NGM Reykjavik 2016
NMGEC7 Work shop: Design Approaches

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Member of:

- The Danish Standard Sub Committee for Eurocode 7: S-1997
- CEN / TC 288: Execution of special geotechnical works
  - WG 14: EN 1537 Ground anchors (done)
  - WG 16: EN 12699 Displacement piles and EN 14199 Micropiles (done)
  - WG 19: EN 12063 Sheet pile walls (coming up)
- CEN / SC7 / EG1: Anchors (the new Amendment A1), (done)
- CEN / SC7 / WG3: TG3 Pile + TG5 Anchors
- ISO / TC 182 / WG3: Testing of geotechnical structures –
  EN ISO 22477-5 Testing of grouted anchors …. (2016!)
  (previously under CEN/TC 341 … with a long history)

…. "funded" by Aarsleff

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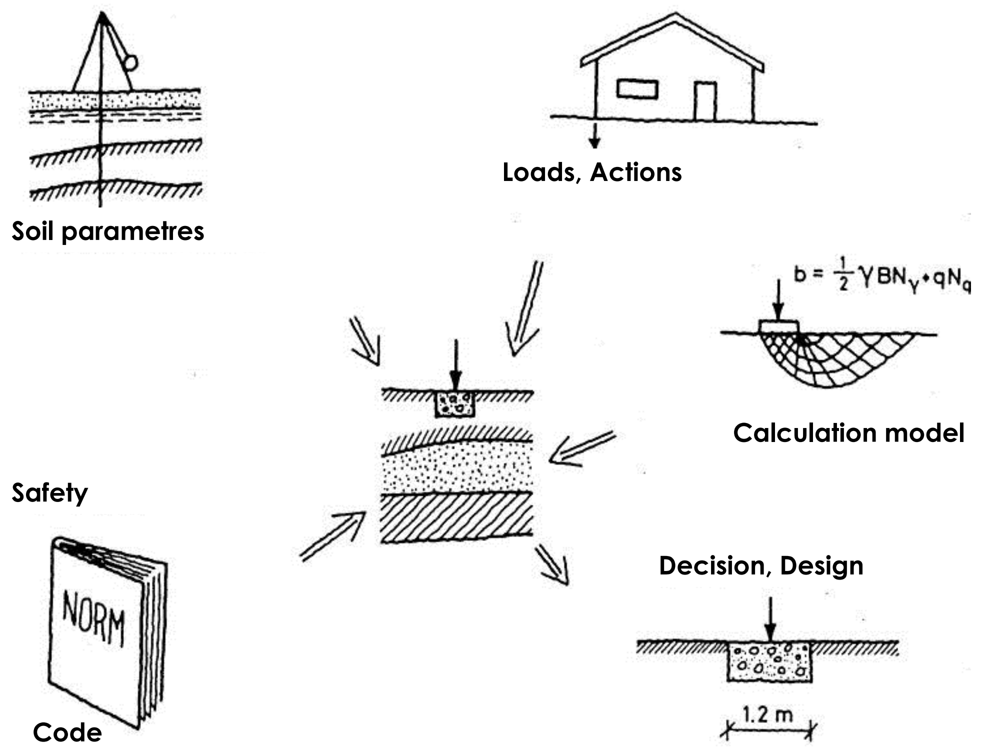

ULS E_d **or** $F_d \leq R_d$

E = effect of action, F = Force (action)
subdivided into permanent actions (G), variable actions (Q) and accidental actions (A)

R = structural (STR) or geotechnical (GEO) resistance (materials and/or elements), measured (m) or calculated (cal).

Index d for design, i.e. increased or reduced

$$E_d = \gamma_E E_k \qquad R_d = \frac{R_k}{\gamma_R} = \frac{R_m \text{ or } Rcal}{\xi\, \gamma_R}$$

EN 1990

6.4.3.2 Combinations of actions for persistent or transient design situations (fundamental combinations)

(1) The general format of effects of actions should be :

$$E_d = \gamma_{Sd} E\{\gamma_{g,j} G_{k,j} ; \gamma_p P ; \gamma_{q,1} Q_{k,1} ; \gamma_{q,i} \psi_{0,i} Q_{k,i}\} \quad j \geq 1 ; i > 1 \qquad (6.9a)$$

(2) The combination of effects of actions to be considered should be based on
– the design value of the leading variable action, and
– the design combination values of accompanying variable actions :

NOTE See also 6.4.3.2(4).

$$E_d = E\{\gamma_{G,j} G_{k,j} ; \gamma_P P ; \gamma_{Q,1} Q_{k,1} ; \gamma_{Q,i} \psi_{0,i} Q_{k,i}\} \quad j \geq 1 ; i > 1 \qquad (6.9b)$$

(3) The combination of actions in brackets { }, in (6.9b) may either be expressed as :

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \qquad (6.10)$$

or, alternatively for STR and GEO limit states, the less favourable of the two following expressions:

$$\begin{cases} \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} \psi_{0,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10a) \\ \sum_{j\geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10b) \end{cases}$$

Loads, design loads from combinations of actions, c.f. EN 1990, 6.4.3.2, cont.

