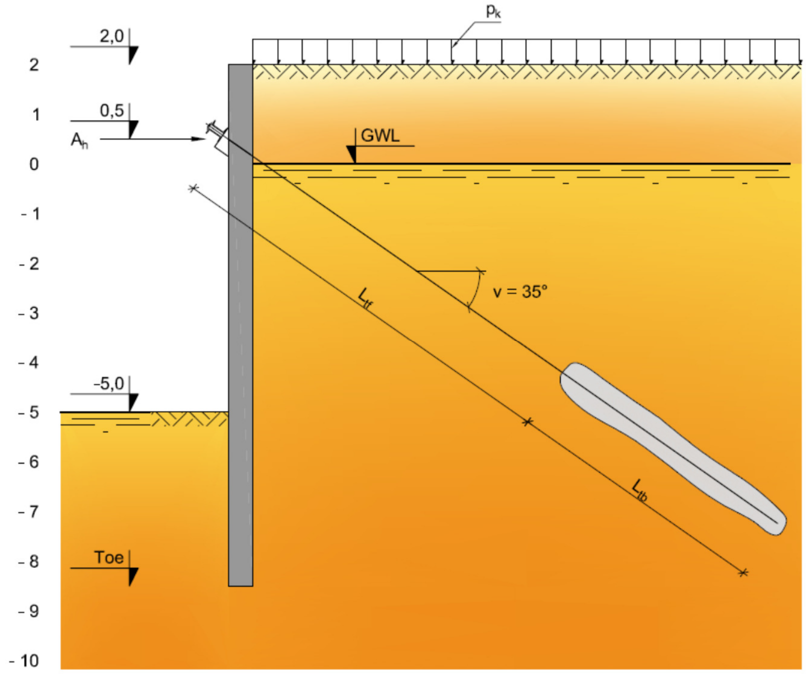
Sand:
$\varphi_k = 35°$, $\gamma/\gamma' = 18/10$ kN/m^3
E = 30 MPa, ν = 0,3
Hydrostatic water pressure
(no gradient)

Wall:
Bending Moment → W (kg/m^2)
Toe level → h (kg/m)

Anchor:
$E_{ULS;d} = \max (F_{ULS;d} ; F_{serv;d})$
Proof load $P_p \rightarrow A_s$ (kg)
L_{tf}, L_{tb}



Prescribed:

Sheet pile wall:
Z- or U-profiles, crimped and installed as double piles (by vibrator without problems)
Steel quality S 240 GP, i.e. f_{yk} = 240 MPa
E = 200.000 MPa

Ground anchors (tendons):
Ø 0,6" strand anchors, i.e. with A_s = 140 mm^2 each strand
Steel quality: St 1570 / 1770, i.e. f_{yk} = 1570 MPa / f_{uk} = 1770 MPa
E = 200.000 MPa
anchor level (at wall): +0,5
inclination: v = 35° to horizontal
distance between anchors, c = 2,0 m (irrespective of module of sheet pile profile)

ULS (GEO)

- Design Approach (DA)
- Partial coefficients for soil parameters and actions
- Wall roughness, $k = \tan\delta / \tan\varphi$.
  k^a for back (active) side and k^p for front (passive) side
- Earth pressure coefficients
- Bending moment in wall M_{Ed}
- Horizontal anchor force per linear meter A_h
- Axial anchor force per anchor $F_{ULS;d}$
- Necessary toe level of wall, i.e. embedment depth and thus height of wall h
- Resultant of vertical component of earth pressures, V
- Resultant of vertical component of earth pressure and anchor force = $V - A_h \tan(v)$
- Theory of earth pressure calculation
- Name and type (LEM or FEM) of software used

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SLS (GEO)

- Section properties of particular sheet pile profile, incl. β_D factor, c.f. EC3-5, 6.4 + National Annex (NA)
- Wall-soil interface roughness, k
- n = number n of Ø0,6" strands in every strand anchor (c-c = 2,0 m)
- L_{tf} = free anchor length = tendon free length
- L_{tb} = fixed anchor length = tendon bond length
- Horizontal deformation of wall
  at top of wall, anchor level, excavation level and toe level
- Vertical deformation of top of wall
- P_0 = Lock off load = pre-stress of anchor (axial per anchor) = 75 % of $F_{ULS;d}$
- $F_{Serv;k}$ = characteristic value of the maximum, axial anchors force, including effect of lock off load, c.f. EN 1997-1/A1:2013
- Maximum bending moment M and normal force N in wall, per linear meter

ULS (STR)

