Pile Design to BS EN 1997-1:2004 (EC7) and the National Annex

Chris Raison BEng MSc CEng MICE MASCE
Raison Foster Associates

- Tel: 024 7669 1925
- Mob: 07974 005990
- E-Mail: chris@raisonfoster.co.uk
- Address: 7 Warwick Street
  Coventry
  CV5 6ET
- Web Site: www.raisonfosterassociates.co.uk

Traditional Pile Design to BS 8004

- Ultimate capacity based on calculation
- Factor of Safety varied between 2.0 and 3.0 for compression loads and ≥ 3.0 for tension
- Actual FoS dependent on quality of GI, prior knowledge of ground conditions and whether preliminary non-working load tests or contract proof load tests were carried out

$$\text{Applied Load} \leq \frac{\text{Ultimate Capacity}}{\text{FoS}}$$

Traditional Pile Design to BS 8004

- Basic calculation methods have not changed

Ultimate Capacity $Q_{ult} = Q_s + Q_b$

Shaft Capacity $Q_s = q_s A_s$

Base Capacity $Q_b = q_b A_b$

Pile Design to EC7

- So what is different?
- EC7 method is a Limit State Design method:
  - Ultimate Limit State (ULS)
    - States associated with collapse, structural failure, excessive deformation or loss of stability of the whole of the structure or any part of it
  - Serviceability Limit State (SLS)
    - States that correspond to conditions beyond which specified service requirements are no longer met

Pile Design to EC7

- Separation of ULS and SLS condition
- Permanent and variable actions
- Favourable and unfavourable actions
- Use of characteristic ground properties
- Use of several partial factors
- Partial factors avoid failure but not necessarily movement

EC7 Limit States

- EC7 Adopts five distinct ultimate limit states:
  - EQU – Loss of equilibrium (tilt or rotation)
  - STR – Internal failure or excessive deformation
    [Strength of structural material is significant]
  - GEO – Failure or excessive deformation of the ground
    [Strength of soil or rock is significant]
  - UPL – Uplift or buoyancy
  - HYD – Hydraulic heave, erosion or piping
- STR and GEO most important for pile design

Pile Design to EC7

- Basic inequality to be checked:

$$E_d \leq R_d$$

- E_d is the design value of the effect of all the actions
- R_d is the design value of the corresponding resistance of the ground or structure
- For pile design, this inequality compares the design action F_d (usually load) against the design resistance R_d

$$F_d \leq R_d$$

Effect of Actions E_d

- E_d is the design value of the effect of all the actions:

$$E_d = E\left\{\gamma_F F_{rep} \quad \frac{X_k}{\gamma_m} \quad a_d\right\}$$

- F_{rep} is the representative action (usually load)
- X_k is the characteristic value of the material property
- a_d is the design value of a geometrical property
- γ_F and γ_m are relevant partial factors

Effect of Actions E_d

- Design values:

$$F_d = \gamma_F F_{rep} \qquad X_d = \frac{X_k}{\gamma_m} \qquad a_d = a_{nom} \mp \Delta a$$

- F_{rep} is the representative action (usually load)
- X_k is the characteristic value of the material property
- a_d is the design value of a geometrical property
- γ_F and γ_m are relevant partial factors

UK National Annex

- UK has adopted Design Approach 1 - DA1
- This requires two calculations:
  - A1 + R1 + M1 Combination 1
  - R4 + A2 + M1/M2 Combination 2

  (Use M1 for calculating resistances and M2 for unfavourable actions such as NSF)
- For Combination 1, partial factors > 1.0 are applied to the actions only - this does not usually control pile length
- For Combination 2, partial factors > 1.0 are applied to resistances with smaller factors applied to variable actions

Design Actions F_d

- F_d is the design action

$$F_d = \gamma_F F_{rep}$$

- F_{rep} is the representative action (usually load)

$$F_{rep} = G_k + \psi Q_k + A_k$$

$$\psi = 1.0 \text{ for leading action or } = \psi_0, \psi_1 \text{ or } \psi_2$$

  - G_k is the characteristic permanent action
  - Q_k is the characteristic variable action
  - A_k is the characteristic accidental action
  - ψ is the factor for combination of variable actions

Partial Factors on Actions

Action		UK NA Factor Set		EC7 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

Notes:

1. Factors can be applied to Actions or the Effect of Actions.
2. Factors given above are for buildings which remain unchanged from EC7 values
3. Combination factors for actions that can exist simultaneously are given in the UK NA to BS EN 1990.
4. There are a wider range of factors for bridges.

Ground Characterisation

- EC7 says a lot about determining characteristic or representative soil properties
- Cautious estimate affecting the occurrence of the limit state
  - Similar to BS 8002 and CIRIA 104
  - Most engineers already adopt cautious estimates
  - Engineering judgement required
  - Statistics can be applied, but is difficult because of the usual limited number of samples and test data
  - For pile design, not a great deal of difference between soil parameters for EC7 design compared to BS 8004 design

Design Soil Parameters

- Design values obtained by dividing the characteristic or representative property by a partial factor

$$X_d = \frac{X_k}{\gamma_m}$$

- Usual properties to be factored are strength [but stiffness may need to be factored for horizontal load design]
- Either effective stress strength, c' and ϕ', or undrained shear strength c_u, or unconfined compressive strength UCS for rocks
- For pile design to the UK National Annex, factored design soil parameters are not used except for negative shaft friction

Partial Factors on Soil Parameters

Soil Property	UK NA Factor Set		EC7 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

UK NA gives no factor for unit weight so presume 1.0; other factors remain unchanged.

For pile design to the UK National Annex, factored design soil parameters are not used except for negative shaft friction

Pile Design to EC7 Based on Resistances

- For pile design, it is necessary to compare the design action F_d (usually load) against the design resistance R_d

$$F_d \leq R_d$$

- But note that this is now in terms of compression or tension load and compression or tension resistance:

$$F_{c;d} \leq R_{c;d} \qquad F_{t;d} \leq R_{t;d}$$

- As is usual, the design resistance $R_{c;d}$ can be assumed to be the sum of the end bearing and shaft design resistances:

$$R_{c;d} = R_{b;d} + R_{s;d}$$

Pile Design to EC7 Based on Resistances

- The design resistances $R_{c;d}$ or $R_{t;d}$ are obtained from the characteristic end bearing and shaft friction by using partial resistance factors

$$R_{c;d} = \left[\frac{R_{b;k}}{\gamma_b} + \frac{R_{s;k}}{\gamma_s}\right] \text{ or } \left[\frac{R_{c;k}}{\gamma_t}\right] \qquad R_{c;k} = R_{b;k} + R_{s;k}$$

Pile Design to EC7 Based on Resistances

- The characteristic end bearing and shaft friction can be computed using existing and recognisable methods either by:
  - Calculation
  - Static load testing
  - Dynamic load testing
  - Correlation with CPT or other insitu ground testing
  - Design charts based on experience
    (e.g. EA-Pfähle used in Germany)

Pile Design by Calculation

- The characteristic base resistance and shaft resistance can be calculated from the characteristic end bearing and shaft friction stresses as follows:

$$R_{b;k} = \frac{A_b \; q_{b;k}}{\gamma_{Rd}} \qquad R_{s;k} = \frac{\sum A_{s;i} \; q_{s;i;k}}{\gamma_{Rd}}$$

- These are similar to the approach used for BS 8004 but include an additional model factor γ_{Rd} to 'correct' the partial resistance factors (applied to the characteristic resistances to obtain the design resistance $R_{c;d}$)

Pile Shaft Friction

- Effective Stress Approach – Granular

$$q_s = \sigma'_v \, k_s \, \tan\delta$$

- Total Stress Approach – Cohesive or Rock (Weak Mudstone)

$$q_s = \alpha \, c_u$$

- Beta Method – Soft Soils or Chalk

$$q_s = \sigma'_v \, \beta \qquad \beta = k_s \, \tan\delta \qquad \beta = 0.45 \text{ to } 0.80 \text{ for Chalk}$$

- UCS Method – Sandstone, Limestone or Strong Mudstone

$$q_s = a \, UCS^b \qquad a = 200 \rightarrow 450 \qquad b = 0.4 \rightarrow 0.6$$

Pile End Bearing

- Effective Stress Approach – Granular

$$q_b = \sigma'_v \, N_q$$

- Total Stress Approach – Cohesive or Rock (Weak Mudstone)

$$q_b = c_u \, N_c$$

- SPT Method – Chalk

$$q_b = 200 \text{ to } 300 \text{ x SPT N}$$

- UCS Method – Sandstone, Limestone or Strong Mudstone

$$q_b = \frac{UCS}{2} N_c$$

Partial Resistance Factors

- The design resistance R_d is obtained from the characteristic end bearing and shaft friction by using partial resistance factors

$$R_{c;d} = \left[\frac{R_{b;k}}{\gamma_b} + \frac{R_{s;k}}{\gamma_s}\right] \text{ or } \left[\frac{R_{c;k}}{\gamma_t}\right]$$

- The partial resistance factors in the UK National Annex have been modified to take account of the type of pile and whether the serviceability behaviour is to be determined either by load test or a rigorous and reliable calculation

Partial Resistance Factors for Driven Piles

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

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 or directly to the calculated shaft or end bearing capacities.
3. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance (ULS check).

Partial Resistance Factors for Bored Piles

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

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 or directly to the calculated shaft or end bearing capacities.
3. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance (ULS check).

Partial Resistance Factors for Cfa Piles

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

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 or directly to the calculated shaft or end bearing capacities.
3. Model factor 1.4, but can be reduced to 1.2 if a load test is completed to calculated unfactored ultimate resistance (ULS check).

Equivalent Lumped FoS

Pile Type	Actions	Resistance Factors		Model Factor	Lumped FoS
	A2	R4 (No SLS)	R4 (SLS)		
Driven End Bearing	1.1	1.7	1.5	1.4	2.6/2.3
				1.2	2.2/2.0
Driven End & Shaft	1.1	1.7/1.5	1.5/1.3	1.4	2.5/2.0
				1.2	2.1/1.9
Bored Shaft Friction	1.1	1.6	1.4	1.4	2.5/2.2
				1.2	2.1/1.9

1. Partial factor on actions assumes 70% permanent and 30% variable.
2. British Standard BS 8004 lumped FoS ranged from 2.0 to 3.0.
3. Model factor 1.2 requires load test to be completed to unfactored ultimate resistance.
4. Lower value for resistance factors dependent on SLS behaviour being verified (by load test or reliable calculation).

