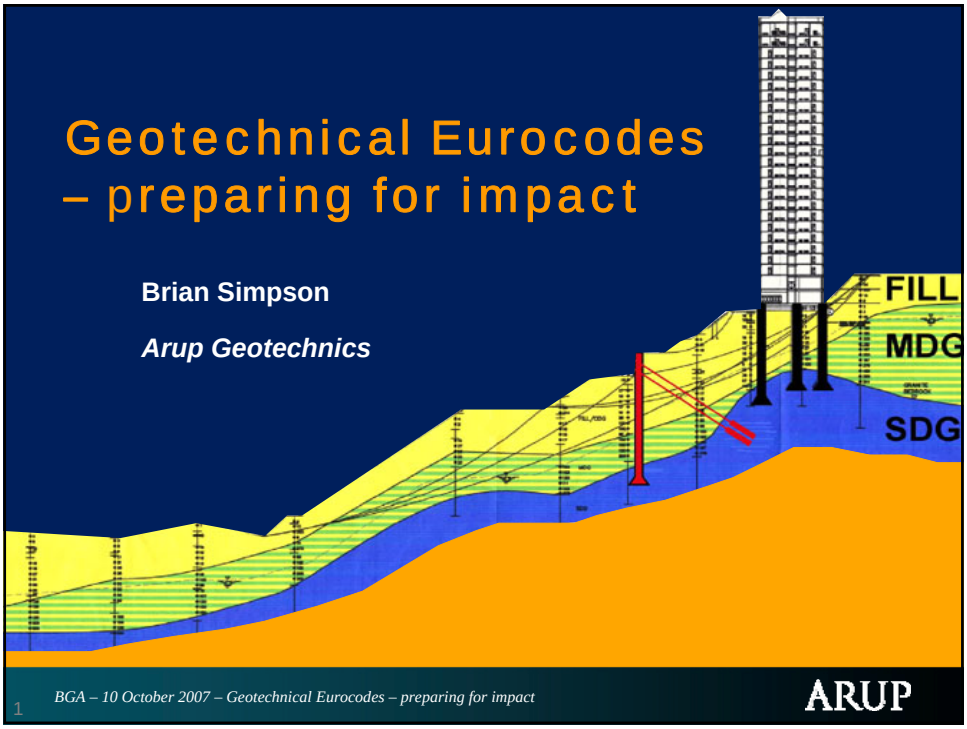
Geotechnical Eurocodes – preparing for impact

Brian Simpson

Arup Geotechnics



ARUP

The Eurocode system (CEN-TC250)

EN 1990 Eurocode 0	Basis of design
EN 1991 Eurocode 1	Actions on structures
EN 1992 Eurocode 2	Design of concrete structures
EN 1993 Eurocode 3	Design of steel structures
EN 1994 Eurocode 4	Design of composite steel and concrete structures
EN 1995 Eurocode 5	Design of timber structures
EN 1996 Eurocode 6	Design of masonry structures
EN 1997 Eurocode 7	**Geotechnical design**
EN 1998 Eurocode 8	Design of structures for earthquake resistance.
EN 1999 Eurocode 9	Design of aluminium alloy structures

Other related EN documents on construction, materials, etc

EN1990 3.3 Ultimate limit states

(4)P The following ultimate limit states shall be verified where they are relevant :

- loss of equilibrium of the structure or any part of it, considered as a rigid body ;
- failure by excessive deformation, transformation of the structure or any part of it into a mechanism, rupture, loss of stability of the structure or any part of it, including supports and foundations ;
- failure caused by fatigue or other time-dependent effects.

Serious failures involving risk of injury or major cost.

Must be rendered very unlikely. An "unrealistic" possibility.

EN1990 3.4 Serviceability limit states

(1)P The serviceability limit states shall be those that concern:

- the functioning of the structure or structural members under normal use ;
- the comfort of people ;
- the appearance of the construction works.

Inconveniences, disappointments and more manageable costs.

Should be rare, but it might be uneconomic to eliminate then completely.