Sheet pile wall

Bending moment in wall M_{Ed} (from ULS-GEO)
Horizontal anchor force per linear meter A_h (from ULS-GEO)
Axial (normal) force in wall $N_{Ed} = A_h \tan(v)$, $v = 35°$
Section properties of particular (chosen) sheet pile profile
Bending resistance $M_{c,Rd}$ c.f. EC3-5, 5.2.2 + NA regarding the β_B factor
Navier stress analysis

Anchors

Axial anchor force per anchor $F_{ULS;d}$ (from ULS-GEO), $F_{Serv;k}$ (from SLS)
Partial coefficients for anchors, c.f. NA for EC7-1/A:2013
Proof load P_p by acceptance test
Design tensile resistance $F_{t,,Rd} = \min(F_{tt,Rd}\ ;\ F_{tg;Rd})$, c.f. EC3-5, 7.2.3

Design basis (ULS)

Country	ULS	Partial coefficients				
	DA / LC	Soil parameters, γ_M			Actions, γ_F	
		γ_φ	$\gamma_{c'}$	γ_{cu}	γ_G	γ_Q
Denmark	DA3, LC4	1,2	1,2	1,8	1,0	1,5
Finland	DA2*	1,0	1,0	1,0	1,15* / 1,35**	1,5* / 0**
Norway	DA3/DA2	1,25	1,25	1,40	1,0	1,3
Sweden	DA3	1,3	1,3	1,5	1,1	1,4

Finland:
* Equation 6.10 b EN 1990, both permanent and variable load
* * Equation 6.10 a EN 1990, only permanent load
The most critical must be used

ULS (GEO): wall roughness k and earth pressure coefficients K(φ_d, k)

Country			Earth pressure coefficients			
			active side		passive side	
	γ_φ	φ_d	k^a	$K_\gamma^a(k)$	k^p	$K_\gamma^p(k)$
Denmark	1,2	29,2	1,0	0,26	1,0	5,86
Finland	1,0	35,0	0,616	0,24	0,356	6,27
Norway	1,25	28,0	0,0		0,5	
Sweden	1,3	26,9	0,5	0,32	0,5	4,57

Wall roughness according to EC7-1

9.5.1 Determination of earth pressures

…

(5) The amount of shear stress, which can be mobilised at the wall-ground interface should be determined by the wall-ground interface parameter δ.

(6) A concrete wall or steel sheet pile wall supporting sand or gravel may be assumed to have a design wall ground interface parameter $\delta_d = k.\varphi_{cv;d}$. k should not exceed 2/3 for precast concrete or steel sheet piling.

(7) For concrete cast against soil, a value of k = 1,0 may be assumed.

…

(10) The value of an earth pressure at an ultimate limit state is generally different from its value at a serviceability limit state. These two values are determined from two fundamentally different calculations. Consequently, when expressed as an action, earth pressure cannot have a single characteristic value.

Active earth pressure coefficients, c.f. EC7-1 Annex C.1

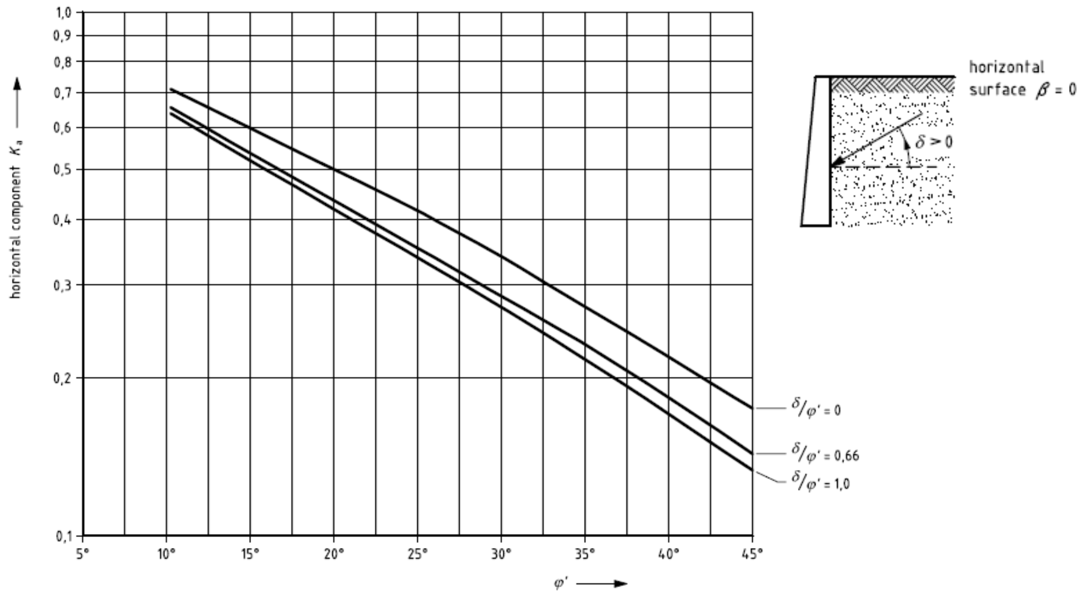

Figure C.1.1 — Coefficients K_a of effective active earth pressure (horizontal component): with horizontal retained surface ($\beta = 0$)