Pile Design From Static Load Tests

- The design resistance $R_{c;d}$ can also be obtained directly from static load testing by applying correlation factors ξ and the same partial resistance factors γ given above

$$R_{c;d} = \left[\frac{R_{c;k}}{\gamma_t}\right]$$

- The characteristic resistance is obtained from the static load test data using the following

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;m}}{\xi_1}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;m}}{\xi_2}\right]$$

Pile Design From Static Load Tests

- Values for ξ_1 and ξ_2 depend on the number of static load tests with values decreasing as the number of load tests increases

Static Pile Load Tests (n = number of tested piles)					
ξ for n =	1	2	3	4	≥ 5
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08

For stiff & strong structures use $\frac{\xi}{1.1} \not< 1.0$ for redistribution

Pile Design From Dynamic Impact Tests

- The characteristic resistance can also be obtained from dynamic impact test data using the following similar relationship:

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;m}}{\xi_5}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;m}}{\xi_6}\right]$$

- An additional model factor γ_{Rd} is also required:
  - 0.85 when using signal matching (CAPWAP)
  - 1.10 when the test includes pile head displacement
  - 1.20 if no measurement of pile head displacement

Pile Design From Dynamic Impact Tests

- Values for ξ_5 and ξ_6 depend on the number of dynamic impact tests with values decreasing as the number of tests increases

Dynamic Impact Tests (n = number of tested piles)					
ξ for n =	≥ 2	≥ 5	≥ 10	≥ 15	≥ 20
ξ_5	1.94	1.85	1.83	1.82	1.81
ξ_6	1.90	1.76	1.70	1.67	1.66

An additional model factor γ_{Rd} is also required:

0.85 when using signal matching (CAPWAP)

1.10 when the test includes pile head displacement

1.20 if no measurement of pile head displacement

Pile Design From Ground Test Results

- The characteristic resistance can also be obtained from empirical relationships with ground test results (such as CPT) using the following similar relationship:

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } R_{c;cal}}{\xi_3}\right] \text{ or } \left[\frac{\text{Minimum } R_{c;cal}}{\xi_4}\right]$$

- Values for ξ_3 and ξ_4 depend on the number of ground test results with values decreasing as the number of profiles increases

Correlation Factors for Ground Tests

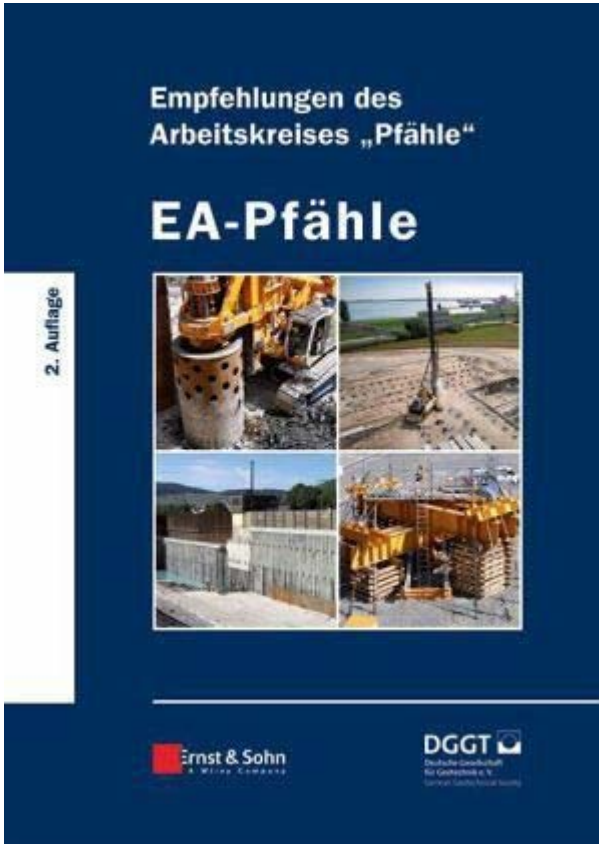
Ground Test Results (n = number of profiles)							
ξ for n =	1	2	3	4	5	7	10
ξ_3	1.55	1.47	1.42	1.38	1.36	1.33	1.30
ξ_4	1.55	1.39	1.33	1.29	1.26	1.20	1.15

For stiff & strong structures use $\frac{\xi}{1.1} \not< 1.0$ for redistribution

- EC7 requires that the method used to determine the pile characteristic resistance from ground test results should be established from pile load tests and comparable experience
- These correlation factors were intended to be used with CPT profiles or pressuremeter data
- However, EC7 includes the 'alternative procedure' or calculation method within section 7.6.2.3 covering ground test results

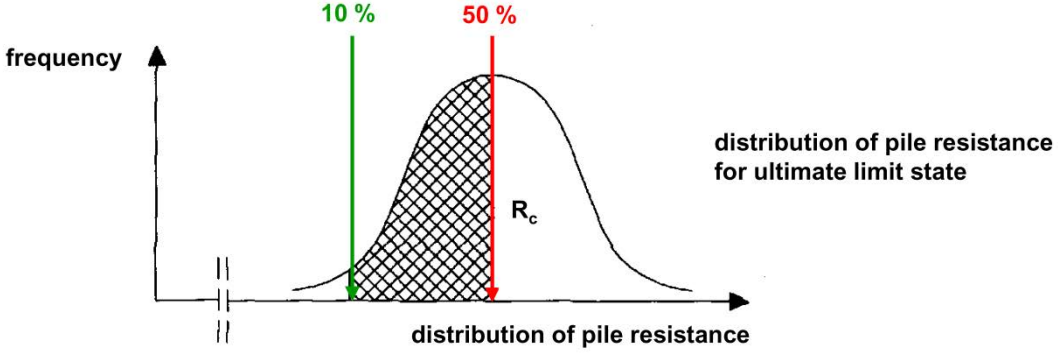
Pile Design From Design Charts [Experience]

- The characteristic resistance can also be obtained from published design charts (such as those given in EA-Pfähle used in Germany)
- Design charts based on a statistical analysis of static pile load tests



Pile Design From Design Charts [Experience]

- Tables give characteristic shaft friction and end bearing for different pile types and ground conditions correlated to CPT cone resistance or undrained shear strength
- Charts give 10% or 50% percentiles. EA-Pfähle recommends using the 10% value



Pile Design From Design Charts [Experience]

in non-cohesive soils

settlement of pile head s/D_s bzw. s/D_b	ultimate base resistance q_b [kN/m²] for a mean tip resistance q_c of a CPT [MN/m²]		
	7.5	15	25
0,02	550 – 800	1,050 – 1,400	1,750 – 2,300
0,03	700 – 1,050	1,350 – 1,800	2,250 – 2,950
0.10 (= s_g)	1,600 – 2,300	3,000 – 4,000	4,000 – 5,300
Intermediary values can be interpolated linearly. For bored piles with foot enlargement values to be reduced to 75 %.			

in non-cohesive soils

mean tip resistance q_c of a CPT [MN/m²]	ultimate skin friction $q_{s1,k}$ [kN/m²]
7,5	55 – 80
15	105 – 140
≥ 25	130 – 170
Intermediary values can be interpolated linearly.	

in cohesive soils

settlement of pile head s/D_s bzw. s/D_b	ultimate base resistance q_b [kN/m²] undrained shear strength $c_{u,k}$ [kN/m²]		
	100	150	250
0,02	350 – 450	600 – 750	950 – 1,200
0,03	450 – 550	700 – 900	1,200 – 1,450
0.10 (= s_g)	800 – 1,000	1,200 – 1,500	1,600 – 2,000
Intermediary values can be interpolated linearly. For bored piles with foot enlargement values to be reduced to 75 %.			

in cohesive soils

undrained shear strength $c_{u,k}$ [kN/m²]	ultimate skin friction $q_{s1,k}$ [kN/m²]
60	30 – 40
150	50 – 65
≥ 250	65 – 85
Intermediary values can be interpolated linearly.	

Tables 5.12 to 5.15 for Bored Piles – Recommended 10% percentiles given in green

Pile Settlement

- EC7 has been written with much more emphasis on SLS behaviour regarding pile settlement and horizontal movement
- EC7 adopts lower partial factors but on the understanding that movements are considered
- The partial resistance factors in the UK National Annex have therefore been modified to take account of the type of pile and whether the serviceability behaviour is to be determined either by load test or a rigorous and reliable calculation

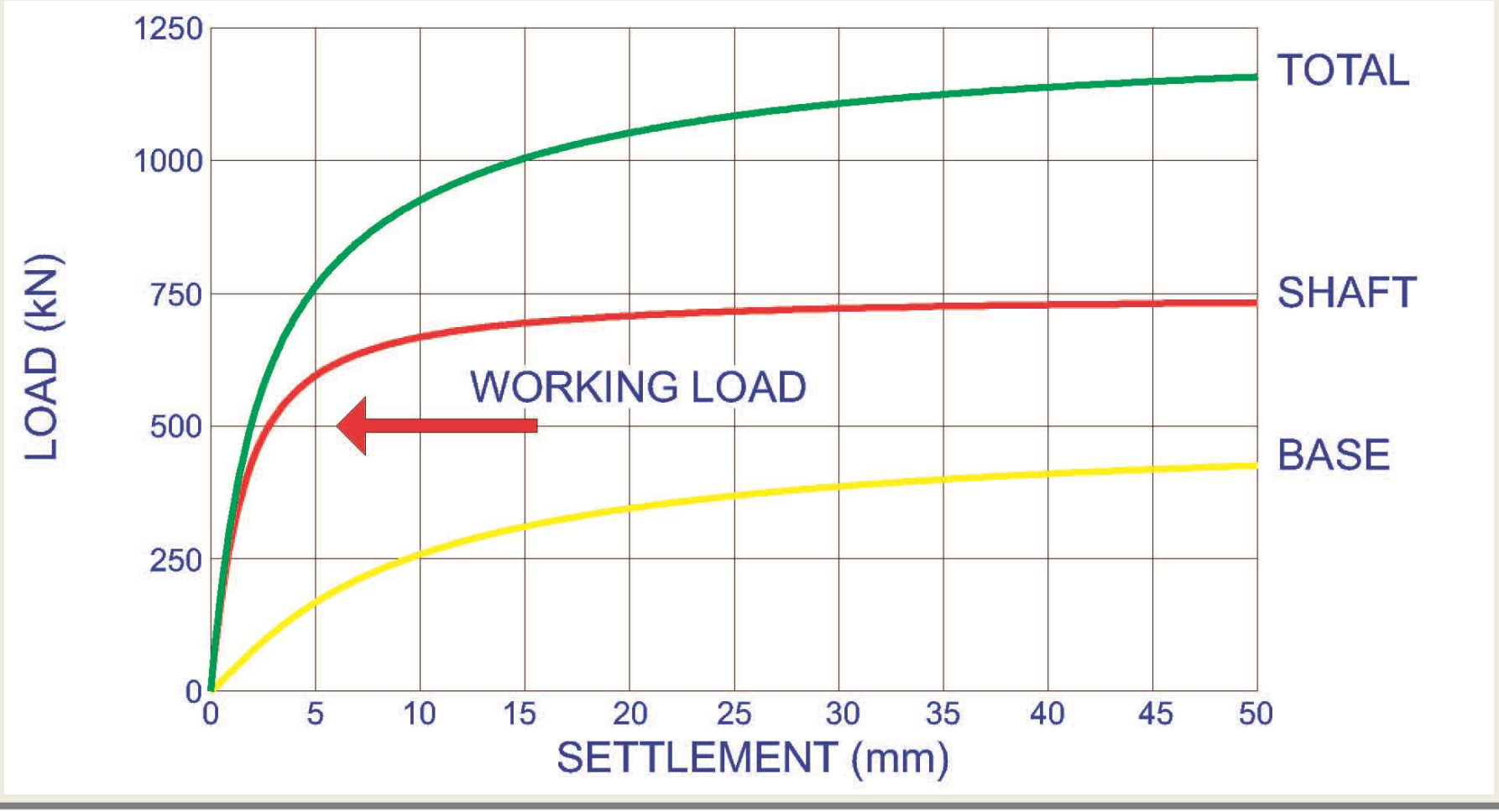
Pile Settlement

- For calculation, the emphasis here is a rigorous and reliable calculation method
- Options:
  - Empirical
  - PIGLET method
  - CEMSET method
  - Poulos Method (incorporated in Oasys PILSET/PILE)
  - Finite Element or Boundary Element methods (REPUTE)

