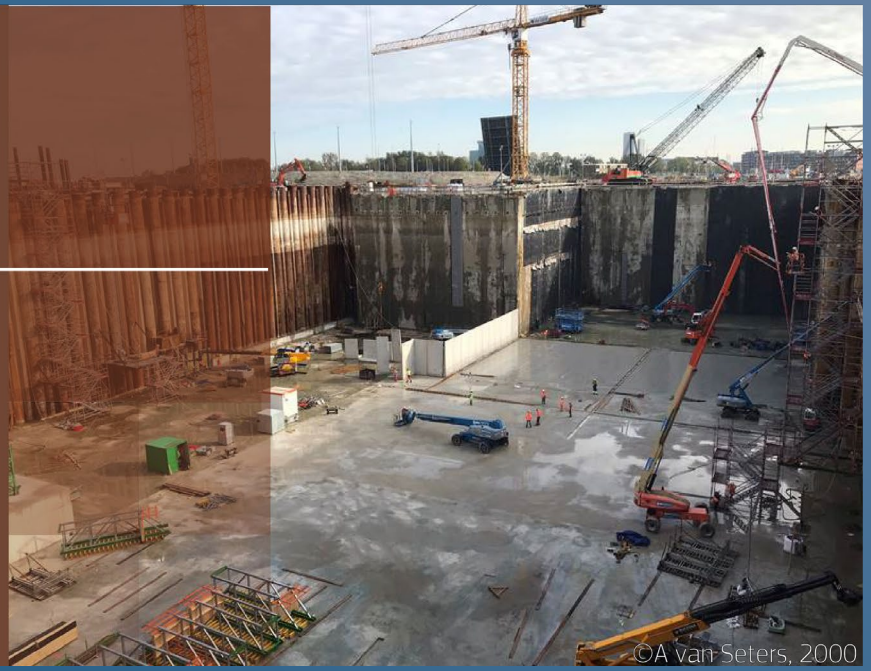
EN 1997

Geotechnical design



Adriaan van Seters

EUROCODE Conference I Berlin I 24 May 2023

2023 EUROCODE DIBt

Contents

1. EN1997-1: General Rules
2. EN1997-2: Ground Properties
3. EN1997-3: Geotechnical Structures

General: Many different soils/rocks in EU, many different traditions
EN1997 concentrates on safety, calculation models in Annex

Phase: All 3 Parts in drafting Phase for Formal Vote
Formal Vote: April-May 2024

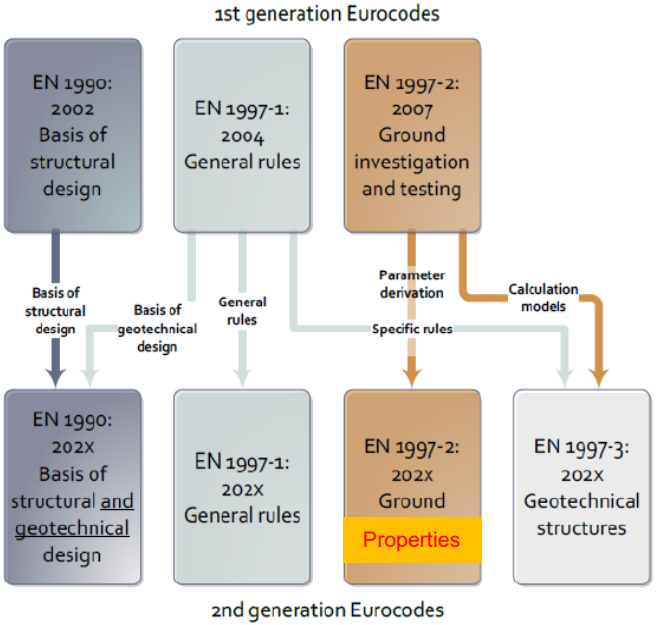
Main changes in Eurocode 7

Old Eurocode (3 parts):

1. EN1990 – Basis of structural design
2. EC7 Part 1 – Geotechnical rules
3. EC7 Part 2 – Testing and derivation of parameters

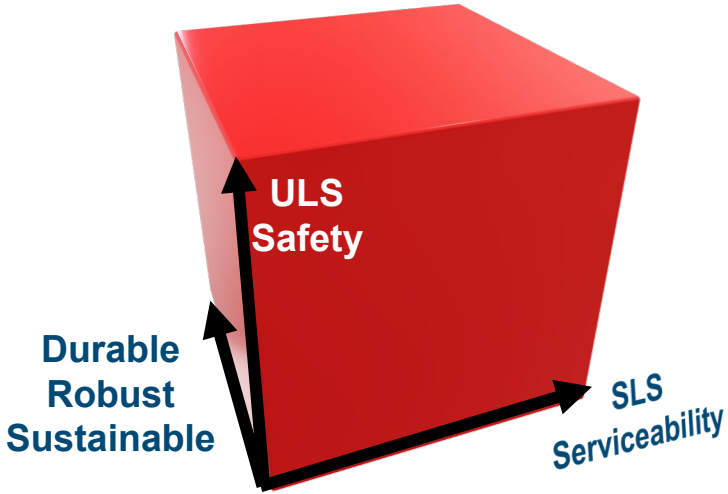
New Eurocode (4 parts!):

1. EN1990 – Basis of design – also geotechnical!
2. EC7 Part 1 – General rules for all structures, safety, characteristic values
3. EC7 Part 2 – Ground Properties and how to derive them from tests
4. EC7 Part 3 – Rules for specific geotechnical structures, many calculation models in Annexes