BS EN 1997-1:2004
Eurocode 7: Geotechnical design

- **Part 1: General rules**
  - **12 sections**
  - **Annexes A to J**
  - **National Annex to Part 1**
- **Part 2: Ground investigation and testing**
  - **6 sections**
  - **Annexes A to X**
  - **National Annex to Part 2**

Euronorms – Execution of special geotechnical works

EN 1536: 1999	**Bored piles**
EN 1537: 1999	**Ground anchors**
EN 1537: 1999	**Ground anchors - Corrigendum**
EN 1538: 2000	**Diaphragm walls**
EN 12063: 1999	**Sheet-pile walls**
EN 12699: 2000	**Displacement piles**
EN 12715: 2000	**Grouting**
EN 12716: 2001	**Jet grouting**
EN 14199: 2005	**Micropiles**
EN 14475: 2006	**Reinforced fill**
EN14475: 2006	**Reinforced fill - Corrigendum**
EN 14679: 2005	**Deep mixing**
EN14679: 2006	**Deep mixing - Corrigendum**
EN14731: 2005	**Ground treatment by deep vibration**
EN15237: 2007	**Vertical drainage**

Outline of EC7 Part 1

1	General
2	Basis of geotechnical design
3	Geotechnical data
4	Supervision of construction, monitoring and maintenance
5	Fill, dewatering, ground improvement and reinforcement
6	Spread foundations
7	Pile foundations
8	Anchorages
9	Retaining structures
10	Hydraulic failure
11	Overall stability
12	Embankments

Annexes A to J

Characteristic values and ULS design values

- For actions (=loads) F:

  Design value =characteristic value * γ_F

  $$F_d = F_k * \gamma_F$$

- The effects of design actions are design action effects, E_d. (Bending moments, internal forces, displacements, etc.)

- For material strengths X:

  Design value = characteristic value / γ_m

  $$X_d = X_k / \gamma_m$$

- For "resistances" R:

  $$R_d = R_k / \gamma_R$$

$$\gamma_E E\{\gamma_F F_{rep}; X_k/\gamma_M; a_d\} = E_d \leq R_d = R\{\gamma_F F_{rep}; X_k/\gamma_M; a_d\}/\gamma_R$$

2.4.7.3.3 Design resistances [ULS]

$$\gamma_E\, E\{\gamma_F\, F_{rep};\, X_k/\gamma_M;\, a_d\} = E_d \le R_d = R\{\gamma_F\, F_{rep};\, X_k/\gamma_M;\, a_d\}/\gamma_R$$

2.4.7.3.3 Design resistances

(1) Partial factors may be applied either to ground properties (X) or resistances (R) or to both, as follows:

$R_d = R\{\gamma_F\, F_{rep};\, X_k/\gamma_M;\, a_d\}$ (2.7a)

or

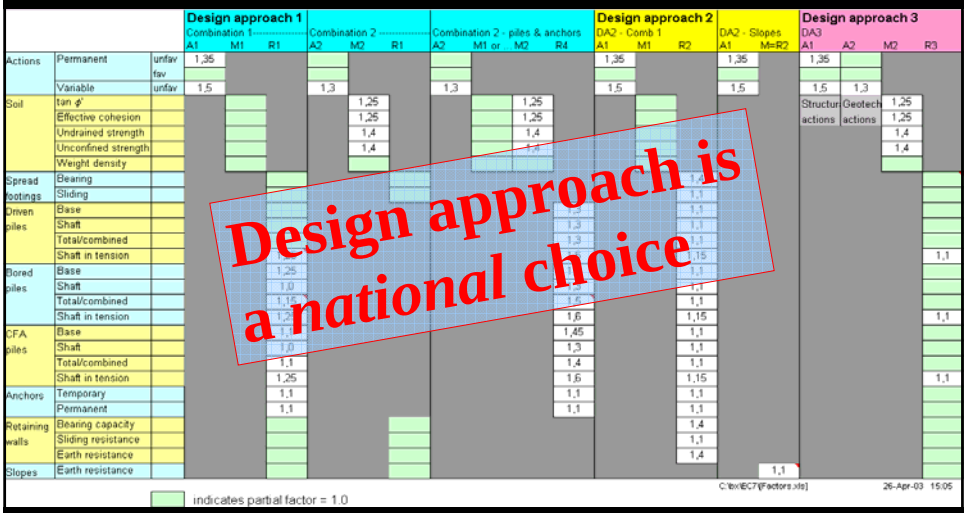
$R_d = R\{\gamma_F\, F_{rep};\, X_k;\, a_d\}/\gamma_R$ (2.7b)

or

$R_d = R\{\gamma_F\, F_{rep};\, X_k/\gamma_M;\, a_d\}/\gamma_R$ (2.7c)