Pile Settlement

- Empirical method: Pile settlements are dependent on the stiffness properties of the founding soil or rock, the pile geometry, and the mechanism of load transfer to the ground.
- Typically:
  - Shaft friction is mobilised at a movement equal to about 1% of the pile diameter
  - End bearing is mobilised at a movement equal to about 10% of the pile diameter
- Good for understanding behaviour but not rigorous

Pile Settlement



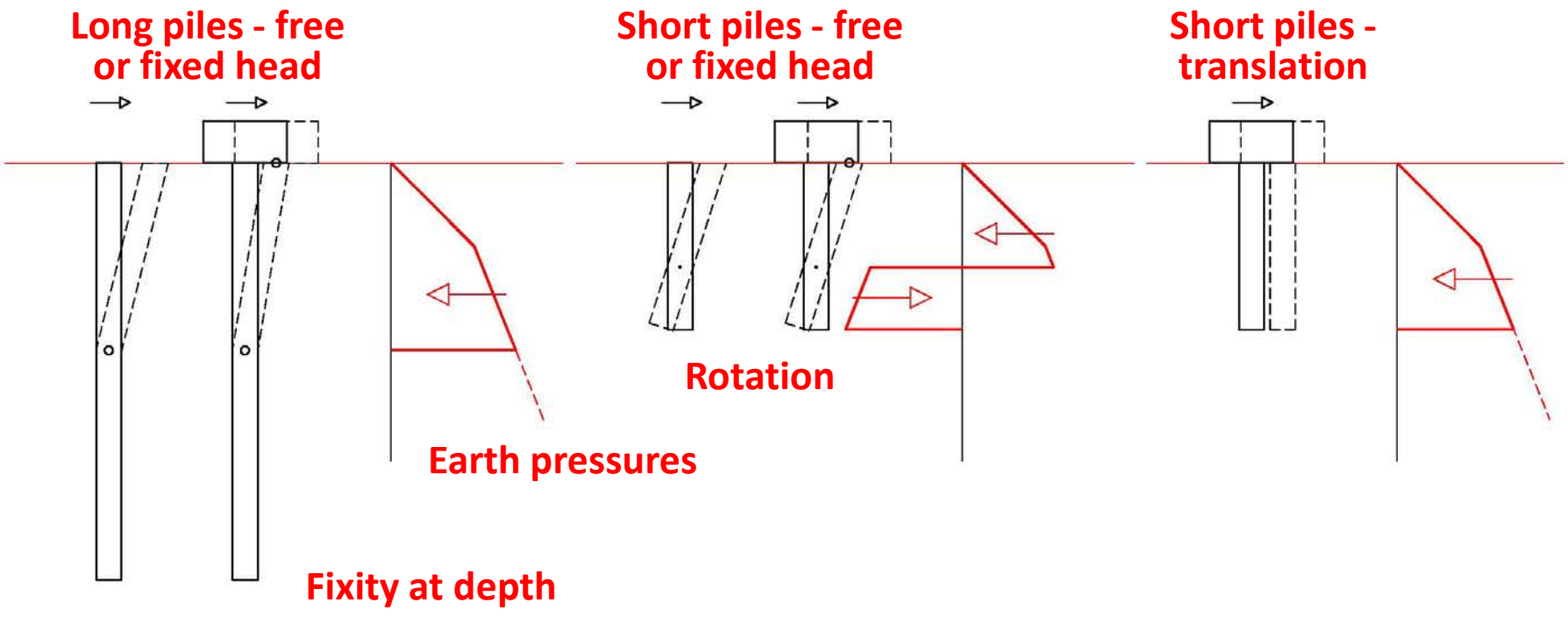
Pile Settlement

Pile Settlement

- Computational approaches for assessing pile settlements are now available for use in the commercial design office in the form of computer programs:
  - PIGLET Closed form elastic continuum equations
    Randolph (1980)
  - CEMSET Simplified hyperbolic functions for the pile base and shaft
    Fleming (1992)
  - PILSET Iterative approach based on Mindlin equations
    Poulos & Davis (1980) - Oasys Limited
  - REPUTE Based on boundary elements

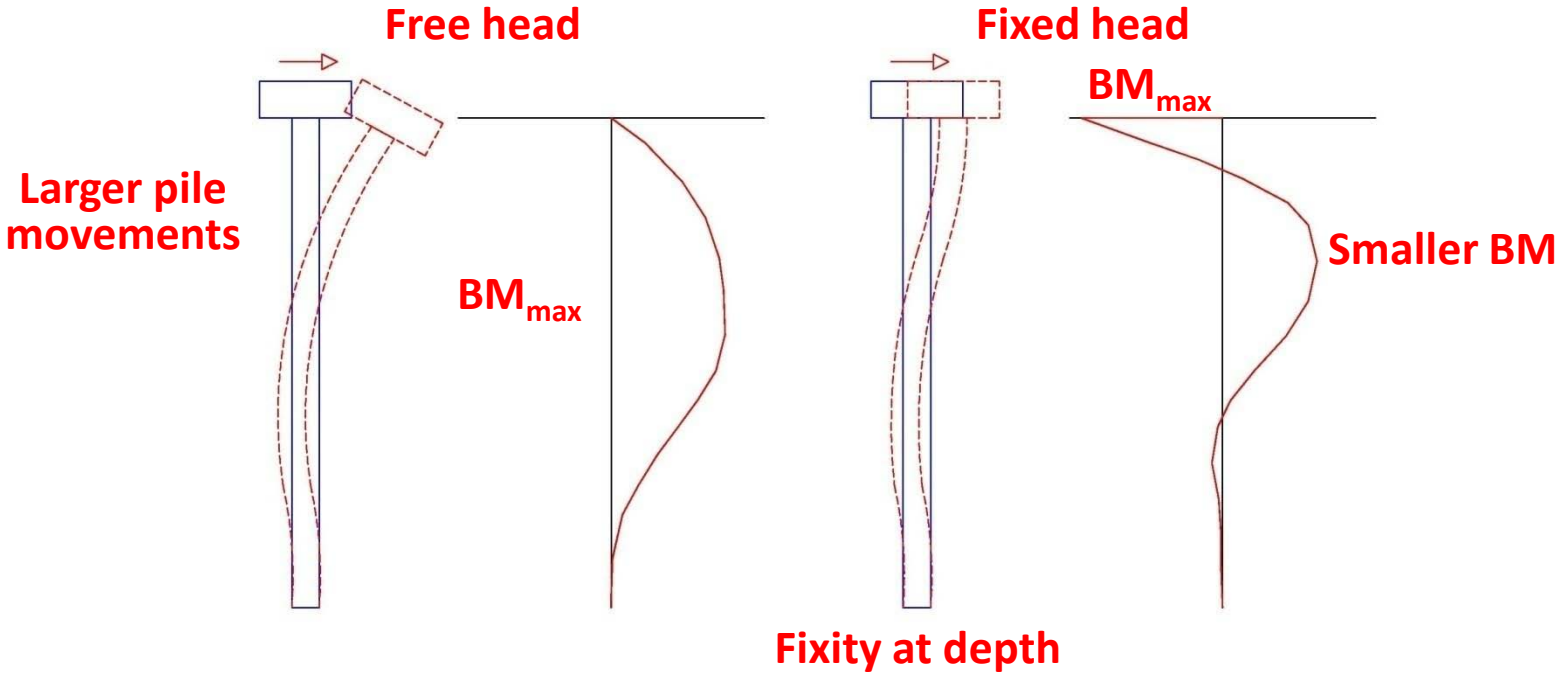
Horizontal Loading

- It is possible to carry out ULS horizontal load analyses but these depend on the assumed mechanism of behaviour



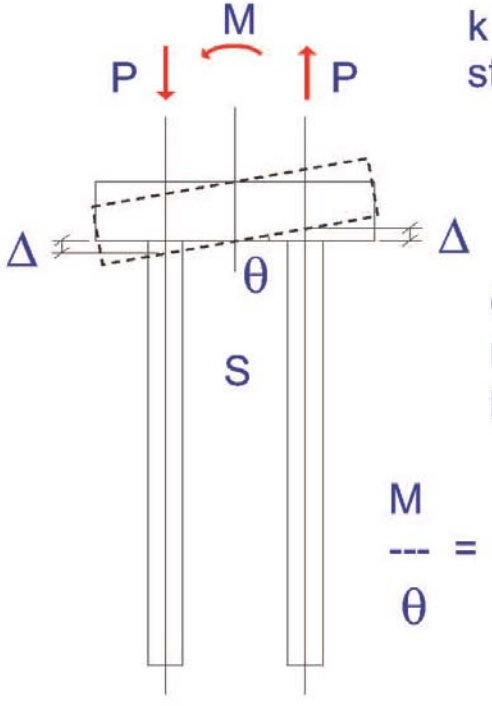
Horizontal Loading

- Note that real piles have flexural stiffness (EI)
- Horizontal behaviour is controlled by head fixity at the cap



