EC7 pile design - TC250/SC7

Evolution Group 7 - FPS/AGS Mirror Group

Meeting 10am Tuesday 20th December 2011

TC250/SC7 Evolution Group 7

- EC Mandate M/466 EN 19th May 2010

- New Eurocodes
- Further Development of existing Eurocodes:
  - Assess existing Eurocodes to reduce the number of Nationally determined parameters
  - Simplify rules where relevant for limited and well identified field of application

TC250/SC7 Evolution Group 7

- Members:
  - AB, Christian Moormann (Germany)
  - Panicos Papadopoulos (Cyprus)
  - Arne Schram Simonsen (Norway)
  - Chris Raison (UK)
  - Sébastien Burlon and Roger Frank (France)
  - Gary Axelsson (Sweden)
  - Boleslaw Klosinski and Kazimierz Gwizdala (Poland)
  - Alessandro Mandolini (Italy)
  - Jan Kos (Czech Republic)
  - Vassilios Papadopoulos (Greece)
  - Leoncio Prieto (Spain)

EG7 FPS/AGS Mirror Group

- Members:
  - Bob Handley – Aarsleff Piling
  - David Preece – Bachy Soletanche Ltd
  - Tony Suckling – Balfour Beatty Ground Engineering
  - Mark Pennington – Balfour Beatty Ground Engineering
  - David Beadman – Byrne Looby
  - Alan Willoner – Carillion
  - Dimitrios Selemetas – Cementation Skanska
  - Derek Egan – Keller Foundations
- In the Loop
  - Andrew Bond – Chairman TC250/SC7 (Eurocode 7 committee)
  - Brian Simpson – Arup
  - Dianne Jennings – Federation of Piling Specialists

Geotechnical Design to EC7

- Section 2.1 - Limit states to be verified by:

- Calculation
- Prescriptive Methods
- Experimental Models and Load Tests
- Observational Method

Section 2.4 – Design By Calculation

- Actions
- Ground Properties
- Geometrical Data
- Characteristic Parameters
- Design Values – (Partial Factors)
- Ultimate Limit States (ULS)
- Design Approach 1, 2 and 3
- Serviceability Limit States (SLS)

Limit States

- EQU – Equilibrium
- STR – Failure in the Structure
- GEO – Failure in the ground
- UPL – Uplift
- HYD – Hydraulic heave

- STR & GEO most relevant to pile foundations

Section 2.4.7.3.4 – Design Approach

- DA1
  - Original proposal with two sets of calculations
  - Action & Material Factors
  - Exception for pile design and ground anchorages
    - Apply to resistances as an alternative to soil strength
- DA2
  - Single calculation
- DA3
  - Single calculation

Section 2.4.7.3.4 – Design Approach

- DA1 – Two Calculations:
  - 1 A1 + M1 + R1
  - 2 A2 + M2/M1 + R4
    (Use M1 for calculating resistance)
    (Use M2 for unfavourable actions such as NSF)
- DA2 – Single Calculation:
  A1 + M1 + R2
- DA3 – Single Calculation:
  A1/A2 + M2 + R3
  (A1 structural or A2 geotechnical actions)

Section 7 - Pile Foundations

Section 7.2 – Limit States

- EQU – Equilibrium
- STR – Failure in the Structure
- GEO – Failure in the ground
- UPL – Uplift
- HYD – Hydraulic heave

- STR & GEO most relevant to pile foundations

- Section lists a significant number of options

Section 7.3 – Actions

- Axial Loads – Compression and tension
- Transverse Loads
- Ground Displacement
  - Negative Shaft Friction
  - Ground heave
  - Lateral Soil Movement – (eg. Slopes or Abutment Loads)

Section 7.4 – Design methods

- Static Load Tests
- Empirical Methods
- Calculation
- Dynamic Load Tests
- Observed performance

Section 7.6.2 – Compressive Ground Resistance

- Static Load Tests
- Ground Test Results
  - [includes alternative calculation method]
- Dynamic Impact Tests
- Pile Driving Formulae
- Wave Equation Analysis

- Why not include calculation (from insitu and laboratory test results) as a separate option?

Section 7.6.3 – Tensile Ground Resistance

- Static Load Tests
- Ground Test Results
  - [includes alternative calculation method]

- Why not include calculation (from insitu and laboratory test results) as a separate option?