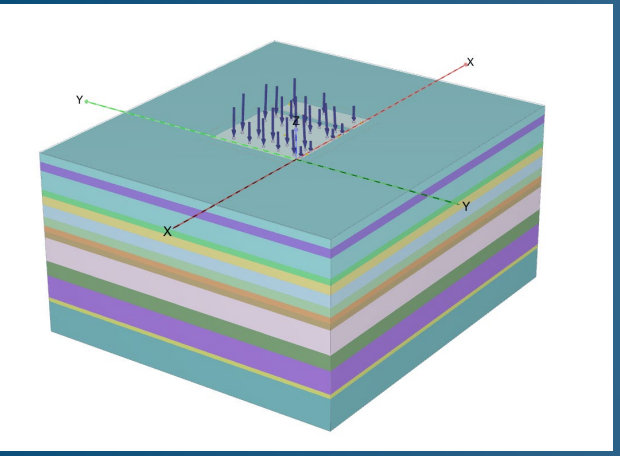


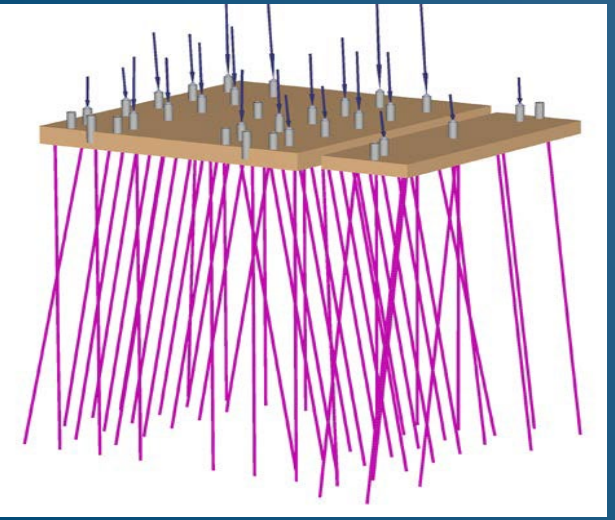
Geotechnical standards…

Toolbox for verification that your
Geotechnical structure is within the CUBE



Thanks to G. Franzen – Geoverkstan (SE), 2023





Eurocode 7 – Part 1 General Rules (EN1997-1)

Eurocode 7 Part 1 – Key Changes

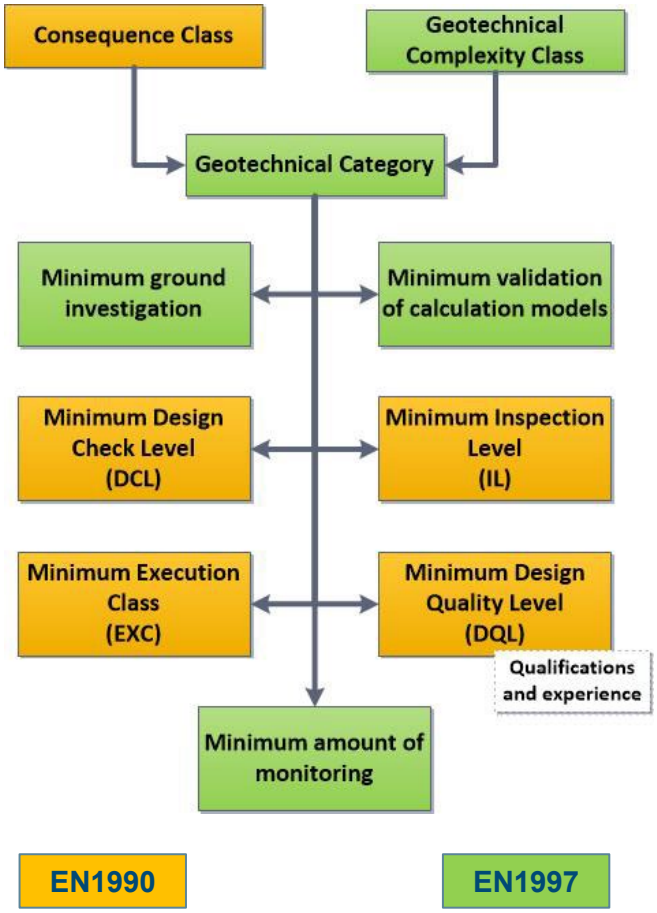
- New Geotechnical Category: Consequence (CC)-class and Ground Complexity (GCC)
- Representative value determination (by engineering judgement, by statistics)
- Improved Safety concept EN 1990 / EN 1997
- Groundwater issues - design groundwater pressures
- Safety for Numerical methods

Geotechnical categories

Geotechnical Category =

Consequence Class CC x
Geotechnical Complexity Class GCC

Consequence Class (CC)	Geotechnical Complexity Class (GCC)		
	Lower (GCC1)	Normal (GCC2)	Higher (GCC3)
High (CC3)			GC3
Medium (CC2)		GC2	
Low (CC1)	GC1		



Representative values

- Representative value – 2 options:

(4) <REQ> The representative value of a ground property X_{rep} shall be determined from either Formula (4.1) or Formula (4.2):

$$X_{rep} = X_{nom} \quad (4.1)$$

$$X_{rep} = X_k \quad (4.2)$$

where

X_{nom} is the nominal value of the ground property;

X_k is the characteristic value of the ground property.