Horizontal Loading – Head Fixity

- Head fixity can be modelled as shown
- Larger pile groups have much larger fixity
- Bending moment is usually maximum at the connection to the pile cap



k is the pile axial stiffness in kN/m

$M = P\,S$

$\Delta = \theta\,S/2$

$P = k\,\Delta$

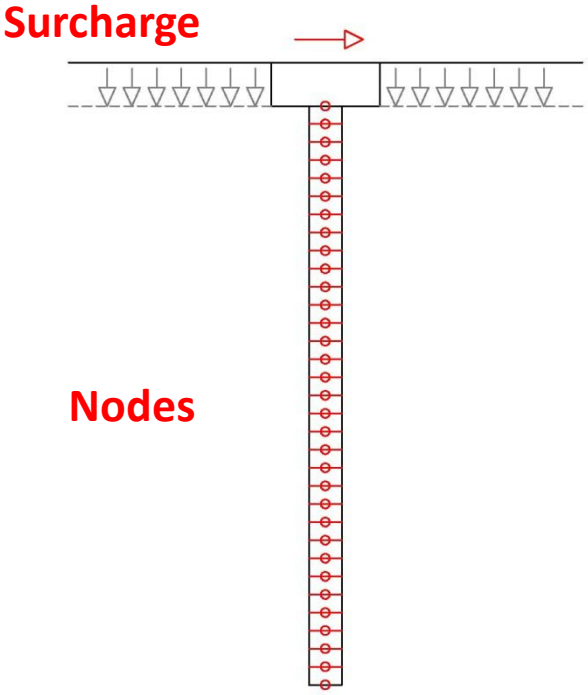
Combine to give moment stiffness per pile.

$$\frac{M}{\theta} = \frac{k\,S^2}{4}\ \text{kNm/radian}$$

Two Pile Cap Head Fixity

Horizontal Loading

- EC7 allows soil-structure interaction software to be used:
  - Options in UK are ALP or WALLAP
  - Pile is modelled as beam elements
  - Ground is modelled as springs
  - Analysis can be based on factored horizontal actions or factored soil strength (and stiffness)
  - Best to analyses without factors
  - Apply partial factors to BM & SF



Horizontal Loading

- ALP uses Brinch Hansen k_q and k_c coefficients

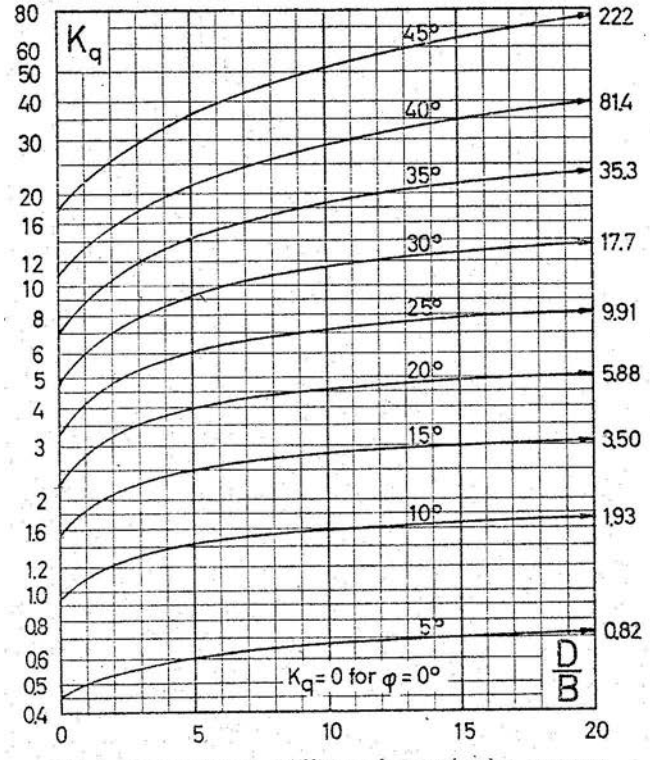


Fig. 5. Earth pressure coefficient for overburden pressure.

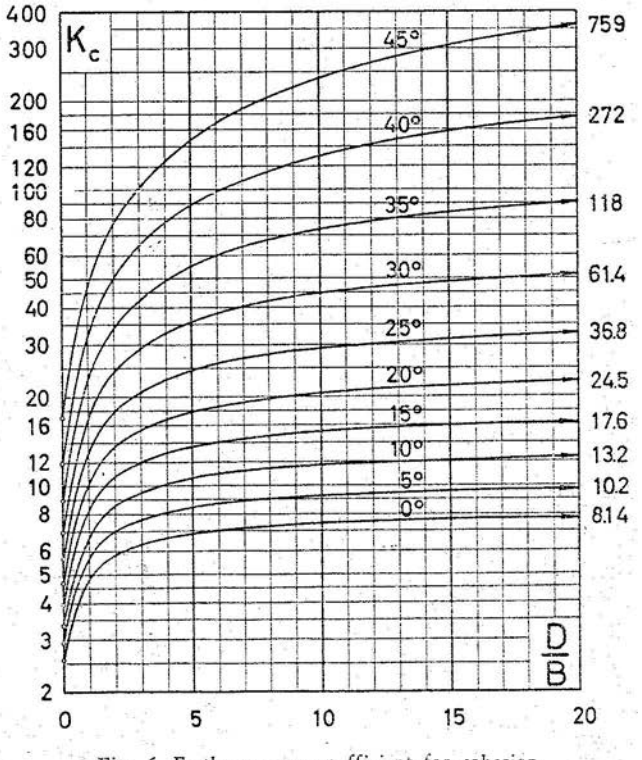


Fig. 6. Earth pressure coefficient for cohesion.

Design Example

- 600mm Cfa bored preliminary test pile
- Installed from a reduced level dig (3.5m below original level)
- Pile bored to 20.6m depth
- Founded in very weak Chalk
- Maximum test load 5,200kN at 61.3mm (Approx 10% D)
- Example design based on:
  - Calculation
  - Static load test

Design Actions F_d for Design Example

- Example calculation

  Permanent Load $G_k = 1400kN$ Variable Load $Q_k = 600kN$

- Factor Set A1

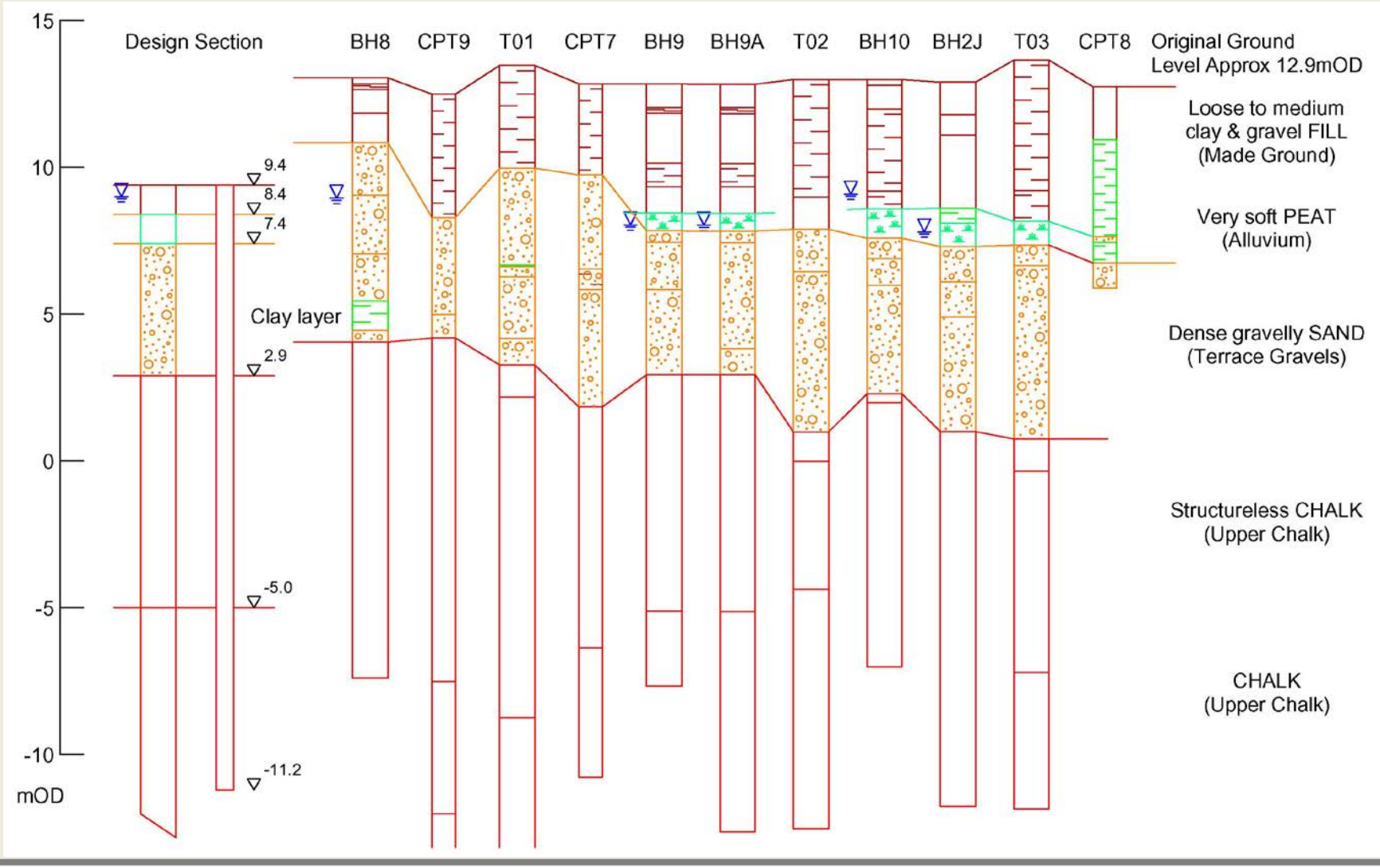
  EC7 Design Action $F_d = 1400 \times 1.35 + 600 \times 1.5$

