Pile and soil data:

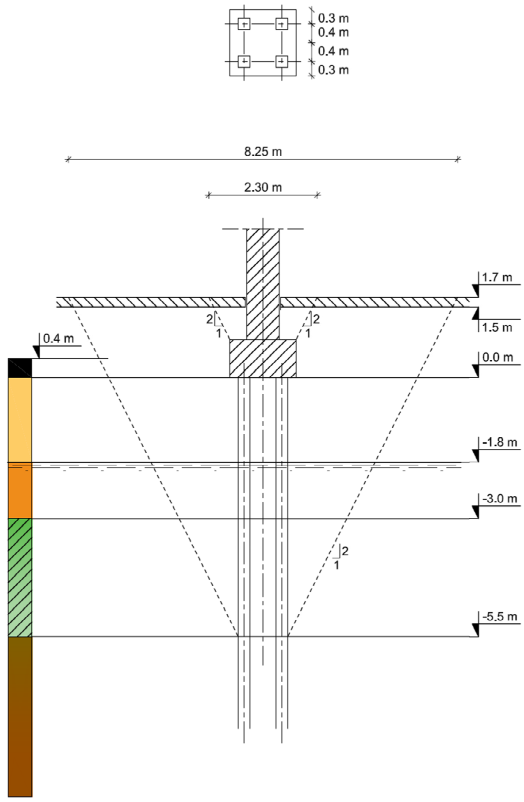
4 nos. of 0,25 x 0,25 m precast, driven piles supporting one column for a stadium roof
Excavation of 0,4 m topsoil
1,5 m backfilling below future floor / pavement

0,4 m of top soil: $\gamma = 16$ kN/m^3

Sand: $\gamma = 18$ kN/m^3 above GWL
$\gamma' = 10$ kN/m^3 below GWL

Soft clay: $\gamma' = 9$ kN/m^3, $c_{uk} = 70$ kN/m^2

Clay till: $c_{uk} = 300$ kN/m^2
or
Dense sand: $I_D = 65$ %, $\gamma' = 10$ kN/m^3, $\varphi'_{pl;k} = 38°$



Design basis

High Consequences Class (CC3), corresponding to Reliability Class 3 (RC3) .

Load

Floor direct on the ground: 0.2 m reinforced concrete, $\gamma = 24$ kN/m^3
Characteristic load on the floor: $p_k = 10$ kN/m^2, 50 % of this influencing settlement.
Original ground level raised and thus loaded by sand fill after removal of 0.4 m topsoil.

Characteristic pile loads for 4 piles:
Permanent action $G_k = 800$ kN incl. plinth and sand fill above plinth
Variable action: $Q_k = 400$ kN

Negative skin friction down to OSBL (= neutral point = level -5,5), due to back fill on previous ground level.

Design basis, cont.

ONE borehole is carried out, in which in situ test like shear vane test, SPT and/or CPT has been carried out – supported by sieve analysis (in the sand case) and off course the geological description of the soil samples.

c_{uk} = characteristic undrained shear strength
I_D = relative density = density index
$\varphi'_{pl;k}$ = characteristic effective plane angle of friction
GWL = Ground Water Level
OSBL = Over Side (Top of) Bearing Layer (in this case = Bottom of settling layer = Neutral Point)

Before installing the piles (by driving) the +0.4 m topsoil is removed. After installation of piles and casting of plinth sand is backfilled and compacted up to level +1.5 upon which the concrete floor is cast. This (backfilling) and the concrete floor are considered to trigger (mobilise) the negative skin friction (draw down).

Task: Determine:

- ULS and SLS design load per pile (= total load / 4)
- Negative skin friction (neutral point is fixed at OSBL at level -5.5) per pile
- Effect of bitumen coating from 0 to -5.5 on negative skin friction, if any
- Necessary toe level (embedment depth below level 0.0 = pile length) in case of
  a) clay till below OSBL
  b) dense (melt water) sand below OSBL
  without and with bitumen on the pile above OSBL
- Structural capacity of pile assuming
  concrete: f_{ck} = 50 MPa
  reinforcement: 4 nos. Y12 Ks 500, i.e. with f_{yk} = 500 MPa, one in each corner of the cross section, Ø5 mm helical
  concrete cover = 35 mm