- Nominal value – “cautious estimate”

- Characteristic value – 5 % lower bound value – Statistics (Informative Annex – Student t-distribution)

Safety EN1990 – Factors on actions

Action or effect				Partial factors γ_F and γ_E for Verification Cases 1 - 4				
Type	**Group**	**Symbol**	**Resulting effect**	**Structural**	**Static equilibrium and Uplift**		**Geotechnical Design**	
				Foundations Raft/piled	Uplift - water		Slopes	Retaining walls
				VC1	VC2(a)	VC2(b)	VC3	VC4
Permanent Action (G_k)	All	γ_G	unfavourable /destabilising	1,35 K_F	1,35 K_F	1,0	1,0	G_K is not factored
	Water	$\gamma_{G,w}$		1,2 K_F	1,2 K_F			
	All	$\gamma_{G,stb}$	stabilising	Not used	1,15		Not used	
	Water	$\gamma_{G,w,stb}$			1,0			
	(All)	$\gamma_{G,fav}$	favourable	1,0	1,0		1,0	
Variable action (Q_k)	All	γ_Q	unfavourable	1,5 K_F	1,5 K_F		1,3	1,1 (≈1.5/1.35)
	Water	$\gamma_{Q,w}$		1,35 K_F	1,35 K_F		1,15	1,0
	(All)	$\gamma_{Q,fav}$	favourable	0				
Effects-of-actions (E)		γ_E	unfavourable	Effects are not factored				1,35 K_F
		$\gamma_{E,fav}$	favourable					1,0

Partial Material factors – Persistent and Transient (NDP)

Ground property	Symbol	M1	M2
Soil and Fill parameters			
Shear strength - Effective stress	$\gamma_{\tau f}$	1,0	1,25 K_M
Peak shear friction	$\gamma_{\tan\varphi,p}$	1,0	1,25 K_M
Peak cohesion	$\gamma_{c,p}$	1,0	1,25 K_M
Critical state/residual friction/cohesion	$\gamma_{\tan\varphi,cs}$, $\gamma_{\tan\varphi,r}$, $\gamma_{c,r}$	1,0	1,1 K_M
Shear strength - Total stress	γ_{cu}	1,0	1,4 K_M
Rock material and rock mass parameters			
Shear/unconfined compressive strength	$\gamma_{\tau f}$, γ_{qu}	1,0	1,4 K_M
Rock discontinuities			
Shear strength	$\gamma_{\tau f,dis}$	1,0	1,25 K_M
Coefficient of residual friction	$\gamma_{\tan\varphi,dis,r}$	1,0	1,1 K_M

Factor K_M

CC-class	K_M
CC1	0,9
CC2	1,0
CC3	1,1

Groundwater – New Clause 6 – EN 1997-1

Groundwater level measurements and groundwater pressures

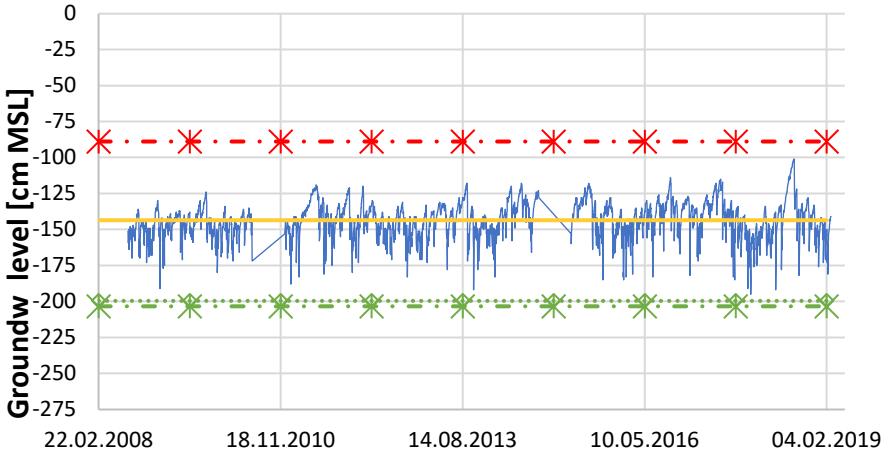
Representative value of Groundwater pressure $G_{w;rep}$:

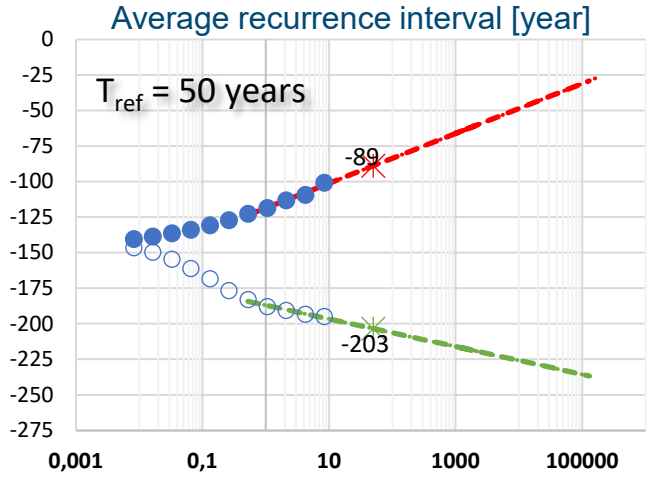
- Alternative 1: Upper or Lower value $G_{w;k;sup}$ or $G_{w;k;inf}$ (see figure)
- Alternative 2: Permanent mean $G_{w;k;mean}$ + Variable $Q_{w;rep}$ (amplitude)

  with variable $Q_{w;rep} = Q_{w;k}$,$Q_{w;comb}$, $Q_{w;freq}$ or $Q_{w;qper}$

Design value:

- Direct Assessment (Nominal value)
- Apply an offset to the representative waterpressure / water level
- Apply a partial factor (see EN 1990)