Three different "Design Approaches"

Partial factors recommended in EN1997-1 Annex A



Partial factors for DA1 – UK National Annex

Values of partial factors recommended in EN1997-1 Annex A

			Design approach 1									
			Combination 1			Combination 2			Combination 2 - piles & anchors			
			A1	M1	R1	A2	M2	R1	A2	M1 or … M2	R4	
Actions	Permanent	unfav	1,35									
		fav										
	Variable	unfav	1,5			1,3			1,3			
Soil	tan ϕ'						1,25				1,25	
	Effective cohesion						1,25				1,25	
	Undrained strength						1,4				1,4	
	Unconfined strength						1,4				1,4	
	Weight density											
Spread footings	Bearing											
	Sliding											
Driven piles	Base											
	Shaft (compression)											
	Total/combined											
	Shaft in tension											
Bored piles	Base											
	Shaft (compression)											
	Total/combined											
	Shaft in tension											
CFA piles	Base											
	Shaft (compression)											
	Total/combined											
	Shaft in tension											
Anchors	Temporary											
	Permanent											
Retaining walls	Bearing capacity											
	Sliding resistance											
	Earth resistance											
Slopes	Earth resistance											

EC7 values	
1,7/1.5	1,3
1.5/1.3	1,3
1.7/1.5	1,3
2.0/1.7	1.6
2.0/1.7	1,6
1.6/1.4	1,3
2.0/1.7	1.5
2.0/1.7	1.6
As	1.45
for	1.3
bored	1.4
piles	1.6
1,1	1,1
1,1	1,1

indicates partial factor = 1.0

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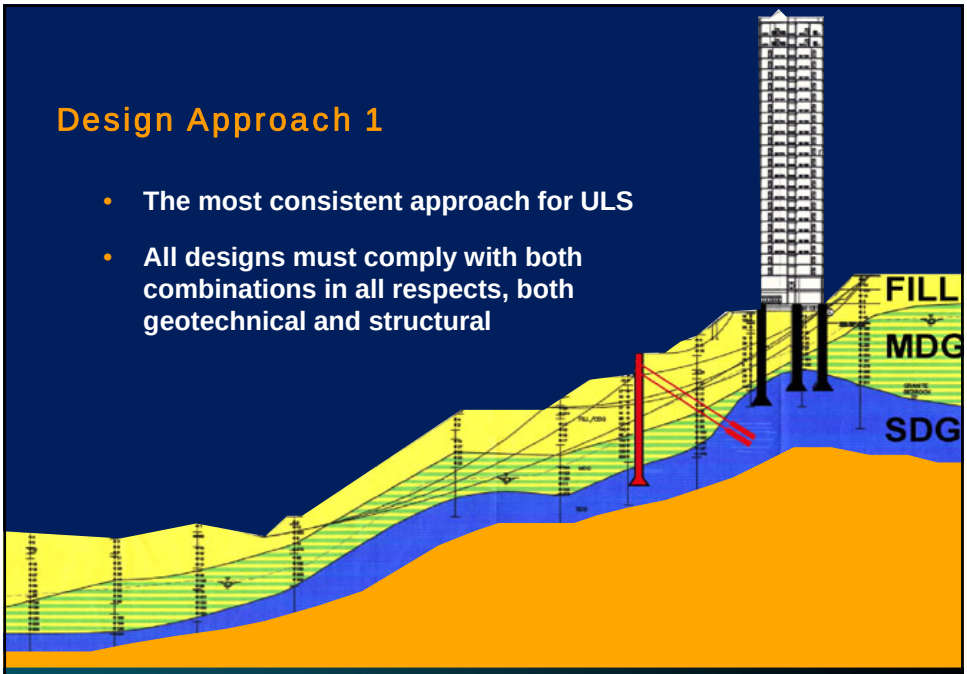
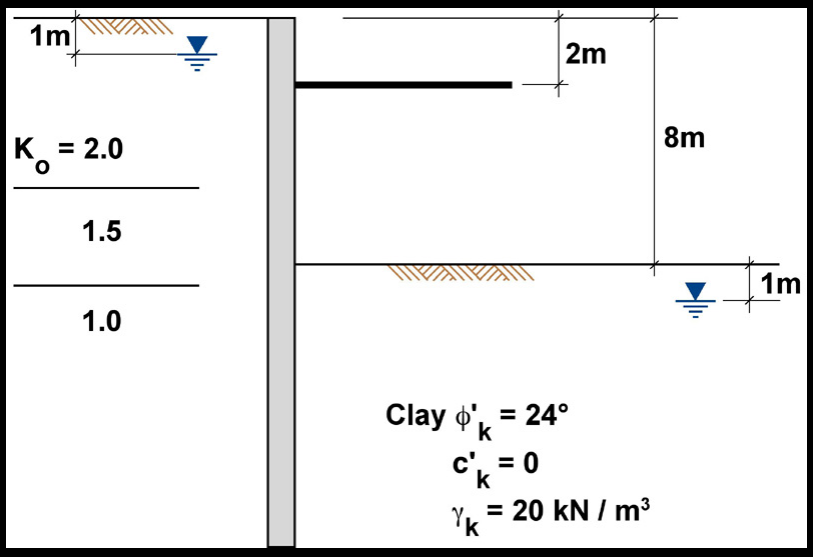
Design Approach 1