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Passive earth pressure coefficients c.f. EC7-1, Annex C.1

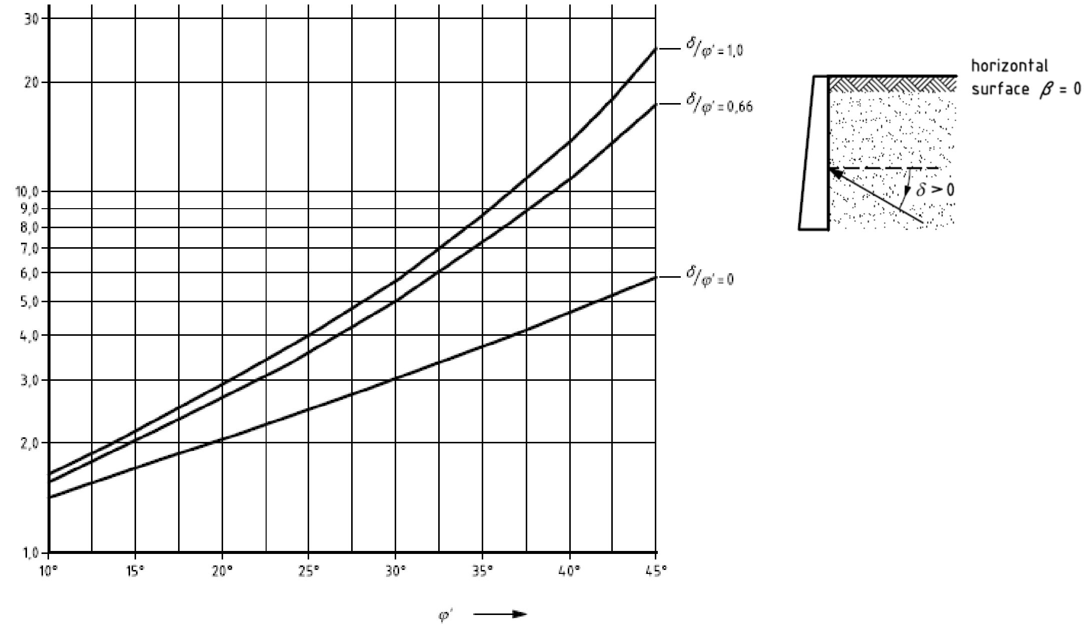

Figure C.2.1 — Coefficients K_p of effective passive earth pressure (horizontal component): with horizontal retained surface ($\beta = 0$)

ULS (GEO)

Country	Retaining wall GEO calculation							Theory	Software	
	M_{Ed}	A_h	$F_{ULS;d}$	Toe	h	V	$V-A_h \tan(v)$		Name	Type
	kNm/m	kN/m	kN	m	m	kN/m	kN/m			LEM/FEM
Denmark	439	186	454	-8,7	10,7	72	-58	J. Brinch Hansen	Spooks	LEM
Finland	605	356	869	-10,5	12,5	-49	-298	Coulomb	Geocalc 3.0	FEM
Norway	655	250	610	-10,5	12,5	175	0	Rankine	GeoSuite	FEM
Sweden	517	195	476	-10,6	12,6	137	0	Mohr-Coulomb	AK spont	LEM

Sweden: Toe: -9.55 for rotational. App. 1,1 m extra is needed for vertical stability

SLS: national choice of input (wall section and number of anchors)

Country	Sheet pile wall					Wall	Ground anchors			
	Profile	β_D	I	A_s	Mass	interf.	Ø0,6"	n A_a	L_{tf}	L_{tb}
			cm^4/m	cm^2/m	kg/m^2	k	n	mm^2	m	m
Denmark	AZ 23-800	1,0	55260	151	118	0,67	4	560	7,0	8,0
Finland	Larssen 607 n	1,0	72320	403	190	0,67	4	560	7,0	8,0
Norway	Larssen 607 n	0,8	72320	240	190		4	560	7	*)
Sweden										

Norway:

β_D = 0,8 for U-profiles, else 1,0

*) the grout principle is not decided, and dimensions hence not calculated.