Section 7.7 – Transversely Loaded Piles

- Load Tests
- Ground Test Results
  - Includes beam on springs type of analysis
  - ALP or WALLAP

- Here the calculation method appears to be more acceptable

Section 7.8 – Structural Design of Piles

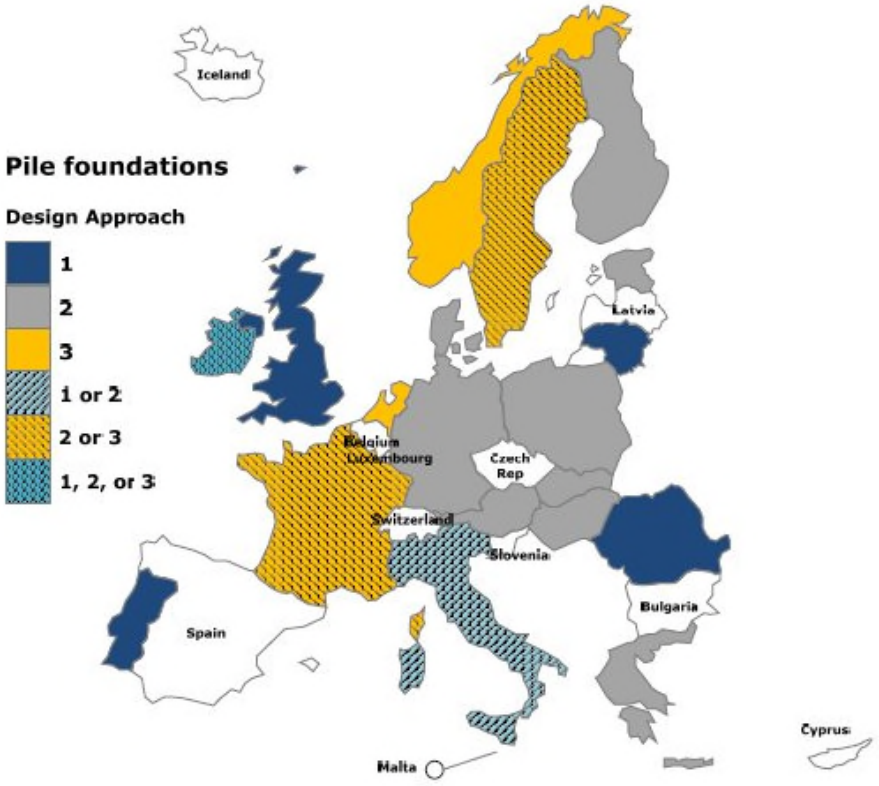
- Interface with EC2 and EC3
- Is EC2 a Problem?
- Should EC7 include rules rather than EC2?

UK National Annex to BS EN 1997-1:2004

Section 2.4.7.3.4 – Design Approach

- DA1 – Two Calculations:
  - 1 A1 + M1 + R1
  - 2 A2 + M2/M1 + R4
    (Use M1 for calculating resistance)
    (Use M2 for unfavourable actions such as NSF)
- DA2 – Single Calculation:
  A1 + M1 + R2
- DA3 – Single Calculation:
  A1/A2 + M2 + R3
  (A1 structural or A2 geotechnical actions)

Section 2.4.7.3.4 – Design Approach



Design Approaches allowed		
DA1	DA2	DA3
IRL ITA LTU PRT ROM UK (6)	AUT, EST, FIN, FRA, DEU, GRC, HUN, IRL, ITA, POL, SVK, SWE ~~(12)~~ (13)	DNK, ~~FRA,~~ IRL, NLD, NOR, SWE ~~(6)~~ (4)

Based on Bond (2010) - Note that the slide is not completely accurate. Norway Should be included in DA2 not DA3. France is just DA2

Partial Factors on Actions or the Effect of Actions

Action		EC7 Factor Set		UK NA Factor Set	
		A1	A2	A1	A2
Permanent	Unfavourable	1.35	1.0	1.35	1.0
	Favourable	1.0	1.0	1.0	1.0
Variable	Unfavourable	1.5	1.3	1.5	1.3
	Favourable	0	0	0	0

Main differences relate to:

1. Use of combination factors for actions that can exist simultaneously.
2. Factors for bridges are more extensive.
3. Basic factors for buildings remain unchanged.

Partial Factors on Soil Parameters

Action	EC7 Factor Set		UK NA Factor Set	
	M1	M2	M1	M2
Friction Angle tan ϕ’	1.0	1.25	1.0	1.25
Effective Cohesion c’	1.0	1.25	1.0	1.25
Undrained Shear Strength Cu	1.0	1.4	1.0	1.4
Unconfined Strength UCS	1.0	1.4	1.0	1.4
Unit Weight γ	1.0	1.0		

Only difference relates to unit weight; other factors remain unchanged.