Effect of consequences class / safety class

Denmark

Consequences class	CC	CC1	CC2	CC3	c.f. EN 1990, Annex B
KFI factor	KFI	0,9	1,0	1,1	
Reliability Class (Safety Class)	RC	RC1	RC2	RC3	c.f. EN 1990, Annex B
factor to control RC	γ_d				
Remark	DK	CC1 is not used for geotechnical structures in Denmark			

Sweden

Consequences class	CC	CC1	CC2	CC3	c.f. EN 1990, Annex B
KFI factor	KFI	NA	NA	NA	
Reliability Class (Safety Class)	RC	RC1	RC2	RC3	c.f. EN 1990, Annex B
factor to control RC	γ_d	0,83	0,91	1	
Remark	We would use Safety Class 2 for this type of foundation (no sudden failure)				

Load factors

Denmark

Limit state		*STR/GEO*				*STR*	*SLS*
Load Combination (LC)		*1*	*2*	*3*	*4*	*5*	
Reference formula in EN 1990		*(6.10a)*	*(6.10b)*	*(6.10a)*	*(6.10b)*	*(6.10a)*	
permanent	γ_G *(-)*	1,2 KFI	1,0 KFI	1,2	1,0	1,0	1,0
variable	γ_Q *(-)*	0	1,5 KFI	0	1,5	1,0	$(1,5)^{0.5}$

Sweden

Limit state		*STR/GEO*		*STR*	*STR/GEO*	*SLS*	*SLS*	*SLS*
Load Combination (LC)		*1*	*2*	*3*	*4*	*plastic*	*elastic*	*long-term*
Reference formula in EN 1990		*6.10a*	*6.10b*	*6.10*	*6.11b (exc)*	*6.14b*	*6.15b*	*6.16b*
permanent	γ_G *(-)*	$\gamma_d \cdot 1,35$	$\gamma_d \cdot 1,2$	$\gamma_d \cdot 1,1$	1,0	1,0	1,0	1,0
variable	γ_Q *(-)*	$\gamma_d \cdot 1,5 \cdot \psi_{0,1}$	$\gamma_d \cdot 1,5$	$\gamma_d \cdot 1,4$	$\psi_{1,1}$ or $\psi_{2,1}$	1,0	$\psi_{1,1}$	$\psi_{2,1}$

SE: downdrag (6.10) is combined with 6.10a with long-term loads for STR
The Danish and Swedish LC numbers 1, 2, 3 and 4 cannot be compared (concerns different LCs)

Design loads per pile

Denmark

Limit state		*STR/GEO*				*STR*	*SLS*
Load Combination	*Charact.*	1	2	3	4	5	
permanent, G (kN)	200	264	220	240	200	200	200
variable, Q (kN)	100	0	165	0	150	0	122
Design load F_{cd} (kN)		264	385	240	350	200	322

Sweden

Limit state		*STR/GEO*		*STR*	*STR/GEO*	*SLS*	*SLS*	*SLS*
Load Combination	*Charact.*	1	2	3	4	*plastic*	*elastic*	*long-term*
permanent, G (kN)	200	270	240	NA	200	200	200	200
variable, Q (kN)	100	75	150	NA	50	100	50	50
Design load F_{cd} (kN)		**345**	390	NA	250	300	250	**250**

SE:
SLS long-term: elastic/plastic analysis used to check cracks/stress in pile
variable (Q) load, SLS long term: 50% long-term variable load

Negative skin friction (downdrag)

Denmark

Limit state		*STR/GEO*				*STR*	*SLS*
Load Combination	*Charact.*	1	2	3	4	5	
without bitumen							286
with bitumen							72

Sweden

Limit state		*STR/GEO*		*STR*	*STR/GEO*	*SLS*	*SLS*	*SLS*
Load Combination	*Charact.*	1	2	3	4	*plastic*	*elastic*	*long-term*
without bitumen		**186**	NA	152	NA	NA	NA	**138**
with bitumen		**74**	NA	60	NA	NA	NA	**55**

SE: With bitumen: 10 kPa value assumed

Design Approach (DA), correlation factors, model factors

Denmark

Design Approach	*DA*	Resistance Factor Approach (RFA), similar to present DA2
Correlation factor	ξ	1,5