6.10 a: when the dead load (G) is dominating

6.10 b: when the variable load (Q) is dominating

But how to cope with differentiating with different classes of consequence (or safety classes)?

And what about, when water pressure is dominating? ⇒ DK: New LC 5 (only STR)

We (DK) does (did) not want to factorise density of soil (γ_m , γ_s) or water (γ_w) !

effective density of soil under water: $\gamma' = \gamma_m - \gamma_w$

effective density of soil under water with gradient: $\gamma'' = \gamma' - i\,\gamma_w$ $i = \Delta H / \Delta s$

effective water density, when flowing: $\gamma_w' = (1 - i)\,\gamma_w$

Design Approaches in EN 1997-1, ULS: STR / GEO

- DA1: 1.1 A1 “+” M1 “+” R1
- 1.2 A2 “+” M2 “+” R1
- DA2: A1 “+” M1 “+” R1 ~ Resistance Factor Approach (RFA)
- DA3: (A1* or A2^T) “+” M2 “+” R3 ~ Material Factor Approach (MFA)

Why not just: **A** “+” **M** “+” **R**

A “+” M “+” **R** Resistance Factor Approach (RFA)

A “+” **M** “+” R Material Factor Approach (MFA)

The relevant approach depend on the geotechnical structure (**in Denmark**):

- Piles and anchors: RFA for GEO, MFA for STR
- Everything else (retaining structures, stability, spread foundations etc.): MFA
- New Load Case 5 (MFA) to cover dominating water pressure, ONLY for STR

DK approach

Differentiation of reliability is controlled by use of Consequences Classes
a γ_0 factor is introduced to control the application of the K_{FI} factor

The K_{FI} factor is applied on the partial coefficients on:

the actions (A)

OR

the materials (strength) (M) and resistances (R)

High Consequences Class, CC3: $K_{FI} = 1,1$
Medium Consequences Class, CC2: $K_{FI} = 1,0$
Low Consequences Class, CC1: $K_{FI} = 0,9$ (1,0 for UPL and EQU)

CC1 not used/allowed for geotechnical structures. However, temporary structures with less serious consequence of failure handled by use of the "alpha concept" $(\gamma_M)^\alpha$
α typically set to 0,5 i.e. using the square root of γ_M

Table A1.2(B+C) DK NA Design values of actions for persistent and transient design situations (STR/GEO) (sets B and C)

Limit state				STR/GEO				STR
Combination of actions				1	2	3	4	5
Reference formula				(6.10a)	(6.10b)	(6.10a)	(6.10b)	(6.10a)
Partial factors for actions								
Permanent action	Weight, general (**)	Unfavourable	$\gamma_{G;sup} \cdot K_{FI}$	$1,2 \cdot K_{FI}$	$1,0 \cdot K_{FI}$	1,2	1,0	1,0
		Favourable	$\gamma_{G;inf}$	1,0	0,9	1,0	0,9	1,0
	Weight of soil and (ground) water, geotechnical structures (***)	Unfavourable	$\gamma_{G;sup}$	1,0	1,0	1,0	1,0	1,0
		Favourable	$\gamma_{G;inf}$	1,0	1,0	1,0	1,0	1,0
Variable action (*)	Leading	Unfavourable	$\gamma_{Q,1} \cdot K_{FI}$	0	$1,5 \cdot K_{FI}$	0	1,5	0
	Other	Unfavourable	$\gamma_{Q,i} \cdot K_{FI}$	0	$1,5 \cdot \psi_0 \cdot K_{FI}$	0	$1,5 \cdot \psi_0$	0
Coefficient applied to partial factors for strength parameters and resistance								
Structural materials, cf. EN 1992 - 1996 and 1999			γ_0	1,0	1,0	K_{FI}	K_{FI}	$1,2\ K_{FI}$
Soil parameters and resistance, cf. EN 1997-1			γ_0	1,0	1,0	K_{FI}	K_{FI}	1,0 ($\gamma_M = \gamma_R = 1,0$)