Partial Resistance Factors for Driven Piles

Action	EC7 Factor Set				UK NA Factor Set		
	R1	R2	R3	R4	R1	R4 (No SLS)	R4 (SLS)
Base	1.0	1.1	1.0	1.3	1.0	1.7	1.5
Shaft	1.0	1.1	1.0	1.3	1.0	1.5	1.3
Total	1.0	1.1	1.0	1.3	1.0	1.7	1.5
Tension	1.25	1.15	1.1	1.6	1.0	2.0	1.7

Main differences for resistance factors relate to:

1. Factor set R4 where different values depend on whether SLS behaviour is verified or not (test or calculation).
2. Model factor to be applied to ground properties to derive characteristic values.
3. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance.
4. Factor set R2 used for Design Approach 2 (not adopted by the UK).
5. Factor set R3 used for Design Approach 3 (not adopted by the UK).

Partial Resistance Factors for Bored Piles

Action	EC7 Factor Set				UK NA Factor Set		
	R1	R2	R3	R4	R1	R4 (No SLS)	R4 (SLS)
Base	1.25	1.1	1.0	1.6	1.0	2.0	1.7
Shaft	1.0	1.1	1.0	1.3	1.0	1.6	1.4
Total	1.15	1.1	1.0	1.5	1.0	2.0	1.7
Tension	1.25	1.15	1.1	1.6	1.0	2.0	1.7

Main differences for resistance factors relate to:

1. Factor set R4 where different values depend on whether SLS behaviour is verified or not (test or calculation).
2. Factor set R1 adopted for UK (Presumably to cater for additional model factor).
3. Model factor to be applied to ground properties to derive characteristic values.
4. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance.
5. Factor set R2 used for Design Approach 2 (not adopted by the UK).
6. Factor set R3 used for Design Approach 3 (not adopted by the UK).

Partial Resistance Factors for Cfa Piles

Action	EC7 Factor Set				UK NA Factor Set		
	R1	R2	R3	R4	R1	R4 (No SLS)	R4 (SLS)
Base	1.1	1.1	1.0	1.45	1.0	2.0	1.7
Shaft	1.0	1.1	1.0	1.3	1.0	1.6	1.4
Total	1.1	1.1	1.0	1.4	1.0	2.0	1.7
Tension	1.25	1.15	1.1	1.6	1.0	2.0	1.7

Main differences for resistance factors relate to:

1. Factor set R4 where different values depend on whether SLS behaviour is verified or not (test or calculation).
2. Factor set R1 adopted for UK (Presumably to cater for additional model factor).
3. Model factor to be applied to ground properties to derive characteristic values.
4. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance.
5. Factor set R2 used for Design Approach 2 (not adopted by the UK).
6. Factor set R3 used for Design Approach 3 (not adopted by the UK).

Example Bearing Capacity – No SLS Check

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EC7 Pile Design - TC250/SC7
Evolution Group 7 - FPS/AGS Mirror Group
GE Example 1 - No SLS check

Job No.	Sheet No.	Rev.
C11/		

Drg. Ref.

Made by CAR Date 19-Dec-11 Data GE_EX1.KPL Checked

PILE BEARING CAPACITY

Pile System Rotary auger bored Diameter 1000 mm

Soil Description	Top Level (mOD)	Soil Type	Shaft Stress Top (kPa)	Shaft Stress Base (kPa)	Shaft Friction (kN)
Stiff to very stiff CLAY	0	Undrained	30	137	8077
Very stiff CLAY	-35.00	Undrained			

Pile Toe Level	-30.70	mOD	NEGATIVE SHAFT FRICTION	0	kN
Base stress	2474	kPa	SHAFT CAPACITY	8077	kN
			END BEARING CAPACITY	1943	kN
			ULTIMATE CAPACITY	10020	kN

No maintained load test

EC7 Model Factor 1.4

Characteristic Shaft Resistance Rsk	5769	kN
Characteristic End Bearing Resistance Rbk	1388	kN
Characteristic Pile Resistance Rk	7157	kN

No verification of settlement

EC7 Resistance Factors

Shaft Factor	1.6
End Bearing Factor	2.0
Shaft Tension Factor	2.0

UK National Annex to EC7 Factor Set R4

EC7 DESIGN RESISTANCE Rcd	4300	kN
EC7 DESIGN TENSION RESISTANCE Rtd	2885	kN
PILE LENGTH	30.70	m

Example Bearing Capacity – SLS Check

TC250/SC7
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EC7 Pile Design - TC250/SC7
Evolution Group 7 - FPS/AGS Mirror Group
GE Example 1 - SLS check

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C11/		

Drg. Ref.