ULS for Numerical Methods – Clause 8.2

Two possibilities:

A – Input factoring

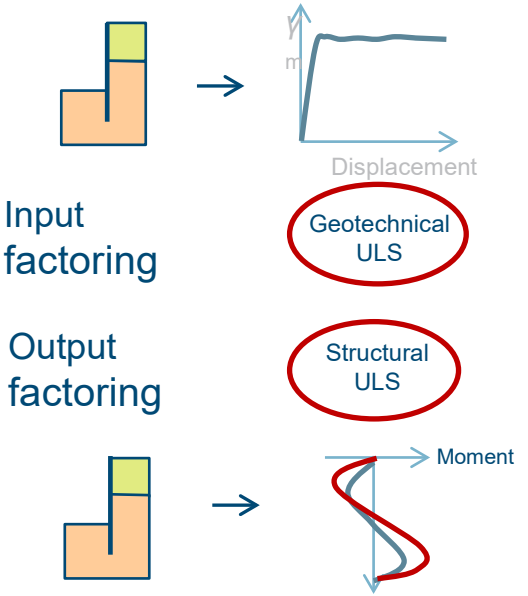
- Factors on actions γ_F from Verification Case 3
- Factors on material properties γ_M from Set M2

AND – Output factoring:

- Factors on effect-of-actions γ_E from Verification Case 4
- Material properties γ_M from Set M1 (= 1,0)
- No resistance factors

B – Output factoring only:

- Factors on effect-of-actions γ_E from Verification Case 4
- Factors on resistance γ_R according to EN1997-3
- Material properties γ_M from Set M1 (= 1,0)




Eurocode 7 – Part 2
Ground properties
(EN1997-2)

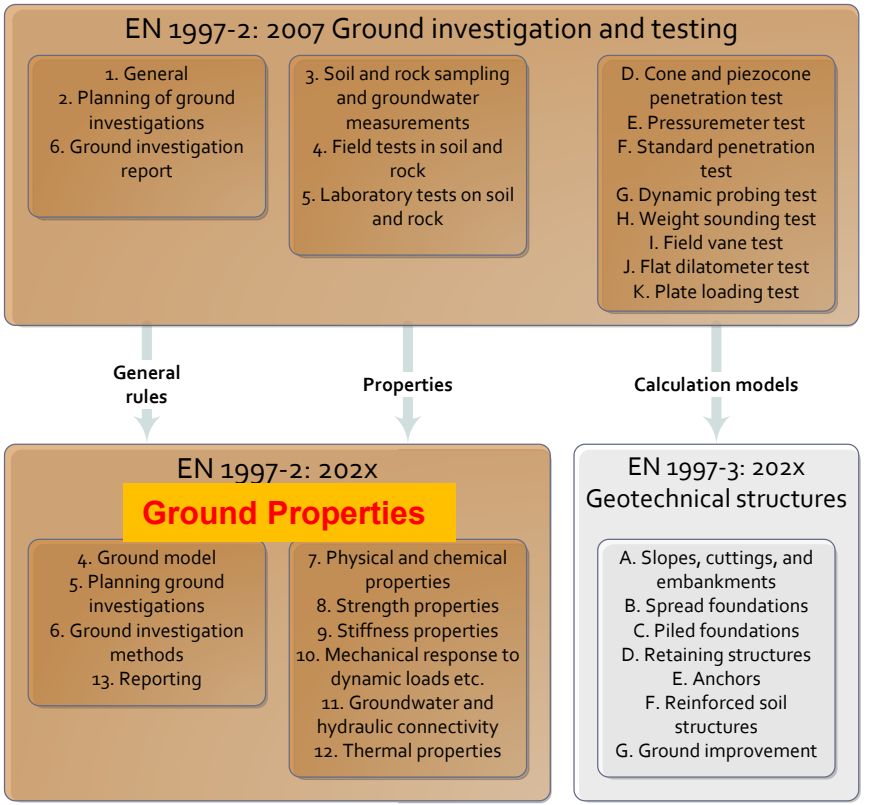
Key changes to EN1997-2

Complete reorganisation of EN1997-2

Focus on DESIGN instead of
GROUND INVESTIGATION

Calculation models in Old Annexes
→ PART 3

ROCK is included



Ground model

Definition: EN 1997-1, 3.1.6.6

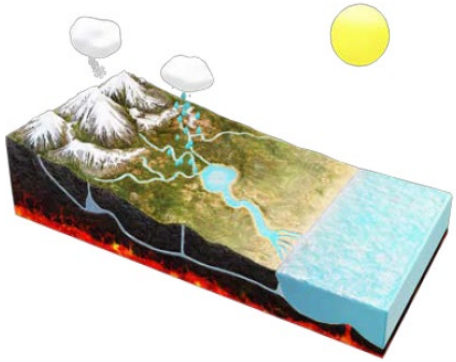
Site specific outline of the disposition and character of the ground and groundwater based on results from ground investigations and other available data.