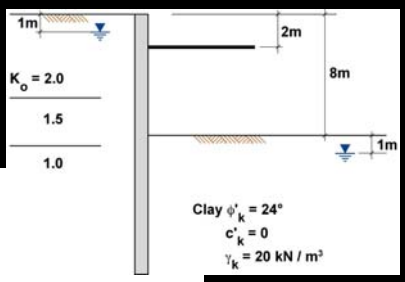
- **The most consistent approach for ULS**
- **All designs must comply with both combinations in all respects, both geotechnical and structural**

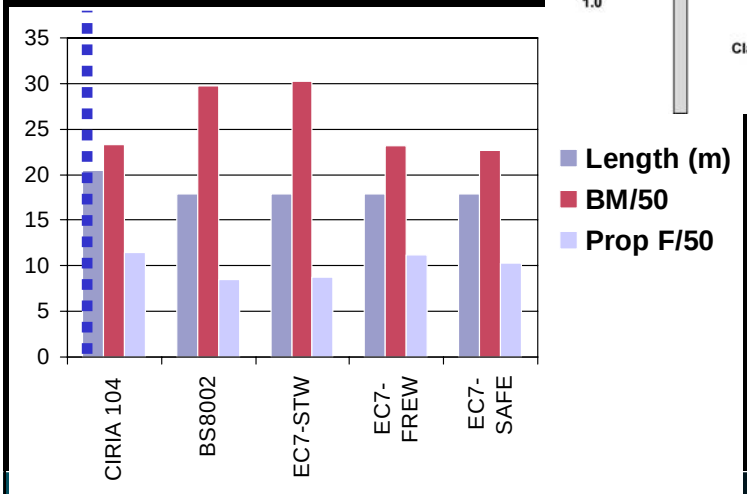


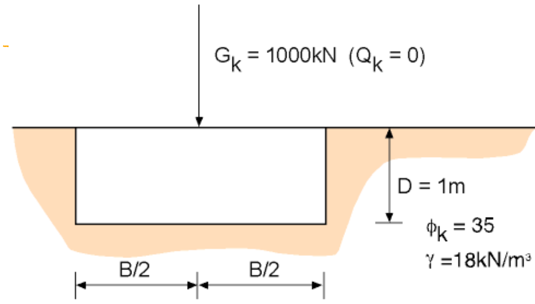
8m propped wall



8m propped wall







		Design approach 1					
		Combination 1			Combination 2		
		A1	M1	R1	A2	M2	R1
Permanent	unfav	1,35					
	fav						
Variable	unfav	1,5			1,3		
tan ϕ'						1,25	
Effective cohesion						1,25	
Undrained strength						1,4	
Unconfined strength						1,4	
Weight density							
Bearing							
Sliding							

Centrally Loaded Footing

Combination 1	**B = 1.05m**	**M = 177kNm**
Combination 2	**B = 1.29m**	**M = 181kNm**

Combination 2 width with Comb1 Loads:

B = 1.29m **M = 218kNm**

Unless non-linear distribution of bearing pressure can be justified.