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Harmonisation Proposal from PT1

Limit State		GEO/STR										
Foundation type		Slopes	Retaining structures			Shallow foundations			Piles / Anchors		Numerical methods	
Combination		1	1a	1b	2	1a	1b	2	3a	3b	4a	4b
Factoring method		MFA	MFA	EFA	RFA	MFA	EFA	RFA	RFA	RFA (ξ)	MFA	EFA
Partial factors on actions (from EN 1990)												
Unfavorable permanent	$\gamma_{G,n}$	??	??	1.0	??	??	1.0	??	??		??	??
Unfavorable variable	$\gamma_{Q,n}$	??		1.1	??	??	1.1		??		??	??
Favourable perm.	$\gamma_{G,fav,n}$	??	??			??			??		??	??
Partial factors on effects of actions $\gamma_{E;0}$												
Permanent / Variable	$\gamma_{EG;0}$ / $\gamma_{EQ;0}$	1.0	1.0	??	1.0	1.0	??	1.0	1.0		1.0	??
Partial factors on ground parameters $\gamma_{M;0}$												
Drained strength	$\gamma_{\varphi,0}$ - $\gamma_{c,0}$	1.25	(1)	1.0	1.0	(1)	1.0	1.0	1.0		(1)	1.0
Undrained strength	$\gamma_{cu,0}$	1.4										
Rock compression strength	γ_0	1.25	(1)	1.0	1.0	(1)	1.0	1.0	1.0		(1)	1.0
Rock tensile strength	γ_0	1.25	(1)	1.0	1.0	(1)	1.0	1.0	1.0		(1)	1.0
Partial factors on ground resistance $\gamma_{R;0}$												
Bearing resistance	$\gamma_{Rv,0}$	1.0	1.0		1.4	1.0		1.4			1.0	1.0
Sliding resistance	$\gamma_{Rh,0}$				1.1			1.1				
Earth resistance	$\gamma_{Re,0}$				1.4			1.4				
Pile shaft resistance	$\gamma_{s,0}$								1.1 - ξ			
Pile shaft (tension)	$\gamma_{s,t,0}$								1.15 – ξ			
Pile base resistance	$\gamma_{b,0}$								1.1 – ξ			
Pile tot. resistance	$\gamma_{t,0}$								1.1 – ξ			
Anchor resistance	$\gamma_{a,0}$								1.15 - ξ			

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Danish proposal

Limit State				GEO/STR				STR
Approach				(6.10a) + (6.10b)		(6.10)		(6.10)
Combination				(6.10a)	(6.10b)	(6.10) - STR	(6.10) - GEO	(6.10)
Partial factors on actions								
Permanent	Structural	Unf.	$\gamma_{G,sup}$	1.2	1.0	1.35	1.0	1.0
		Fav.	$\gamma_{G,inf}$	1.0	0.9	1.0	1.0	1.0
	Geotechnical	Unf.	$\gamma_{G,sup}$	1.0	1.0	1.0	1.0	1.0
		Fav.	$\gamma_{G,inf}$	1.0	1.0	1.0	1.0	1.0
Variable	Leading	Unf.	$\gamma_{Q,1}$	0	1.5	1.0	1.3	0
	Accompanying	Unf.	$\gamma_{Q,i}$	0	1.5 ψ_0	0	1.3 ψ_0	0

Partial factors on ground parameters

		MFA	RFA	MFA	RFA	MFA	RFA	MFA	RFA	EFA
Coefficient of shearing resistance	γ_φ	1.2	-	1.2	-	-	-	1,25	-	1.0
Effective cohesion	γ_c	1.2	-	1.2	-	-	-	1,25	-	1.0
Undrained shear strength	γ_{cu}	1.8	-	1.8	-	-	-	1,4	-	1.0
Unconfined strength	γ_{qu}	1.8	-	1.8	-	-	-	1,4	-	1.0
Weight density	γ_γ	1.0	-	1.0	-	-	-	1,0	-	1.0

Partial factors on ground resistance

Bearing resistance	γ_{Rv}	-	1.3	-	1.3	-	-	-	1.3	1.0
Sliding resistance	γ_{Rh}	-	1.3	-	1.3	-	-	-	1.3	1.0
Earth resistance	γ_{Re}	-	1.3	-	1.3	-	-	-	1.3	1.0
Pile shaft resistance	$\gamma_{s,n}$	-	1.3	-	1.3	-	-	-	1.3	1.0
Pile shaft (tension)	$\gamma_{s,t,n}$	-	1.3	-	1.3	-	-	-	1.3	1.0
Pile base resistance	$\gamma_{b,n}$	-	1.3	-	1.3	-	-	-	1.3	1.0
Pile tot. resistance	$\gamma_{t,n}$	-	1.3	-	1.3	-	-	-	1.3	1.0
Anchor resistance	$\gamma_{a,n}$	-	1.3	-	1.3	-	-	-	1.3	1.0