EN 1997-2, 4.1(1)

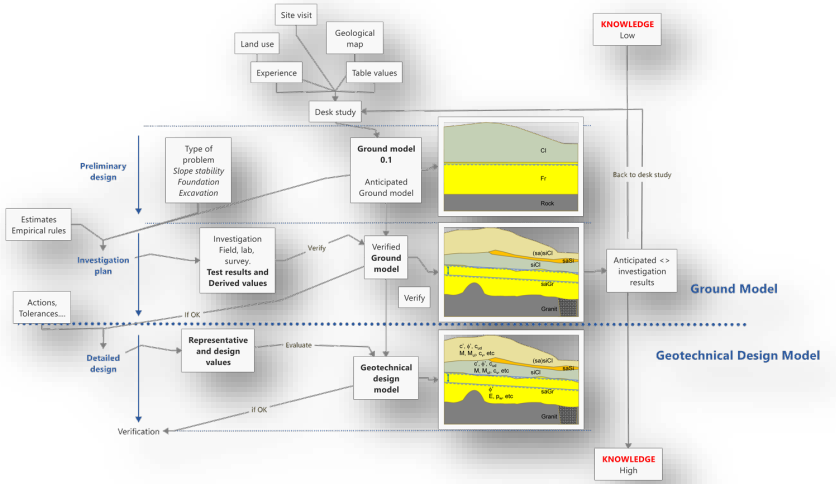
A Ground Model shall comprise the geological, hydrogeological, and geotechnical conditions at the site, based on the ground investigation results.

EN 1997-2, 4.1(4)

The Ground Model shall be progressively developed and updated based on potential new information.



Ground Model



Thanks to G. Franzen – Geoverkstan (SE), 2023

Derivation of ground parameters

Methods for parameter derivation:

- Physical, chemical and “state properties” (Clause 7)
- Strength parameters (Clause 8, Annex E)
- Stiffness and consolidation properties (Clause 9, Annex F)
- Cyclic, Dynamic en Seismic properties (Clause 10, Annex G)
- Geohydraulical properties (Clause 11)
- Thermal properties (Clause 12)

All Clauses have same layout:

Direct determination – from field/lab tests

Indirect determination – through correlations

Table 8.1 – Direct determination of soil strength properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
Peak effective cohesion and friction (c'_p, φ'_p)	Consolidated triaxial compression	EN ISO 17892-9	1	See 8.2.1 (4) to (10)
	Direct shear	EN ISO 17892-10	1	
	Direct simple shear	See Table B.5	1	

(8) <PER> In addition to 8.1.4, the values of the Hoek-Brown strength parameters for a rock mass may be determined using Formulae (8.6) to (8.8):

$$m_b = m_i e^{\left(\frac{GSI-100}{28-14D}\right)} \quad (8.6)$$

$$s = e^{\left(\frac{GSI-100}{9-3D}\right)} \quad (8.7)$$

$$a = \frac{1}{2} + \frac{1}{6} e^{\left(\frac{-GSI}{15}\right)} - e^{\left(\frac{-100}{15}\right)} \quad (8.8)$$

Table 8.2 – Indirect determination of soil strength properties

Property	Test	Standard	MQC	Comments on suitability and interpretation
Angle of peak effective friction (φ'_p)	Cone Penetration Test	EN ISO 22476-1	-	See Annex E for correlations (with I_D) for coarse soils correlations
	Standard Penetration Test	EN ISO 22476-3	-	
	Menard Pressuremeter Test	EN ISO 22476-4	-	-
	Flexible Dilatometer Test	EN ISO 22476-5	-	-
	Flat Dilatometer Test	EN ISO 22476-11	-	-

Eurocode 7 – Part 3 Geotechnical structures (EN1997-3)

Overview of EN1997-3

New Structures:

- Pile groups and pile rafts (Clause 6)
- Reinforced fill structures (Clause 9)
- Soil nailed structures (Clause 10)
- Ground Improvement (Clause 11)
- Ground water control (Clause 12)
- Rock bolts and surface support (Clause 13)

Existing, but completely updated clauses

- Slopes (Clause 4)
- Spread foundations (Clause 5)
- Piled foundations (Clause 6)
- Retaining structures (Clause 7)
- Anchors (Clause 8)

4. Slopes

Slopes in Soils and Rock –
Ultimate Limit State:

- Material Factoring Approach: partial factors on material properties, VC3

(Harmonisation – 1 method)

Clause 4 is basis for:

- Spread foundation on a slope (5)
- Anchors (8)
- Reinforced fill structures (9)
- Soil nailed structures (10)
- Rock bolts (13)

Table 4.1 (NDP) – Partial factors for the verification of ground resistance of slopes, cuttings, and embankments for fundamental (persistent and transient) design situations

Verification of	Partial factor on	Symbol	Material factor approach (MFA)[a,b]
Overall stability	Actions and effects-of-actions	γ_F and γ_E	DC3
	Ground properties[c]	γ_M	M2[b]
Bearing resistance	see Clause 5		

a Values of the partial factors for Design Cases 3, (DC3) are given in EN 1990 Annex A.
b Values of the partial factors for Sets M1 and M2 are given in EN 1997-1.
c Also includes ground properties of Class AI ground improvement (Clause 11)

5. Spread Foundations

Analytical Bearing models

- Bearing failure and overturning

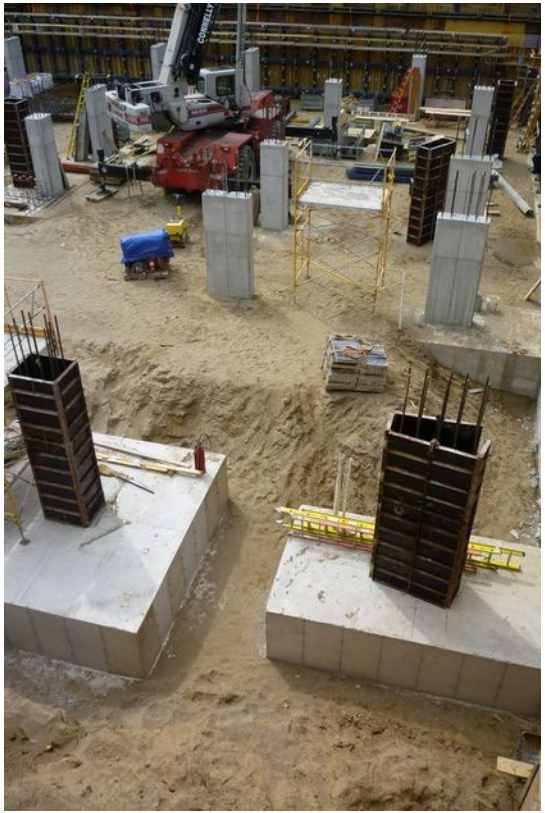
  (Brinch Hansen/Vesic – all EU-states):

