu}
=> 324 / (1 x 400sq x 30) => 360mm

a_1 => 0.9 Z => 0.9 x 400 => 360mm

A_s => M/(0.87f_y) Z
=> 324 / (0.87 x 460 x 360)
=> 2249mmsq / m

thus provide Y25 @ 175 (2805mm^2/m)

Constructing a Raft Foundation

- Raft foundations should be placed on fully compacted draining infill separated by a polythene sheet not exceeding 1.0m in depth. The raft and fully compacted fill tend to act compositely in resisting the heave forces. Heave movement is reduced by removing the most desiccated clay layer.
- For protection against the possibility of future tree planting producing damaging ground movement the bored pile foundation is more suitable. The upper part of the pile shaft in the clay desiccation zone should be sleeved to reduce uplift selling forces
- Heaving pressures in clays may be up to 200KN/m^2

BICC BUILDING INDUSTRY CONSULTATIVE COUNCIL	Project Tas-Sellum Apartment Blk.	Job ref:
	Part of Structure Pile design in clay material	Sheet No. PO 6/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref:	Calculations	Output

For undrained conditions, it is assumed that the base resistance is given by

$$(9C_u + \sigma_v) / 1.5$$

=> (9.150kN/msq + 20kN/cum x L) / 1.5

=> $900kN/m^2 + 13.33\ell$

the shaft resistance is given by

$\propto C_u / 1.5$ => where $\propto$ => 0.4

=> 0.4 x 150 / 1.5 => 40kN/msq

if piles are assumed at 4.5m ₵

N => (19,942 / 2 in No x 27m) x 4.5m

=> 1,661kN/pile

1,661kN => $900\pi \times 1^2/4 + 40 \times (\pi 1)\ell + 13.33\ell\ \pi \times 1^2/4$

ℓ => 7.00m

say 8.0m depth to cater for top 1.0m disturbance

	Project: Tas-Sellum Apartment Blk.	Job ref:
BICC	Part of Structure: Piling in Rock	Sheet No: PO 7/2
	Drawing ref: Done by: DHC Chkd By:	Date 03/05

Ref:	Calculations	Output

Assume that a soft rock formation is encounted 6.0m below surface.

The Pile will be socketed in rock for a depth of 1.5m and the above clay adhesion ignored.

Ref:- Foundations on Rock DC Wyllie

Considering end-bearing only

N_{ULT} => $\sigma_{ur} \times \pi B^2 / 4$

--> 1,800kN/msq x πx $1^2/4$ => 1,413kN

Side wall shear resistance

τ_{ult} => 0.5 $\sqrt{\sigma_{ur}}$

=> 0.5 $\sqrt{1800}$ => 670kN/msq

Q_{ult} => τ_{ult}x πBL

--> 670kN/msq x πx 1 x 1.5 => 3155kN

the % of load taken in end bearing varies from 30% to 50%

N_{ULT} => 1413kN + 1413kN x 2 => 4239kN

N_{ULT} / γ_m => 4239kN / 1.5 => 2826kN / pile

this pile spacing increases to

2826kN / 1,661kN x 4.5m => 7.5m centres

or go for 600mm diameter pile spacing at 4.0m centres

above reference gives a calculation for settlement which works out at 3mm

Indirect Design Methods

This is the traditional method used in most countries. In this method calculations are carried out at characteristic stress levels (CP 2004 – table 1 enclosed) with unfactored load and ground parameters.

Although EC7 does not provide provision for this method, it is expected to be included in the revised version.

Foundations on rock applicable to this method, although Annex G of EC7 gives presumed bearing resistances dependant on the rocks compressive strength and discontinuity spacing.

Foundation Settlement EC7 – Appendix F

Adjusted elasticity method $s = pBf/E_m$ (cohesive & non-cohesive)

p is elastic bearing pressure linearly distributed

f is the settlement coefficient?

E_m is the soil modulus of elasticity

Appendix H outlines structural deformation & foundation movement

ALLOWABLE SETTLEMENTS & ROTATIONS

For normal structures with isolated foundations total settlements up to 50mm acceptable. A max relative rotation of 1/500 acceptable for most structures, given in EC7.

Other sources’ max raft total settlement of clay up to 125mm with differential settlements of 45mm acceptable. For sand, total given at 50mm and differential at 30mm.

Isolated foundations max. deflection on clay given at 75mm (sand 50mm).

Brick buildings total settlement quoted at 75-100mm.

Angular distortion of 1/300 also quoted.