Partial factors on effects of actions

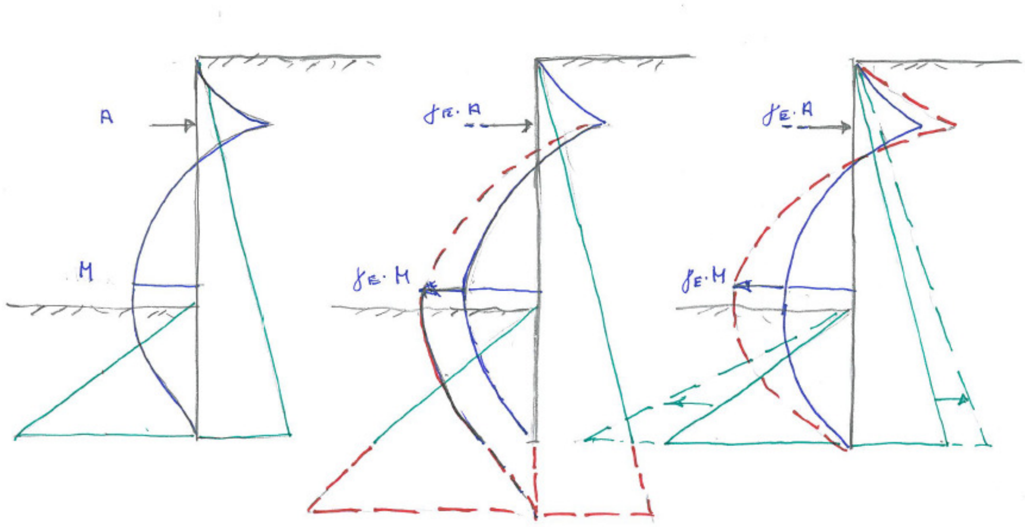
Structural effects	γ_E	1.0	1.0	1.2

Partial factors on materials/resistances for structural limit states

	MFA / RFA	MFA / RFA	MFA / RFA	MFA / RFA	-

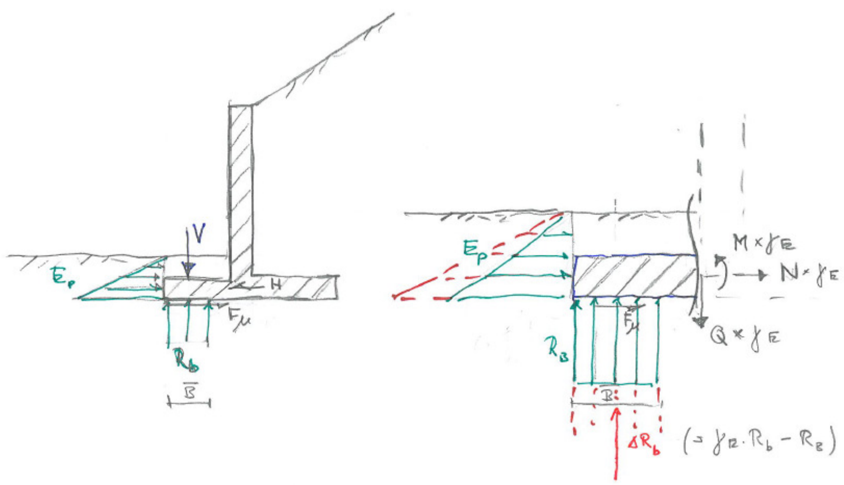
However, the Effect of Action Approach (EFA) does not fulfil equilibrium with reactions

Example: Retaining wall



However, the Effect of Action Approach (EFA) does not fulfil equilibrium with reactions

Example: Footing of gravity wall



A common Nordic view - on Design Approaches … amongst other things?

1. MFA and/or RFA, preferably not EFA

2. Differentiation of safety levels depending on:
   - Loss of lives
   - Loss of value
   - Complexity of soil and structure
   - Robustness
   - …. Mechanism of failure: ductile or without warning (friable)
     with or without extra capacity

3. Partial coefficients – on actions, soil/material parameters and resistances

4. Handling of water pressure:
   Horizontal – or "nearly" and Vertical (Uplift), what is the difference?