Sweden

Design Approach	*DA*	DA2 (GEO)	DA3 (STR)
Correlation factor, Model pile	ξ	table A.10	NA
or Alternative procedure	$\gamma_{rd,e}$	**1,4** (instead of corr. Factor)	NA
Model factor	γ_{rd}	**1,6** (API /Toolan) **1,1** (alpha-method)	NA

Table A.10 - Correlation factors ξ to derive characteristic values from ground test results (*n* - the number of profiles of tests)

ξ for *n* =	1	2	3	4	5	7	10
ξ_3	1,40	1,35	1,33	1,31	1,29	1,27	1,25
ξ_4	1,40	1,27	1,23	1,20	1,15	1,12	1,08

Partial geotechnical resistance factors γ_R

Denmark

Limit state		*STR/GEO*				*STR*	*SLS*
Load Combination	*Charact.*	1	2	3	4	5	
Base	γ_b	1,3	1,3	1,3 KFI	1,3 KFI		$(\xi\ \gamma_R)^{0,5}$
Shaft (compression)	γ_s	1,3	1,3	1,3 KFI	1,3 KFI		$(\xi\ \gamma_R)^{0,5}$
Total/combined (compression)	γ_t	1,3	1,3	1,3 KFI	1,3 KFI		$(\xi\ \gamma_R)^{0,5}$
Shaft in tension	$\gamma_{s:t}$	1,3	1,3	1,3 KFI	1,3 KFI		$(\xi\ \gamma_R)^{0,5}$

Sweden: GEO: DA2

Base	γ_b	1,2
Shaft (compression)	γ_s	1,2
Total/combined (compression)	γ_t	**1,2**
Shaft in tension	$\gamma_{s:t}$	1,3

STR: DA3

Angle of shearing resistance	γ_φ	1,3
Effective cohesion	$\gamma_{c'}$	1,3
Undrained shear strength	γ_{cu}	1,5
Unconfined strength	γ_{qu}	1,5
Weight density	γ_γ	1

Necessary toe level (depth below 0), m

Denmark

Limit state	*ULS*	*SLS*	
Bitumen coating		*No*	*Yes*
a) clay till below OSBL	8,9	10,1	7,5
b) sand below OSBL	?	?	?

Sweden

Limit state	*ULS*		*SLS*	
Bitumen coating	*No*	*Yes*	*No*	*Yes*
a) clay till below OSBL	**11**	**8**	NA	NA
b) sand below OSBL	**12**	**10**	NA	NA

SE: re a) No SLS deformation requirement stated, ULS is checked assuming very large ground settlements

Structural resistance $R_{STR,d}$(kN)

Denmark

Partial factor on concrete strenght, f_{ck}	γ_c	1,40
Partial factor on reinforcement yield stress, f_{yk}	γ_s	1,20
Structural design bearing resistance $R_{STR,c,d}$(kN)	N_{Rd}-	2232

Sweden

Partial factor on concrete strenght, f_{ck}	γ_c	1,40
Partial factor on reinforcement yield stress, f_{yk}	γ_s	1,20
Structural design bearing resistance $R_{STR,c,d}$(kN)	N_{Rd}-	1200

SE: buckling length in the clay is 2,8 m. Slenderness ratio too high; 2nd order theory must be used according to EN 1992. Material yield limits the design load (STR)

A common Nordic view - on pile foundation design?

1. Design Approach (DA): MFA, RFA – or EFA
2. Partial coefficients – on actions, soil/material parameters and resistances
3. Handling of negative skin friction (drawdown)
   pragmatic way(s) / approach vs. determination of neutral point
   (mix of ULS and SLS)
4. Buckling of piles
5. Bending (ULS stresses in pile) due to second order effect in soft clays
6. Limitation (reduction) of number and kind of (Swedish) factors –
   make it simple, not more complicated
7. Harmonise effect of testing of piles: relative number of tests → reduction of safety
8. Specify rules and consequence of test of bored/drilled piles
9. Use correlation factors with care and (common) sense

A common Nordic view - on pile foundation design?

The term **common** has two meanings:

united … **or** … what makes sense.

Hopefully we (the Nordic countries) will achieve both –

so we can replace or with **and**