$$R_N = A'\left(c'N_c b_c d_c g_c i_c s_c + q'N_q b_q d_q g_q i_q s_q + 0.5\gamma' B' N_\gamma b_\gamma d_\gamma g_\gamma i_\gamma s_\gamma\right)$$

- Drained and undrained

- Sliding failure

- Serviceability / Settlements (methods in Annex B)



5. Spread foundations – partial factors

Partial factor on		Material factor approach			Resistance factor approach	
		(a)	(b)	(c)	(d)	(e)
Spread foundations		**2 checks: (a) and (b)**				**H / V < 0.2**
Actions/effects	γ_F, γ_E	VC1 $\gamma_G = 1.35\ K_F$ $\gamma_Q = 1.5\ K_F$	VC3 $\gamma_G = 1.0$ $\gamma_Q = 1.3\ K_F$	VC1 $\gamma_G = 1.35\ K_F$ $\gamma_Q = 1.5\ K_F$	VC1 $\gamma_G = 1.35\ K_F$ $\gamma_Q = 1.5\ K_F$	VC4 $\gamma_E = 1.35\ K_F$ $\gamma_Q = 1.1$
Ground properties	γ_M	M1 $\gamma_{tan\varphi} = 1.0$ $\gamma_{cu} = 1.0$	M2 $\gamma_{tan\varphi} = 1.25\ K_M$ $\gamma_{cu} = 1.4\ K_M$	M2 $\gamma_{tan\varphi} = 1.25\ K_M$ $\gamma_{cu} = 1.4\ K_M$	Not factored	
Bearing resistance	γ_{Rv}	Not factored			1.4	
Sliding resistance	γ_{Rh}	Not factored			1.1	

Different Verification cases

6. Piled foundations

- Pile classification system (Examples in Annex) → Partial Factors

Pile type	Description	Class
Displacement pile	Pile installed in the ground without excavation of material	Full displacement
		Partial displacement
Replacement pile	Pile installed in the ground after the excavation of material	Replacement
Pile not listed above	---	Unclassified

- Axial loading – single piles; only Resistance Factoring (RFA)
- Transverse loading: only Material Factoring (MFA)
- Ground model method (averaging ground parameters over site)
- Model pile method (averaging calculated capacities over site)
- Correlation factors (depend on number of load tests/ground investigation and variation of results)

6. Piled Foundations – pile groups

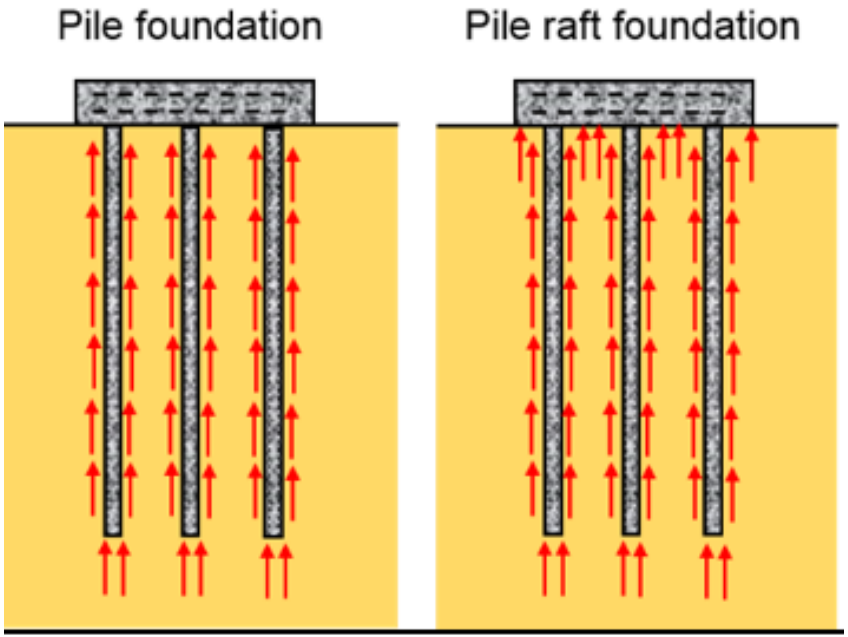
Pile groups and piled rafts

ULS verification:

- Axially loaded: MFA and RFA
- Transverse loads: MFA

Annex: models for group bearing capacity – tension/compression

Annex: model for negative shaft friction



7. Retaining structures

- Analytical (spring) and continuum models
- Maximum active and passive pressures
- Material factoring MFA or:
- Resistance factoring RFA (Effect of actions)
- Observational Method!