Must check SLS

Serviceability limit state (settlement)

B = 2m ???

Apply DA1-2 ULS loads

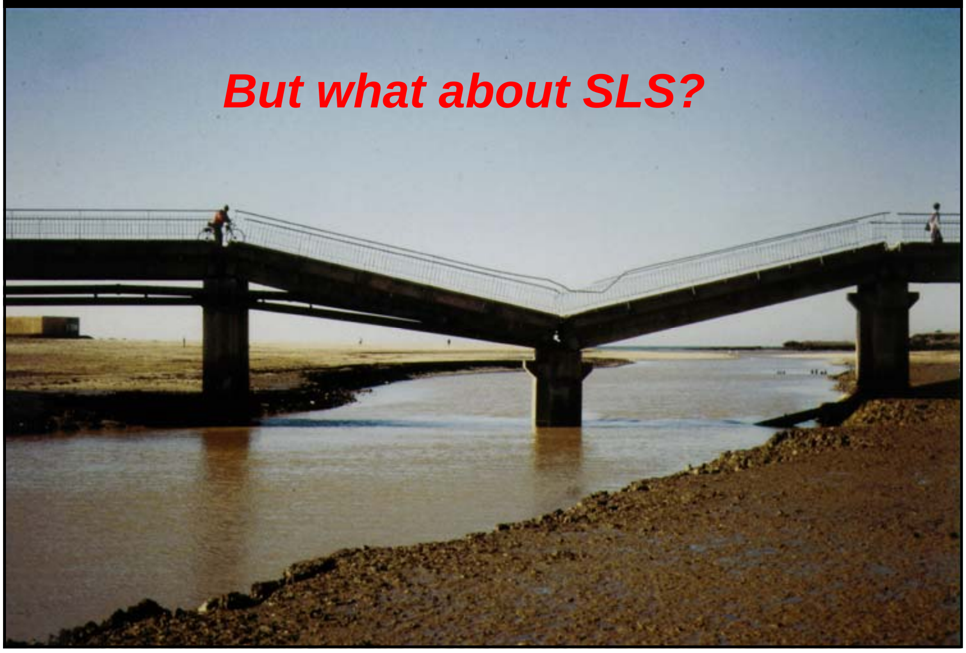
M_{ULS} = 250 kNm

Apply DA1-1 ULS loads

M_{ULS} = 326 kNm

The final design must satisfy all the criteria

Rupture du sol sans instabilité géométrique (grand déplacement)



Serviceability limit states in Section 2

2.4.8 Serviceability limit states

(1)P Verification for serviceability limit states in the ground or in a structural section, element or connection, shall either require that:

$$E_d \leq C_d, \qquad (2.10)$$

or be done through the method given in 2.4.8(4).

(2) Values of partial factors for serviceability limit states should normally be taken equal to 1,0.

NOTE The values of the partial factors may be set by the National annex.

2.4.9 Limiting values for movements of foundations

(1)P In foundation design, limiting values shall be established for the foundation movements.

(3)P The amount of permitted foundation movement shall be selected during the design.

NOTE Permitted foundation movements may be set by the National annex.

Serviceability limit states in Section 6

6.6.1 General

(1)P Account shall be taken of displacements caused by actions on the foundation, such as those listed in 2.4.2(4).

(2)P In assessing the magnitude of foundation displacements, account shall be taken of comparable experience, as defined in 1.5.2.2. If necessary, calculations of displacements shall also be carried out.

(3)P For soft clays, settlement calculations shall always be carried out.