  EC7 Design Action $F_d = 2790kN$

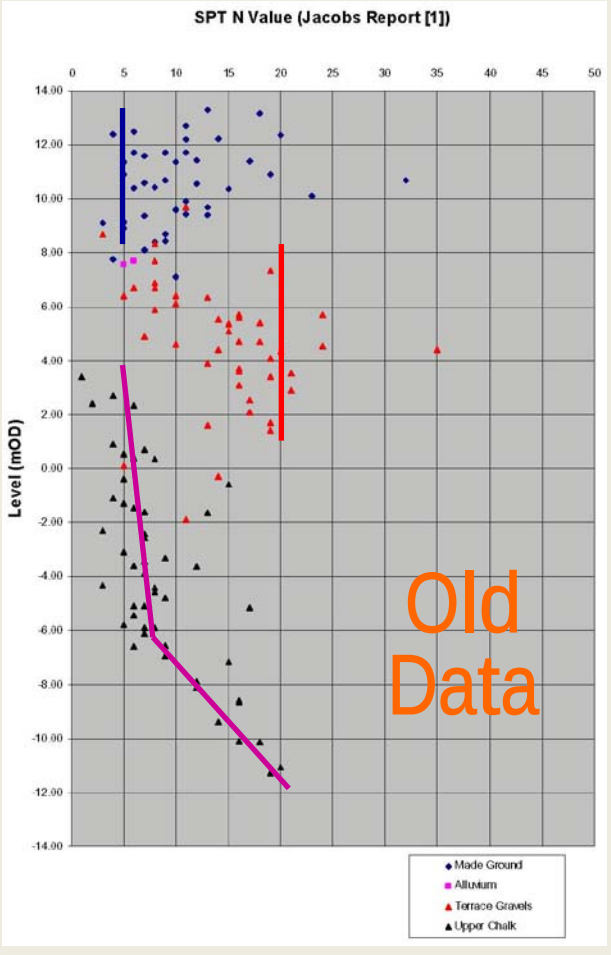
- Factor Set A2

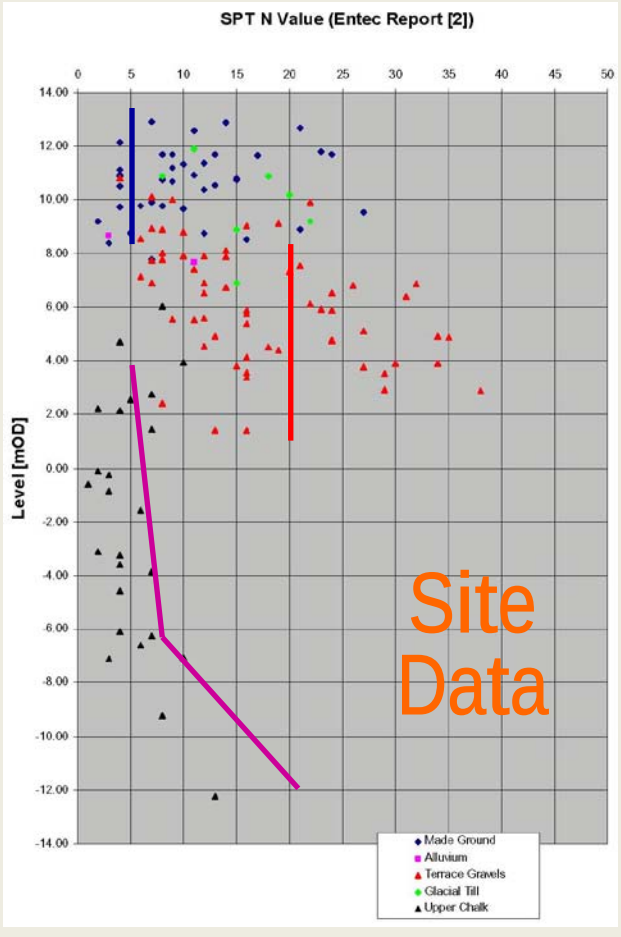
  EC7 Design Action $F_d = 1400 \times 1.0 + 600 \times 1.3$