Normally we don't use strand anchors in combination with strand anchors grouted in sand.

SLS: national out put

Country	Deformation, u_x (mm)					u_z (mm)	Anchor forces		Section forces		Software	
	Top	Anchor	Excav	Toe		Top	P_0	$F_{Serv;k}$	M	N	Name	Type
	at 2,0	at 0,5	at -5,0	level	mm	at 2,0	kN	kN	kNm/m	kN/m		LEM/FEM
Denmark	55	61	64	-8,7	35	26	340	473	294	204	Plaxis	FEM
Finland	30	40	57	-10,5	0,4	-	349	436	507	125	Geocalc 3.0	FEM
Norway	-4	9	35	-10,5	0	-	450	502	416	144	GeoSuite	FEM
Sweden												

ULS (STR)

Country	ULS	Partial coefficients on steel				Sheet pile wall				
	DA / LC	f_{yk} < 500 MPa				M_{Ed}	γ_M	$\gamma_M * M_{Ed}$	A_h	N_{Ed}
		γ_{M0}	γ_{M0}	γ_{M1}	γ_{M2}	kNm/m			kN/m	kN/m
Denmark	DA3, LC4	1,1	1,2	1,2	1,35	439			186	130
Finland	DA2*	1,0	-	-	-	605	1,15	696	356	249
Norway	DA3/DA2	1,05	1,05	1,10	1,25	655	1,0 *)	655	250	175
Sweden	DA3	1,0	1,0	1,0	1,2	517			195	137

Finland:

Coefficient γ_M (kuorman mallikerroin) is used to multiply the design value of the bending moment: 1,15 if temporary wall (in this case), 1,35 if permanent wall

Norway:

As DA3 is critical -> γ_M = 1,0, with critical DA2 would be 1,35.
Some consultants would with DA2 use 1,4 or higher

ULS (STR)

Country	Profile	β_B	Mass, g	h x g	Stress analysis (elastic)			
					σ_n	σ_m	σ_{tot}	f_{yk} / σ_{tot}
			kg/m^2	kg/m	MPa	MPa	MPa	f_{yk} = 240
Denmark	AZ 23-800	1,0	118	1263	8,6	188	197	1,22
Finland	Larssen 607 n	1,0	190	2375	6,2	189	195	1,23
Norway	Larssen 607 n	0,8	190	2375	7,3	205	212	1,13
Sweden	AZ 23-800	1,0	118	1487	9,0	222	231	1,04

ULS (STR)

Country	Anchors				Acceptance test						Tensile resistance		
	$F_{ULS;d}$	$F_{Serv;k}$	γ_{Serv}	$E_{ULS;d}$	$\gamma_{a;acc;ULS}$	$\gamma_{a;acc;SLS}$	P_p	Limit of P_p (kN)			k_t	$F_{tt;Rd}$	$F_{tg;Rd}$
	kN	kN		kN	(8.13)	(8.14)	kN	80 % f_{uk}	95 % f_{yk}	90 % f_{yk}		kN	kN
Denmark	454	473	1,00	473	1,30	NA	615	793	835		1,0	734	733
Finland	869	436	1,00	869	1,25	NA	1086	-	-	791	1,0	-	879
Norway	610	502	1,35	678	1,10		745	793	835		0,9	714	837
Sweden	476	476	1,35	643	1,05	NA	675	793	835		0,9	743	879

All countries chose 4 nos. of (Ø0,6" strands, … even Finland ?

Sweden:
k_t = 0,9 assuming that the connection to the sheet pile do not induce bending (in the anchor)

A common Nordic view - on retaining wall design?

1. Design Approach (DA): MFA, RFA – or EFA
2. Partial coefficients – on actions, soil/material parameters and resistances
3. Handling of water pressure. (not) factoring of water pressure, gradients, flow
4. Roughness of wall
5. Earth pressure theory and – Guru (the ground model)
6. Use of effective cohesion (c') on active and/or passive side
7. Need for compatibility (rotational capacity of yield hinges if any, yield of anchors), single - vs multi anchored walls (soil-structure-interaction-model)
8. Ductility (β factors on sheet pile design c.f. EC3-5)
9. Toe (end) bearing resistance of retaining walls (steel sheet piles vs. concrete walls)
10. Estimate of lifetime, corrosion loss, ductility
11. Effect of pre stress of anchors
12. Method of testing of (grouted) anchors