Made by CAR Date 19-Dec-11 Data GE_EX2.KPL Checked

PILE BEARING CAPACITY

Pile System Rotary auger bored Diameter 1000 mm

Soil Description	Top Level (mOD)	Soil Type	Shaft Stress Top (kPa)	Shaft Stress Base (kPa)	Shaft Friction (kN)
Stiff to very stiff CLAY	0	Undrained	30	128	6939
Very stiff CLAY	-35.00	Undrained			

Pile Toe Level	-27.97	mOD	NEGATIVE SHAFT FRICTION	0 kN
Base stress	2302	kPa	SHAFT CAPACITY	6939 kN
			END BEARING CAPACITY	1808 kN
			ULTIMATE CAPACITY	8747 kN

No maintained load test

EC7 Model Factor	1.4
Characteristic Shaft Resistance Rsk	4956 kN
Characteristic End Bearing Resistance Rbk	1291 kN
Characteristic Pile Resistance Rk	6248 kN

Settlement verified by load test

EC7 Resistance Factors

Shaft Factor	1.4
End Bearing Factor	1.7
Shaft Tension Factor	1.7

UK National
Annex to EC7
Factor Set R4

EC7 DESIGN RESISTANCE Rcd	4300 kN
EC7 DESIGN TENSION RESISTANCE Rtd	2915 kN
PILE LENGTH	27.97 m

Example Bearing Capacity – ULS & SLS Check

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EC7 Pile Design - TC250/SC7
Evolution Group 7 - FPS/AGS Mirror Group
GE Example 1 - ULS & SLS check

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Drg. Ref.

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PILE BEARING CAPACITY

Pile System Rotary auger bored Diameter 1000 mm

Soil Description	Top Level (mOD)	Soil Type	Shaft Stress Top (kPa)	Shaft Stress Base (kPa)	Shaft Friction (kN)
Stiff to very stiff CLAY	0	Undrained	30	118	5849
Very stiff CLAY	-35.00	Undrained			

Pile Toe Level	-25.15	mOD	NEGATIVE SHAFT FRICTION	0	kN
Base stress	2124	kPa	SHAFT CAPACITY	5849	kN
			END BEARING CAPACITY	1669	kN
			ULTIMATE CAPACITY	7518	kN

Maintained load test to ultimate capacity — EC7 Model Factor 1.2

Characteristic Shaft Resistance Rsk	4874	kN
Characteristic End Bearing Resistance Rbk	1390	kN
Characteristic Pile Resistance Rk	6265	kN

Settlement verified by load test

EC7 Resistance Factors

Shaft Factor	1.4
End Bearing Factor	1.7
Shaft Tension Factor	1.7

UK National Annex to EC7 Factor Set R4

EC7 DESIGN RESISTANCE Rcd	4300	kN
EC7 DESIGN TENSION RESISTANCE Rtd	2867	kN
PILE LENGTH	25.15	m

Discussion & Feedback 1

- How is EC7 Pile Design Actually Done?
- Is the UK Fixed on DA1 for Pile Design?
  - Two Combinations to Consider
  - Strength Factors or Resistance Factors?
  - Compatibility with Structural Design
- Should EC7 be Revised to Include the NA Factors?
- Is Design by Calculation Already Covered by 7.6.2.3?

Discussion & Feedback 2

- Where Are the Problems?
  - Are the Model Factors Correct?
  - Are the Partial Factors Acceptable?
  - Are Designs Compatible with BS 8004?
  - How is Negative Shaft Friction Included?
  - How is Ground Heave Included?
  - Is There a Better Way?

Discussion & Feedback 3

- Transverse Loading?
  - Resistance Factor or Factors on Strength?
  - SLS or ULS?
  - Horizontal Loads from the Ground?
- Piled Retaining Walls
  - Include Some Detail in Piling Section?
  - Any Particular Issues?
- Structural Design
  - Problems with EC2 or Not?
  - Should EC7 Include Structural Design?

Discussion & Feedback 4

- Other Limit States EQU, UPL and HYD
  - Importance for Pile Design
  - UPL and Resistance
- Informative Appendices
  - Too Much Guidance?
  - Include Pile Design?
- Other Issues