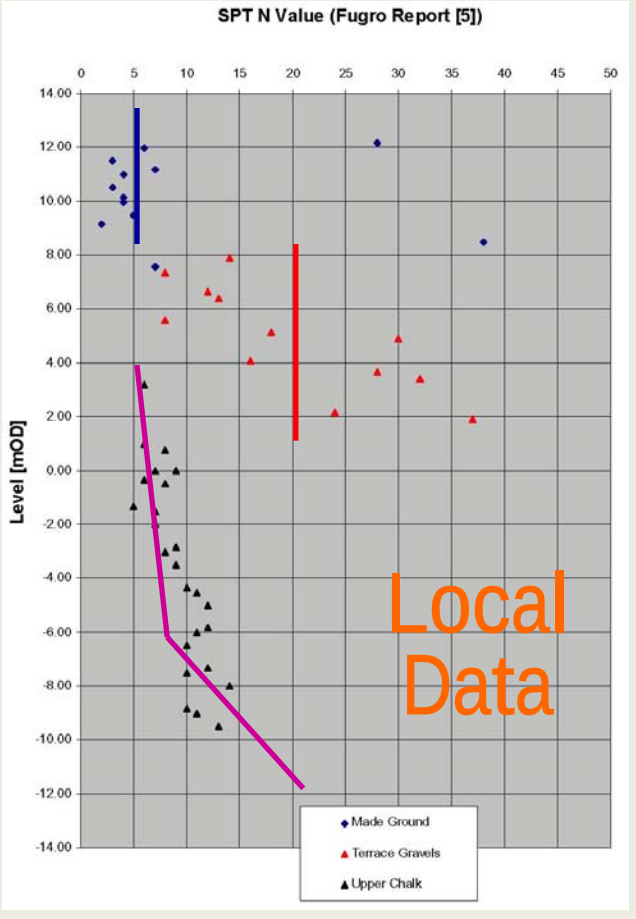
  EC7 Design Action $F_d = 2180kN$



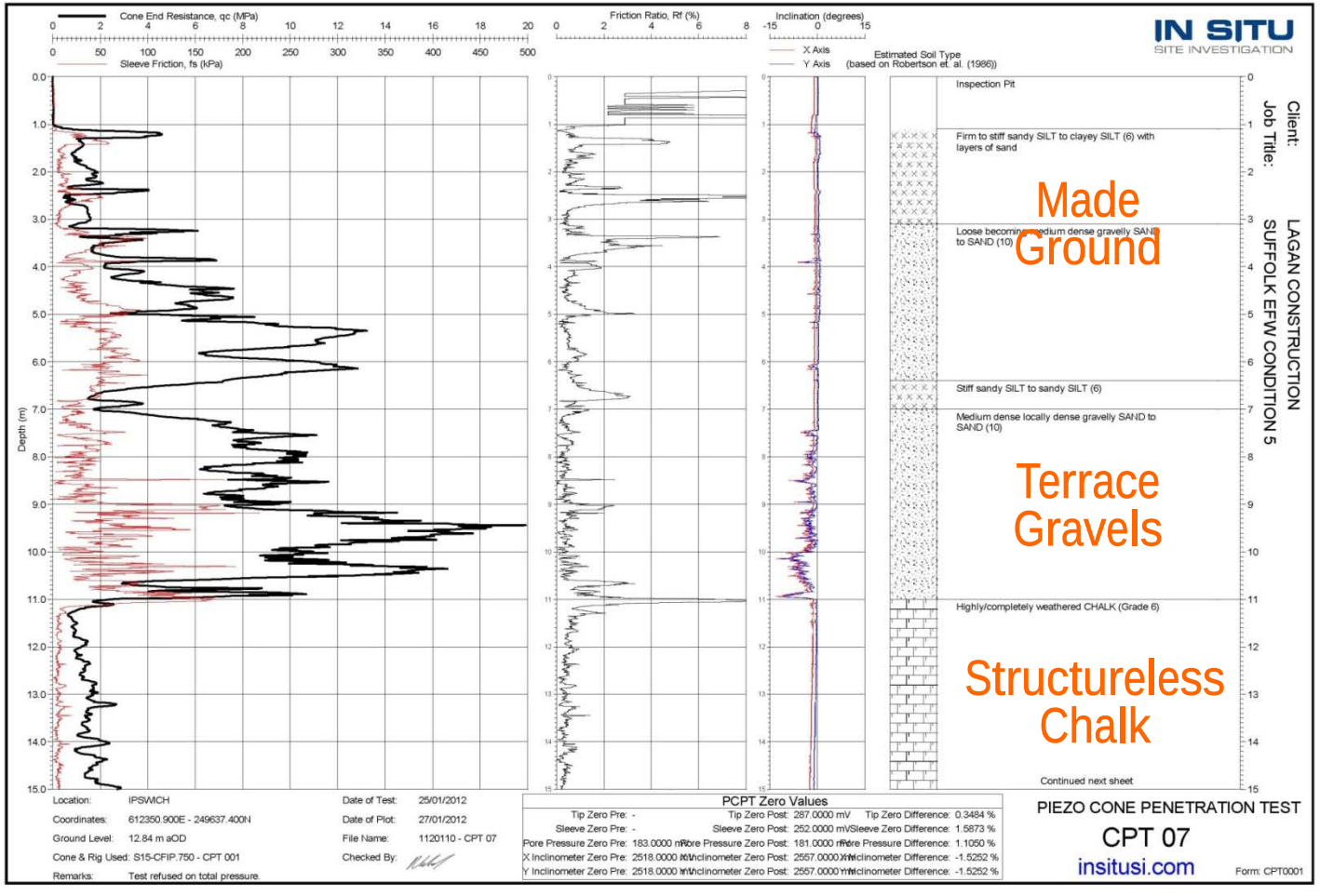
Geological Section



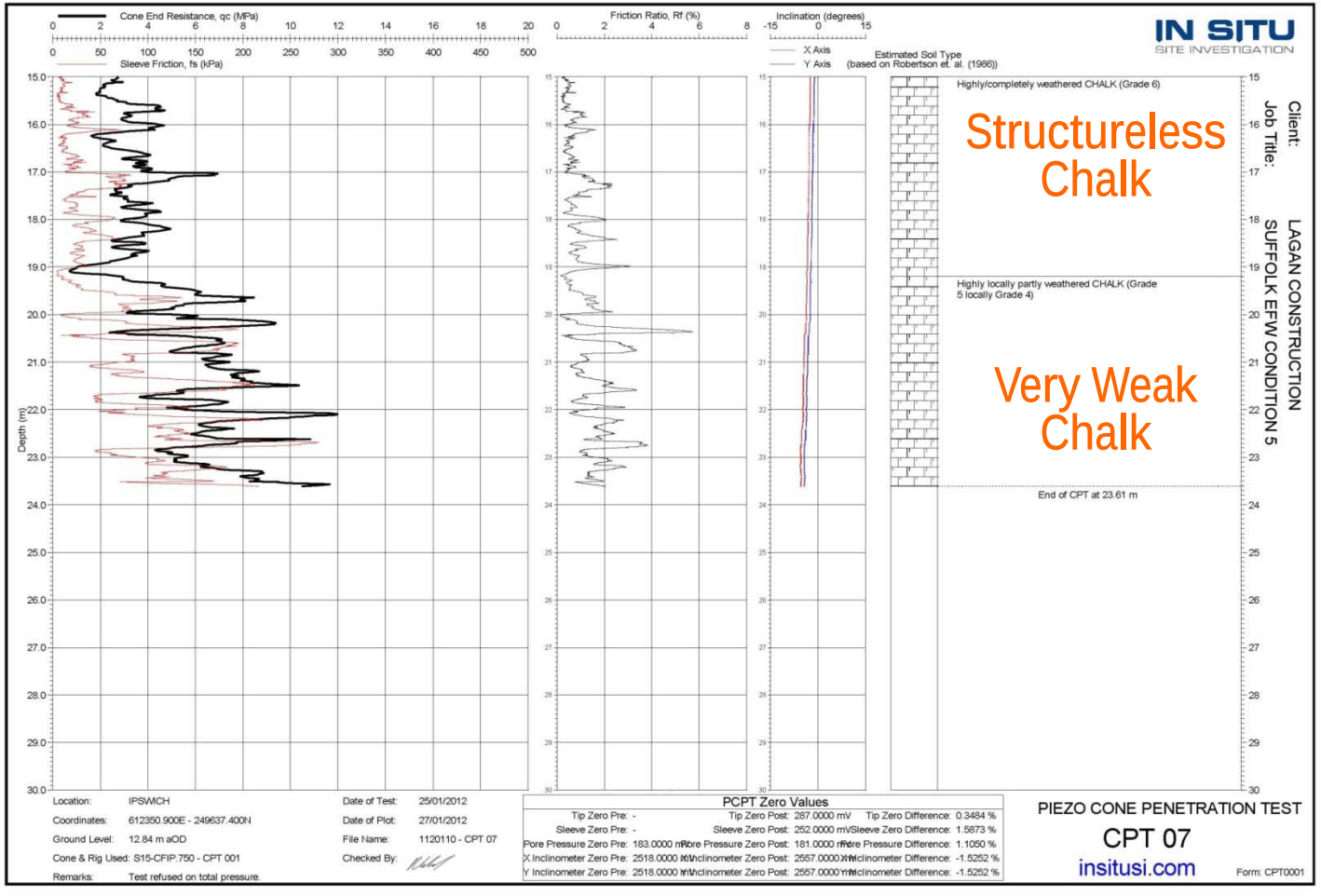




Insitu SPT Data



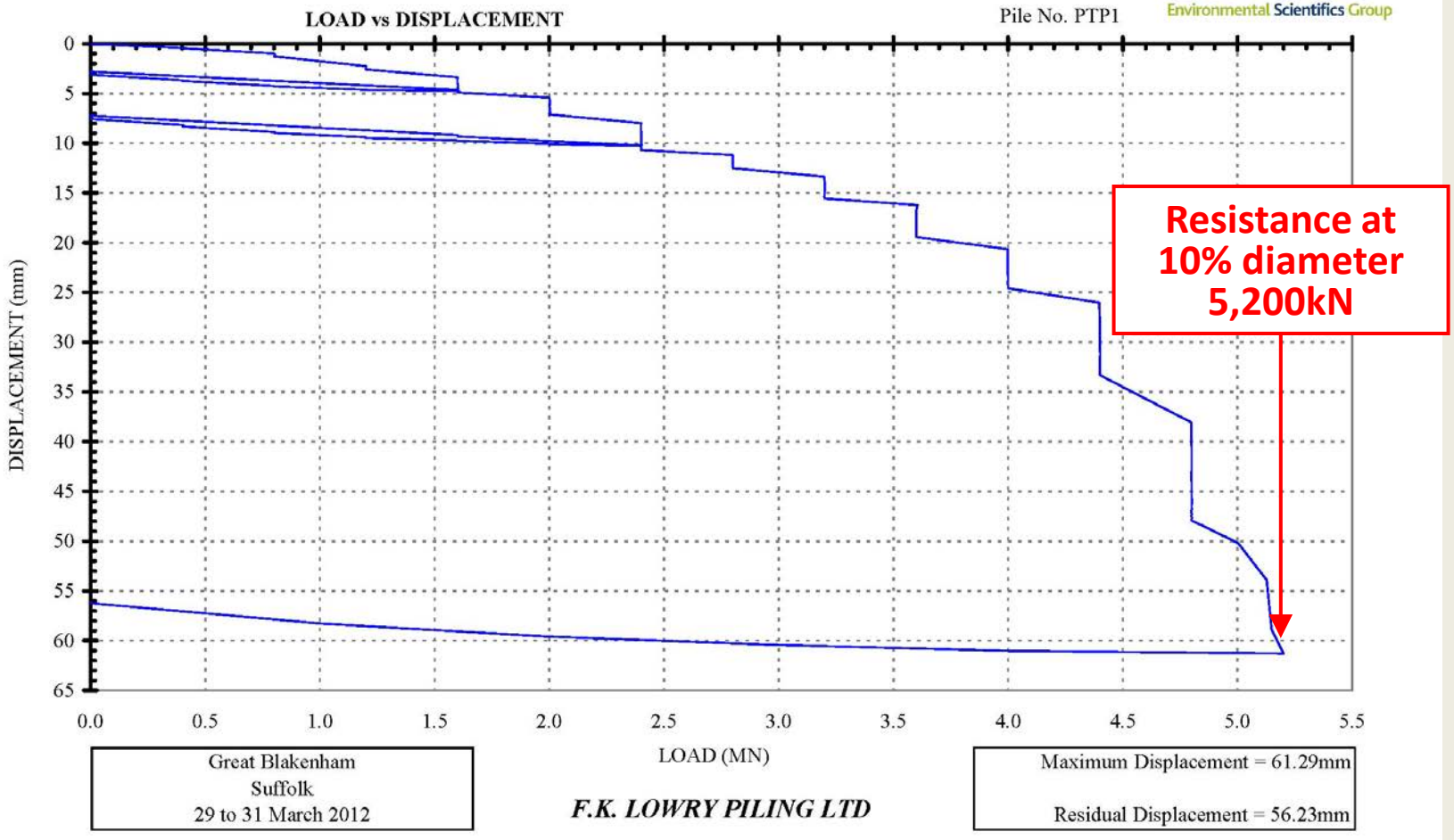
Insitu CPT Data



Insitu CPT Data

Pile Load Test Results

ESG Environmental Scientifics Group



Design Parameters for Design Example

Soil Description	Top Level mOD	Soil Properties	Design Parameters
Granular BACKFILL	9.4	$\phi' = 35°$	$\tan\delta = 0.7$ $k_s = 1.0$
Very soft PEAT	8.4	$c_u = 25$	$\alpha = 0.6$
Dense gravelly SAND	7.4	$\phi' = 35°$	$\tan\delta = 0.7$ $k_s = 1.0$
Structureless CHALK	2.9	N = 5 bl/300mm	$q_s = \sigma_v' \beta$ $\beta = 0.8$
Weak Chalk	-5.0	N = 15 bl/300mm	$q_s = \sigma_v' \beta$ $\beta = 0.8$ $q_b = 200$ N

Enhanced base		N = 40 bl/300mm	$q_b = 8{,}000$kPa

PILE BEARING CAPACITY

Pile System Cfa bored Diameter 600 mm

Soil Description	Top Level (mOD)	Soil Type	Shaft Stress Top (kPa)	Shaft Stress Base (kPa)	Shaft Friction (kN)
Granular BACKFILL	9.40	Drained	0	6	6
Very soft PEAT	8.40	Undrained	15	15	28
Dense gravelly SAND	7.40	Drained	11	44	234
Structureless CHALK	2.90	Chalk	50	114	1223
Very weak CHALK	-5.00	Chalk	114	165	1632

Pile Toe Level	-11.20	mOD	NEGATIVE SHAFT FRICTION	0	kN
Base stress	3000	kPa	SHAFT CAPACITY	3123	kN
			END BEARING CAPACITY	848	kN
			ULTIMATE CAPACITY	3971	kN

Maintained load test to ultimate capacity — EC7 Model Factor 1.2

Characteristic Shaft Resistance Rsk	2603	kN
Characteristic End Bearing Resistance Rbk	707	kN
Characteristic Pile Resistance Rk	3309	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	2275	kN
EC7 DESIGN TENSION RESISTANCE Rtd	1531	kN
PILE LENGTH	20.60	m

cf 5,200kN measured

Calculation still on low side

Bearing Capacity – β 0.80

PILE BEARING CAPACITY

Pile System Cfa bored Diameter 600 mm

Soil Description	Top Level (mOD)	Soil Type	Shaft Stress Top (kPa)	Base (kPa)	Shaft Friction (kN)
Granular BACKFILL	9.40	Drained	0	6	6
Very soft PEAT	8.40	Undrained	15	15	28
Dense gravelly SAND	7.40	Drained	11	44	234
Structureless CHALK	2.90	Chalk	50	114	1223
Very weak CHALK	-5.00	Chalk	114	165	1632

Pile Toe Level -11.20 mOD
Base stress 8000 kPa

NEGATIVE SHAFT FRICTION	0 kN
SHAFT CAPACITY	3123 kN
END BEARING CAPACITY	2262 kN
ULTIMATE CAPACITY	5385 kN

Maintained load test to ultimate capacity

EC7 Model Factor 1.2

Characteristic Shaft Resistance Rsk	2603 kN
Characteristic End Bearing Resistance Rbk	1885 kN
Characteristic Pile Resistance Rk	4487 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	2968 kN
EC7 DESIGN TENSION RESISTANCE Rtd	1531 kN
PILE LENGTH	20.60 m

Step 1 Model Factor

Step 2 Resistance Factors

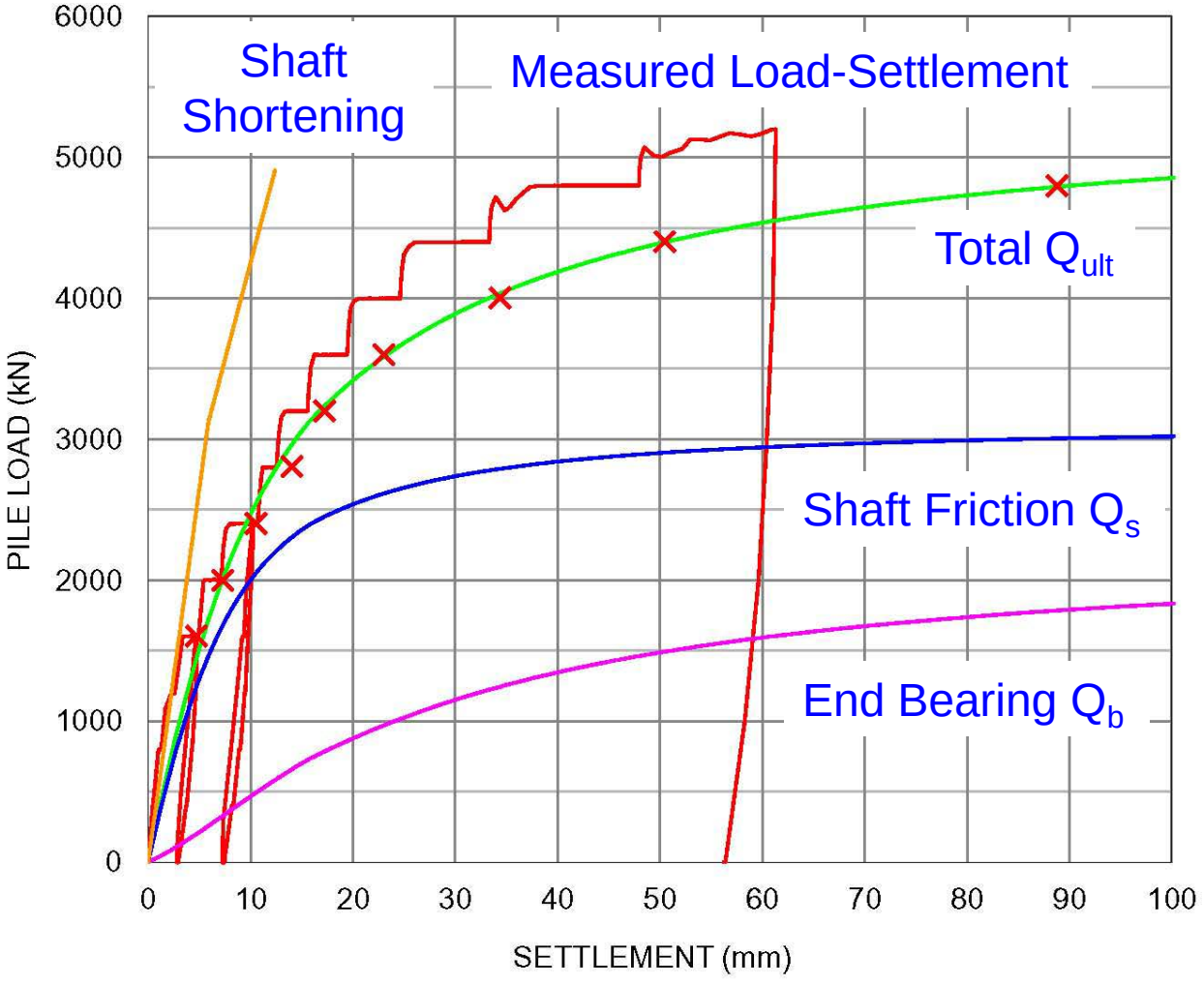
BC calculation down to here is the same as we have always carried out