(4) For spread foundations on stiff and firm clays in Geotechnical Categories 2 and 3, calculations of vertical displacement (settlement) should usually be undertaken. Methods that may be used to calculate settlements caused by loads on the foundation are given in 6.6.2.

(5)P The serviceability limit state design loads shall be used when calculating foundation displacements for comparison with serviceability criteria.

(6) Calculations of settlements should not be regarded as accurate. They merely provide an approximate indication.

(7)P Foundation displacements shall be considered both in terms of displacement of the entire foundation and differential displacements of parts of the foundation.

Serviceability limit states in Section 6

6.6.2 Settlement

(1)P Calculations of settlements shall include both immediate and delayed settlement.

(2) The following three components of settlement should be considered for partially or fully saturated soils:

— s_0: immediate settlement; for fully-saturated soil due to shear deformation at constant volume, and for partially-saturated soil due to both shear deformation and volume reduction;

— s_1: settlement caused by consolidation;

— s_2: settlement caused by creep.

(16) For conventional structures founded on clays, the ratio of the bearing capacity of the ground, at its initial undrained shear strength, to the applied serviceability loading should be calculated (see 2.4.8(4)). If this ratio is less than 3, calculations of settlements should always be undertaken. If the ratio is less than 2, the calculations should take account of non-linear stiffness effects in the ground.

Serviceability limit states in Section 9

9.8 Serviceability limit state design

9.8.1 General

(1)P The design of retaining structures shall be checked at the serviceability limit state using the appropriate design situations as specified in 9.3.3.

(5) The design values of earth pressures should be derived taking account of the allowable deformation of the structure at its serviceability limit state. These pressures may not necessarily be limiting values.

Serviceability limit states in Section 9

9.8.2 Displacements

(1)P Limiting values for the allowable displacements of walls and the ground adjacent to them shall be established in accordance with 2.4.8, taking into account the tolerance to displacements of supported structures and services.

(2)P A cautious estimate of the distortion and displacement of retaining walls, and the effects on supported structures and services, shall always be made on the basis of comparable experience. This estimate shall include the effects of construction of the wall. The design may be justified by checking that the estimated displacements do not exceed the limiting values.

(3)P If the initial cautious estimate of displacement exceeds the limiting values, the design shall be justified by a more detailed investigation including displacement calculations.

(5)P A more detailed investigation, including displacement calculations, shall be undertaken in the following situations:

— where nearby structures and services are unusually sensitive to displacement;
— where comparable experience is not well established.

(6) Displacement calculations should also be considered in the following cases:

— where the wall retains more than 6 m of cohesive soil of low plasticity,
— where the wall retains more than 3 m of soils of high plasticity;
— where the wall is supported by soft clay within its height or beneath its base.

NATIONAL ANNEX

Draft UK National Annex to Eurocode 7:

Geotechnical design –

Part 1: General rules

NA.1 Scope

NA.2 Nationally Determined Parameters

NA.3 Decisions on the status of informative annexes

NA.4 References to non-contradictory complementary information

Bibliography

Annex A (informative)
Design Approach and values of partial, correlation and model factors for ultimate limit states to be used in conjunction with BS EN 1997-1:2004

NA.3 Decisions on the status of informative annexes

EC7 Annex	Title	Comments in UK National Annex
A	Partial and correlation factors for ultimate limit states and recommended values	Recommended values adopted except for piling
B	Background information on partial factors for Design Approaches 1, 2 and 3	May be used, but only DA1 relevant to UK
C	Sample procedures to determine limit values of earth pressures on vertical walls	May be used, with clarification/correction
D	A sample analytical method for bearing resistance calculation	May be used, mentioning need for depth factors
E	A sample semi-empirical method for bearing resistance estimation	May be used
F	Sample methods for settlement evaluation	May be used
G	A sample method for deriving presumed bearing resistance for spread foundations on rock	May be used
H	Limiting values of structural deformation and foundation movement	May be used, noting that relates mainly to buildings
J	Checklist for construction supervision and performance monitoring	May be used

NA.4 References to non-contradictory complementary information (NCCI)

The following is a list of references that contain non-contradictory complementary information for use with BS EN 1997-1:2004.