8. Anchors

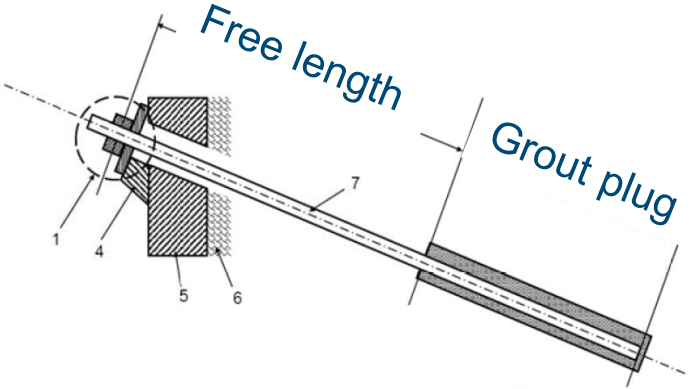
Anchors with free length

Design based on tests or comparable experience

3 Types of tests:

- Investigation test (failure, lost anchor)
- Suitability test (anchor in project)
- Acceptance test (control test, all anchors)

ULS-verification **only** by testing (acceptance test)

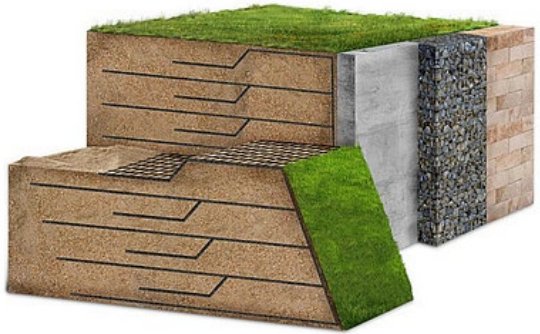


9. Reinforced fill

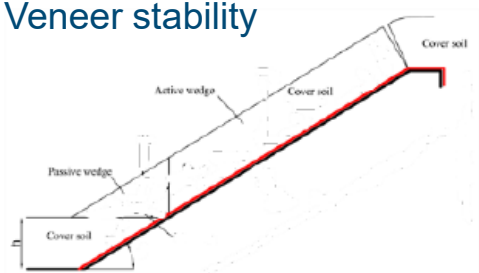
Reinforced Fill

- Reinforced fill
- Embankment bases
- Veneer stability

Annex F – Design methods



Veneer stability



10. Soil nailed structures

Clause 10 includes:

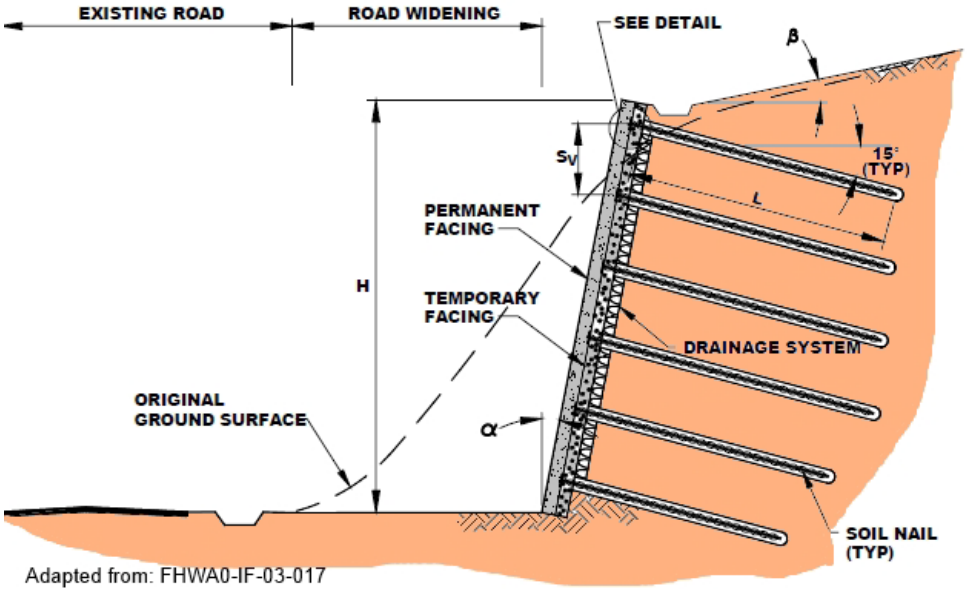
- soil nails (see figure)
- sprayed concrete
- wire mesh
- facing elements.

ULS –

Material factoring

Resistance factoring

Design by testing



Adapted from: FHWA0-IF-03-017

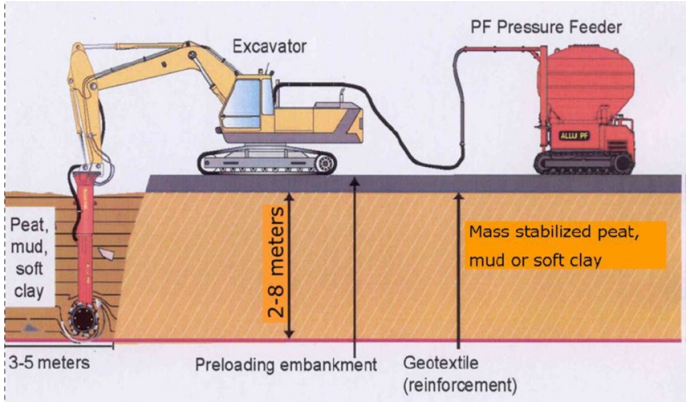
11. Ground Improvement

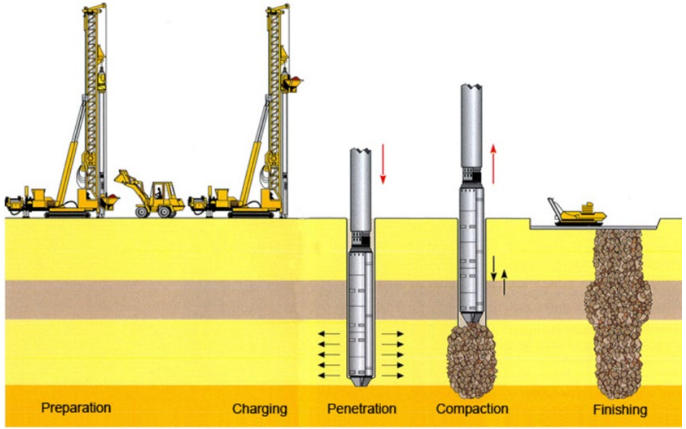
Diffused methods:

- compaction
- replacement
- grouting
- deep mixing (figure)

Discrete methods:

- stone/sand columns (figure)
- jetgrouting
- deep mixing
- steel/concrete columns





Vibro replacement to form stone columns (gravel columns) (Keller catalogue)

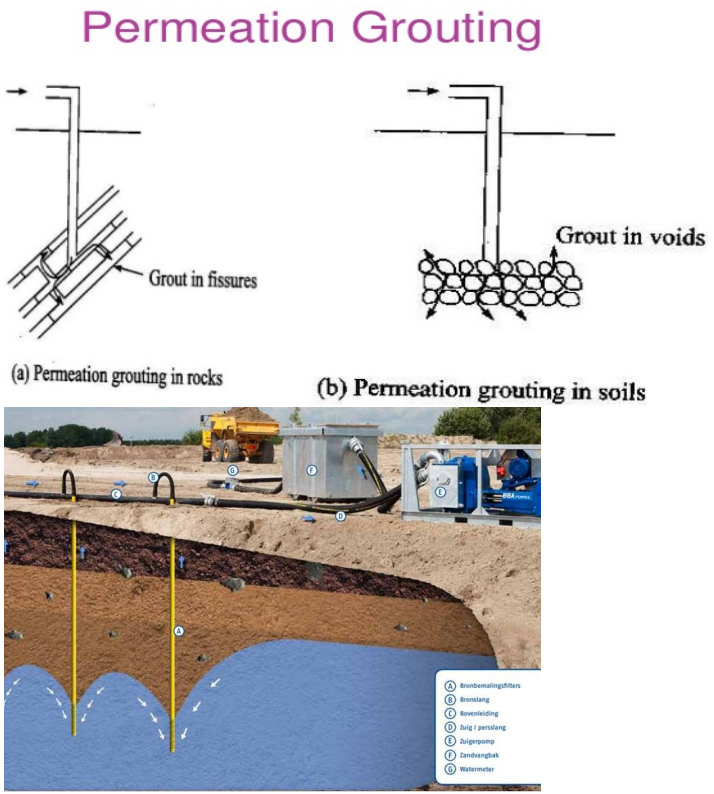
12. Groundwater control

Groundwater control:

- Grouting
- Drainage systems and pumping
- Vertical barriers

For hydraulic conductivity check:

- Serviceability Limit State governs!



13. Rock Bolts and Surface support

Clause 13 includes:

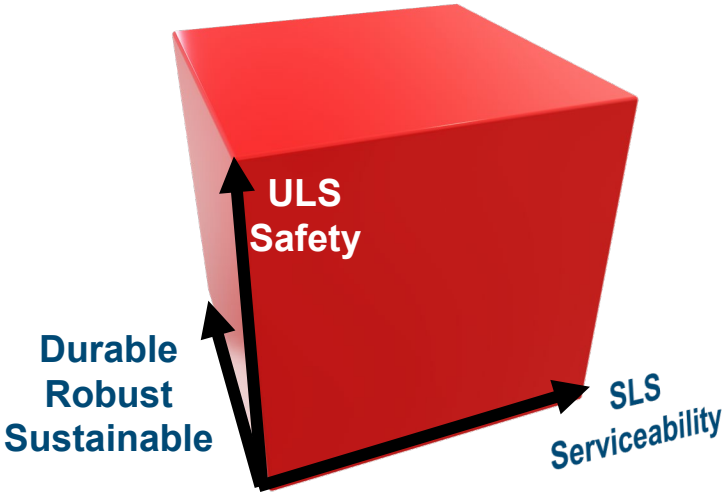
- rock bolts
- sprayed concrete
- wire mesh

ULS –
Resistance factoring
Design by testing
Prescriptive measures!

CONCLUSION: a New Generation Eurocode 7

Update your toolbox!

And stay inside the CUBE!



Thanks to G. Franzen – Geoverkstan (SE), 2023

Further information on EN1997

Webinars with NEN, ISSMGE:

Period	Topic
24 mei-23 (!)	Ground model, characteristic values, reliability
sep-23	Slopes, reinforced fill, soil nails, rock bolts + traffic loading
dec-23	Part 2: Ground Properties
feb-24	Ground improvement
mei-24	Rock engineering
sep-24	Spread foundations, retaining structures, anchors
dec-24	Dynamic ground properties and seismic design (with EN1998)

See: NEN-website, events

JRC-Guidelines, written by SC7, published in 2024:

- From Derived to Design material properties
- Ground Model
- Reliability-based verification with EN1997
- Implementation of design in Execution phase
- Design examples

Thank you for listening

Presented by
Adriaan van Seters
Chair CEN/TC 250/SC 7 – Geotechnical Design

Organisation
FUGRO
The Netherlands

Email: chair-ec7@fugro.com
www.fugro.com

2023 EUROCODE DIBt