No change for EC7

EC7 model and resistance factors applied

$R_{c;d}$ 2,968kN

Enhanced Base



5,385kN

3,123kN

2,262kN

CEMSET Fit to Test Results

Design Based on Calculation

- Calculated design resistance $R_{c;d}$

$$R_{b;k} = \frac{2{,}262}{1.2} = 1{,}885\text{kN} \qquad R_{s;k} = \frac{3{,}123}{1.2} = 2{,}603\text{kN}$$

$$R_{c;d} = \left[\frac{1{,}885}{1.7} + \frac{2{,}603}{1.4}\right] = 2{,}968\text{kN}$$

- Based on calculation with the best CEMSET fit to the measured load-settlement behaviour

Design Based on Static Load Tests

- Design resistance $R_{c;d}$

$$R_{c;k} = \text{Min}\left[\frac{\text{Mean } 5{,}200\text{kN}}{1.55}\right] \text{ or } \left[\frac{\text{Minimum } 5{,}200\text{kN}}{1.55}\right]$$

$$R_{c;k} = 3{,}355\text{kN}$$

$$R_{c;d} = \left[\frac{3{,}355}{1.7}\right] = 1{,}974\text{kN}$$

- Note that this method is based on the measured resistance at 10% of the pile diameter rather than the extrapolated ultimate capacity (about 5,400kN based on CEMSET)

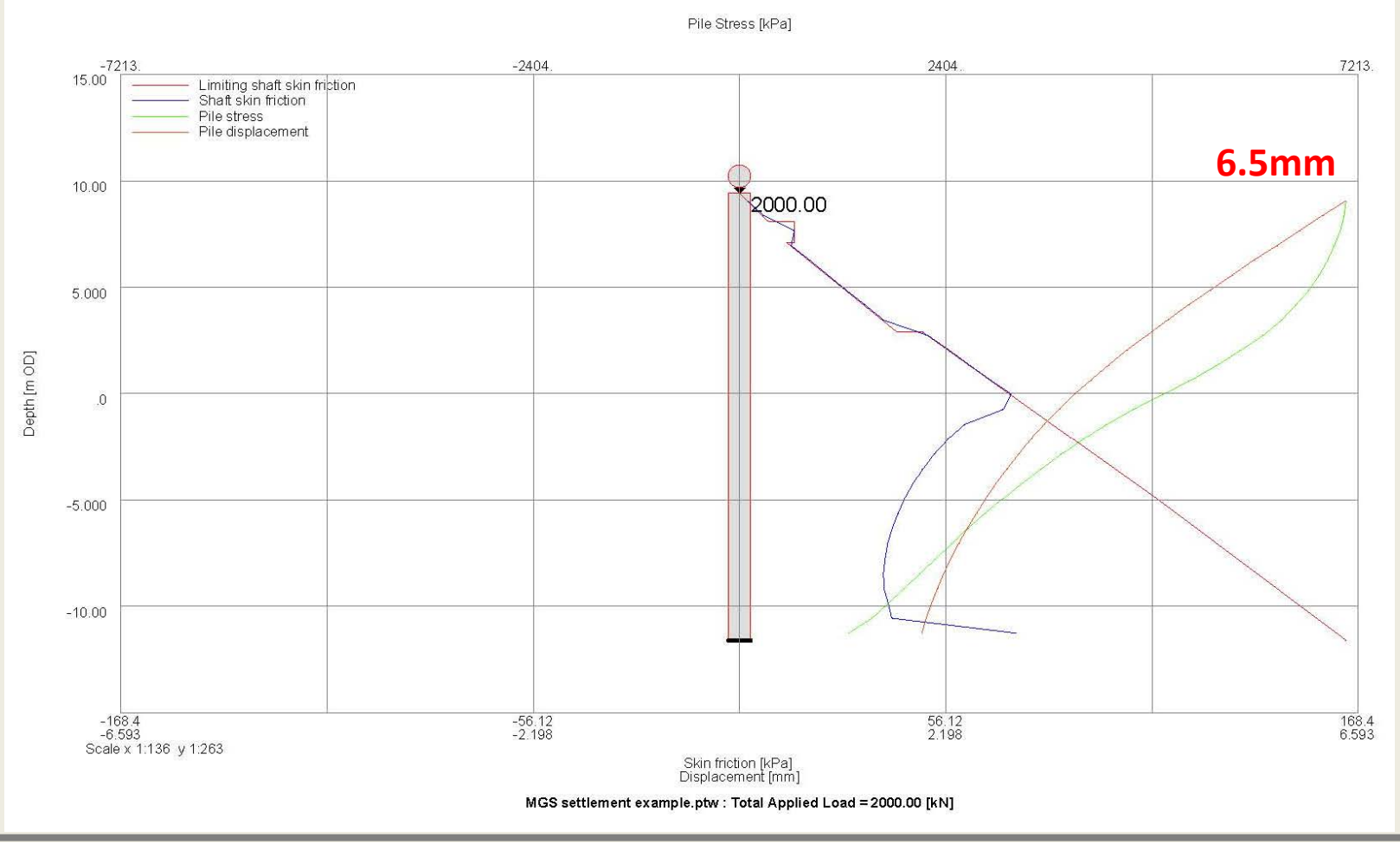
Design Based on Static Load Tests

- Assuming say 3 pile load tests and a stiff/strong structure would allow a reduced correlation factor of 1.29 to be used giving $R_{c;d}$ = 2,371kN

Comparison Between Design Methods

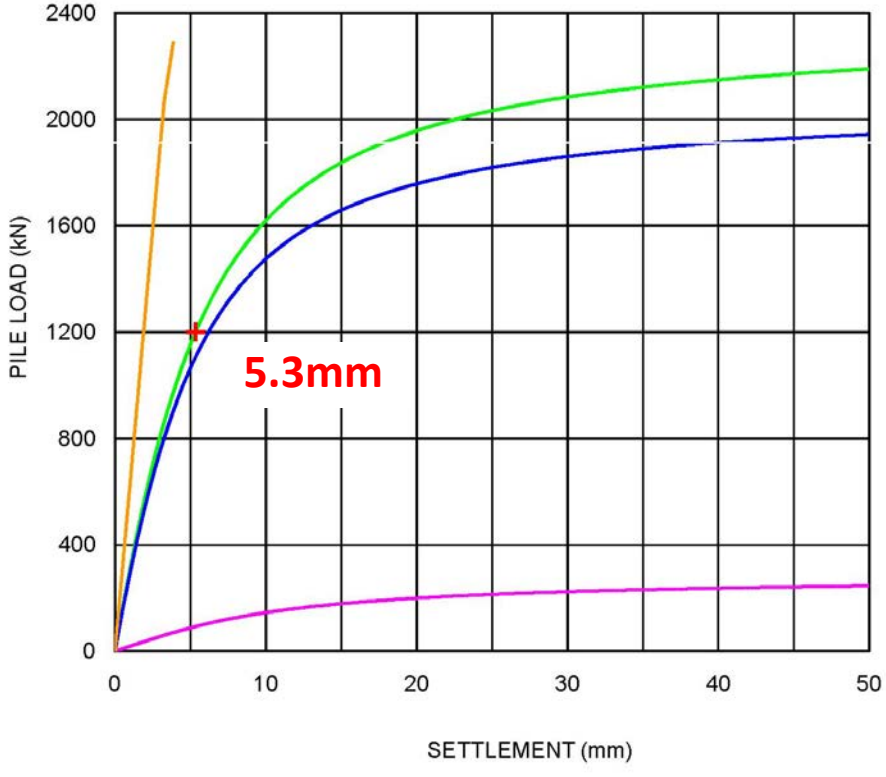
- Nominal pile load 2,000kN
- EC7 Design Action 2,180kN
- Design Resistance:
  - Based on Calculation 2,275kN to 2,968kN
  - Based on Static Load Test 1,974kN to 2,371kN