- BS 1377;
- BS 5930;
- BS 6031;
- BS 8002;
- BS 8004;
- BS 8008;
- BS 8081;
- PD 6694-1[1];
- CIRIA C580 [2];
- UK Design Manual for Roads and Bridges [3].

Design aspects of some of these, or parts of them, might be in conflict with the design principles in BS EN 1997-1:2004. Until such time as "residual" documents are prepared to remove such conflicts and in the event that use of these documents presents a conflict, the Eurocode takes precedence.

EN 1997-1 Geotechnical Design does not cover the design and execution of reinforced soil structures. In the UK, the design and execution of reinforced fill structures and soil nailing should be carried out in accordance with BS 8006 , BS EN 14475 and prEN 14490[2]. The partial factors set out in BS 8006 should not be replaced by similar factors from Eurocode 7.

Annex A (informative)
Design Approach and values of partial, correlation and model factors for ultimate limit states to be used in conjunction with BS EN 1997-1:2007

Values of partial factors recommended in EN1997-1 Annex A

			Design approach 1										
			Combination 1			Combination 2			Combination 2 - piles & anchors				
			A1	M1	R1	A2	M2	R1	A2	M1 or … M2	R4		
Actions	Permanent	unfav	1,35										
		fav											
	Variable	unfav	1,5			1,3			1,3				
Soil	tan φ'						1,25			1,25			
	Effective cohesion						1,25			1,25			
	Undrained strength						1,4			1,4			
	Unconfined strength						1,4			1,4			
	Weight density												
Spread footings	Bearing												
	Sliding												
Driven piles	Base											1.7/1.5	1,3
	Shaft (compression)											1.5/1.3	1,3
	Total/combined											1.7/1.5	1,3
	Shaft in tension											2.0/1.7	1.6
Bored piles	Base											2.0/1.7	1,6
	Shaft (compression)											1.6/1.4	1,3
	Total/combined											2.0/1.7	1.5
	Shaft in tension											2.0/1.7	1.6
CFA piles	Base											As	1.45
	Shaft (compression)											for	1.3
	Total/combined											bored	1.4
	Shaft in tension											piles	1.6
Anchors	Temporary											1,1	1,1
	Permanent											1,1	1,1
Retaining walls	Bearing capacity												
	Sliding resistance												
	Earth resistance												
Slopes	Earth resistance												

EC7 values

indicates partial factor = 1.0

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A.3 Partial factors for Structural (STR) and Geotechnical (GEO) limit states verification

A.3.1 Partial factors on actions (γ_F) or the effects of actions (γ_E)

Table A.NA.3 – Partial Factors on actions (γ_F) or the effects of actions (γ_E) for the Structural (STR) and Geotechnical (GEO) limit states

Structure type	Value	
	Set A1	Set A2
Buildings	See Table NA.A1.2(B) in the National Annex to BS EN 1990:2002	See Table NA.A1.2(C) in the National Annex to BS EN 1990:2002
Bridges	See Table NA.A2.4(B) in the National Annex to BS EN 1990:2002	See Table NA.A2.4(C) in the National Annex to BS EN 1990:2002

The partial factors specified in the National Annex to BS EN 1990:2002 might not be appropriate for self-weight of water, ground-water pressure and other actions dependent on the level of water, see **2.4.7.3.2**(2). The design value of such actions may be directly assessed in accordance with **2.4.6.1**(2)P and **2.4.6.1**(6)P of BS EN 1997-1:2004. Alternatively, a safety margin may be applied to the characteristic water level, see **2.4.6.1**(8) of BS EN 1997-1:2004.

NCCI, PDs, Residual Documents and BSs

- **CEN requires that conflicting national standards are withdrawn by 2010.**
- **"Published Documents" – BSI documents with do not have the status of a BS but provide NCCI.**
- **PD 6694-1, Recommendations for the design of structures subject to traffic loading to BS EN 1997-1**
  - Out for public comment shortly
- **Where does this leave other BS's?**
  - BS8002, BS8004 – need PDs as Residual Documents
  - BS8006 – independent
  - BS8081 – unchanged for the time being
  - BS6031 – being revised – possible EN to be drafted.