Example PILE/PILSET Settlement Calculation



Example CEMSET Settlement Calculation

Shaft Shortening



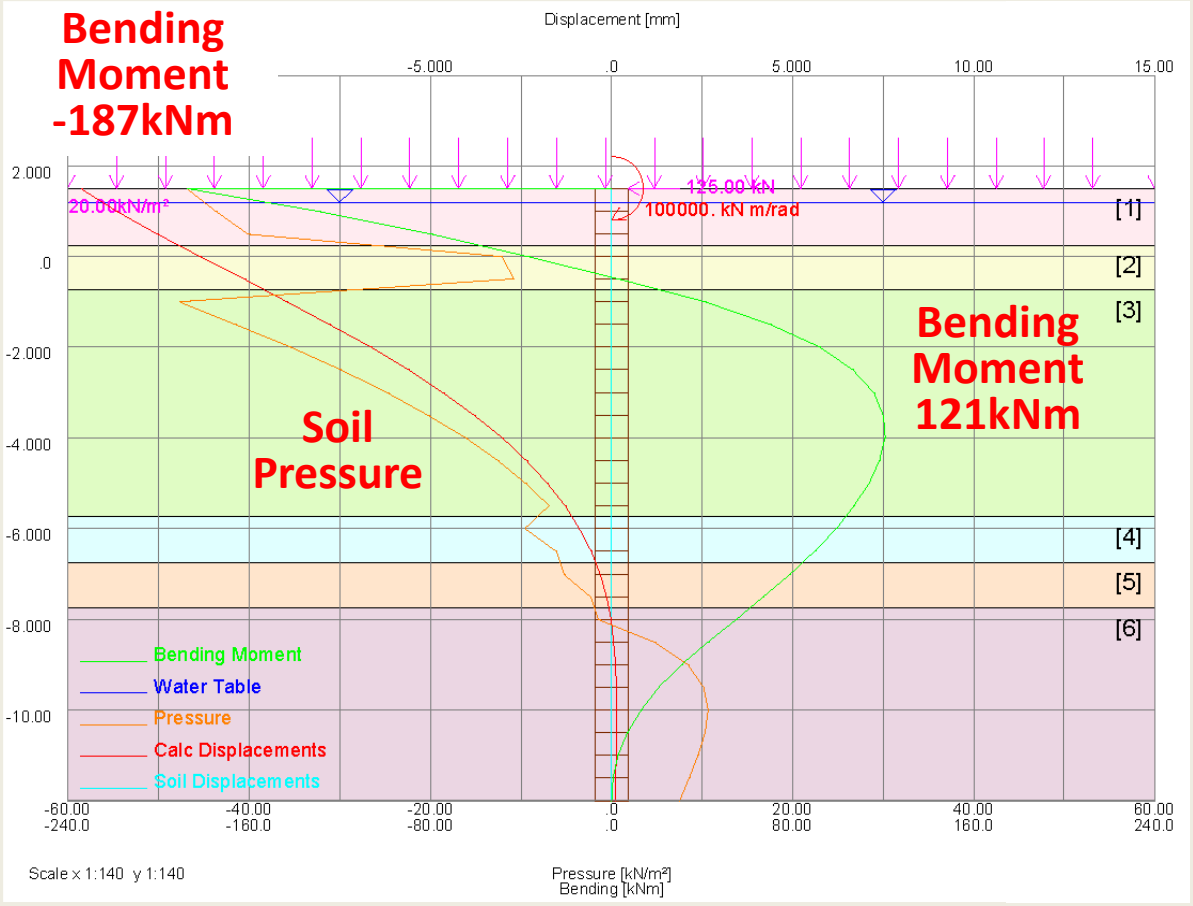
Total

Qs

Qb

Example ALP Horizontal Load Analysis

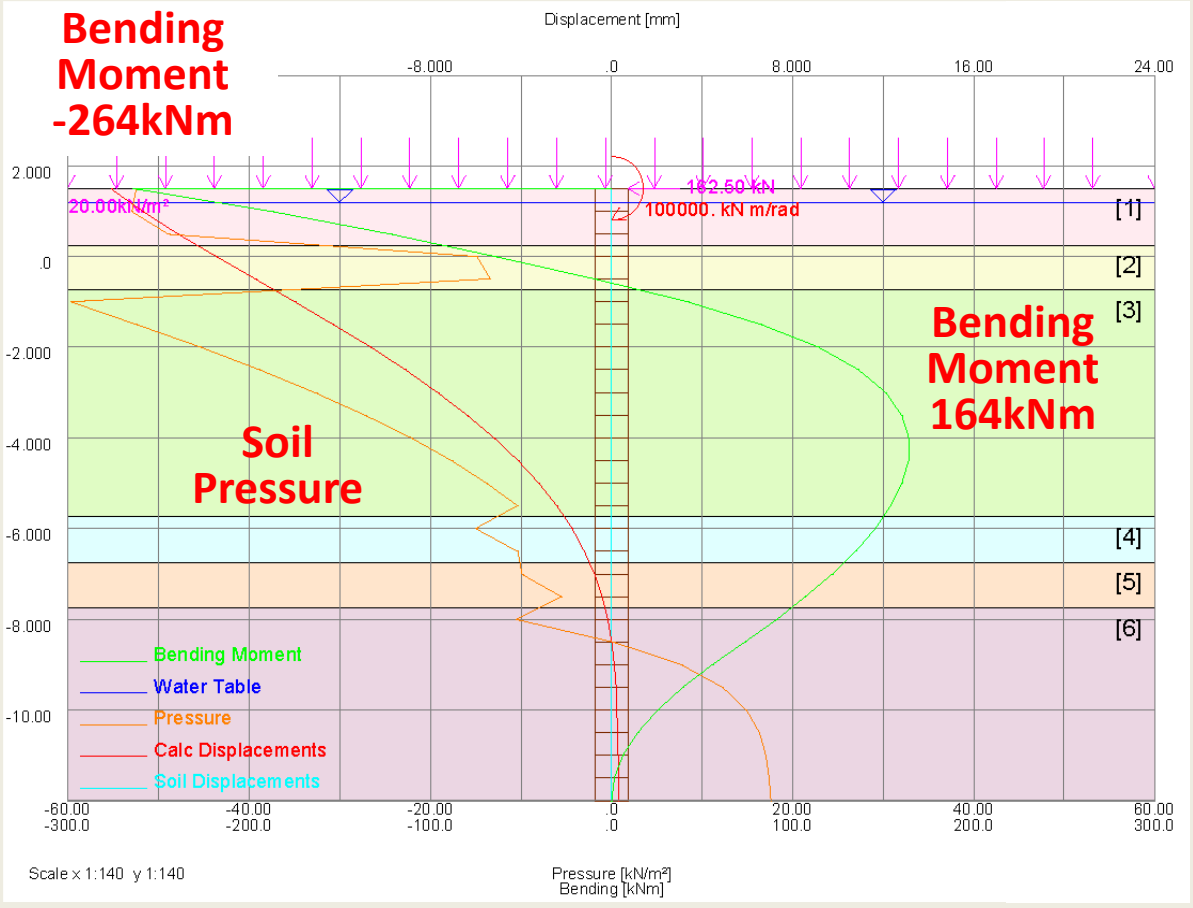
Pile Deflection 14.6mm



SLS - Unfactored

Example ALP Horizontal Load Analysis

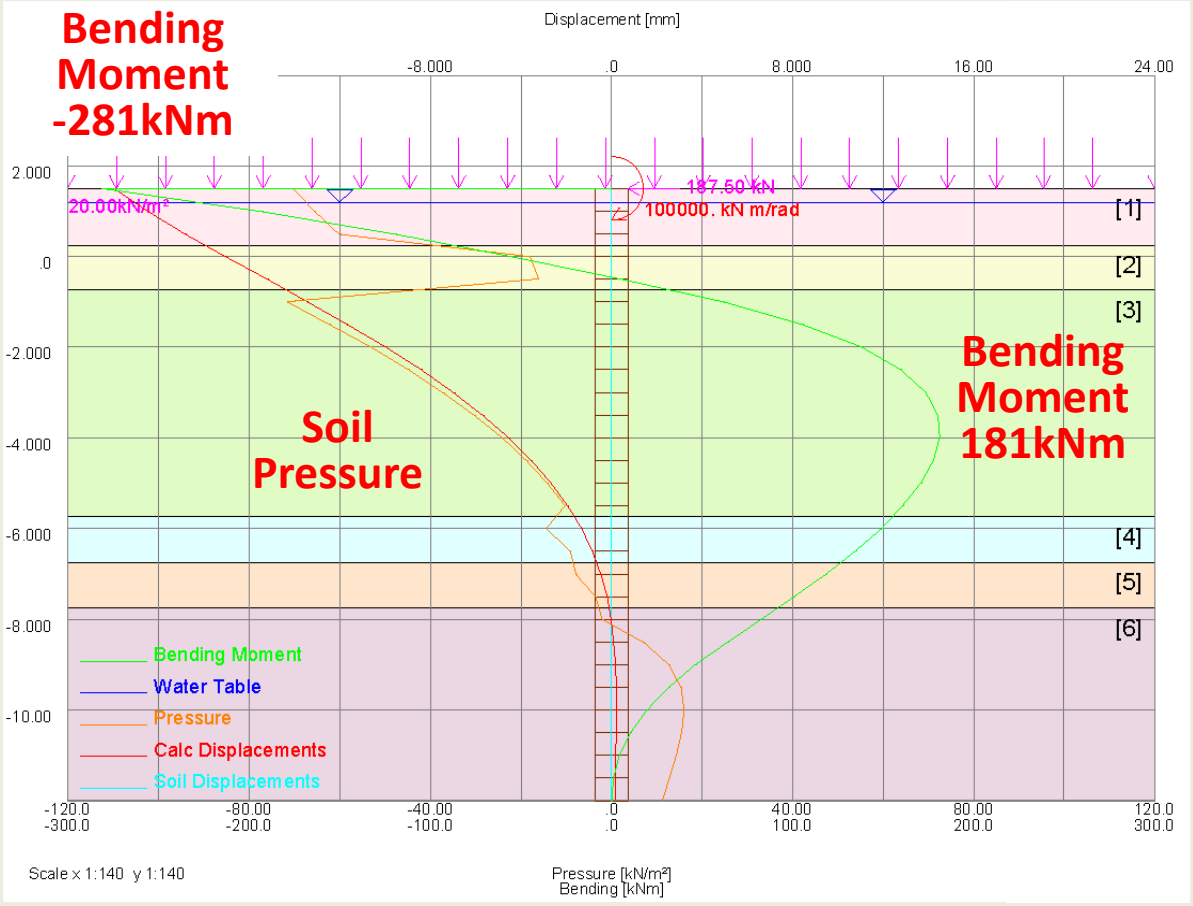
Pile Deflection 22.1mm



ULS – A2/M2 Factor Sets

Example ALP Horizontal Load Analysis

Pile Deflection 22.0mm



ULS – A1/M1 Factor Sets

Example ALP Horizontal Load Analysis

	SLS No factors	ULS A2/M2	ULS A1/M1	ULS A1/M1*	
Material Factor γ_m		1.25	1.0	1.0	
Horizontal G_k	0	0	0	0	kN
Horizontal Q_k	125	125	125	125	kN
Partial Factor γ_G		1.0	1.35	1.0	
Partial Factor γ_Q		1.3	1.5	1.0	
Horizontal G_d	0	0	0	0	kN
Horizontal Q_d	125.0	162.5	187.5	125.0	kN
At Pile Head					
Calculated Moment M	-187	-264	-281	-187	kNm
Partial Factor γ		1.0	1.0	1.5	
Design Moment M_d		-264	-281	-281	kNm
Peak at Depth					
Calculated Moment M	121	164	181	121	kNm
Partial Factor γ		1.0	1.0	1.5	
Design Moment M_d		164	181	182	kNm

ULS A1/M1* - Partial factors applied to effect of actions

ULS – A1/M1 Factor Sets

Conclusions

- EC7 does not tell the Designer how to design piles but does give rules and procedures to be followed
- EC7 has complicated pile design with the introduction of numerous partial factors; load factors, combination factors, material factors, resistance factors, model factors and correlation factors
- But EC7 does provides a more logical framework

Thanks for Your Attention