Reinforcing the 2nd generation Eurocode 7

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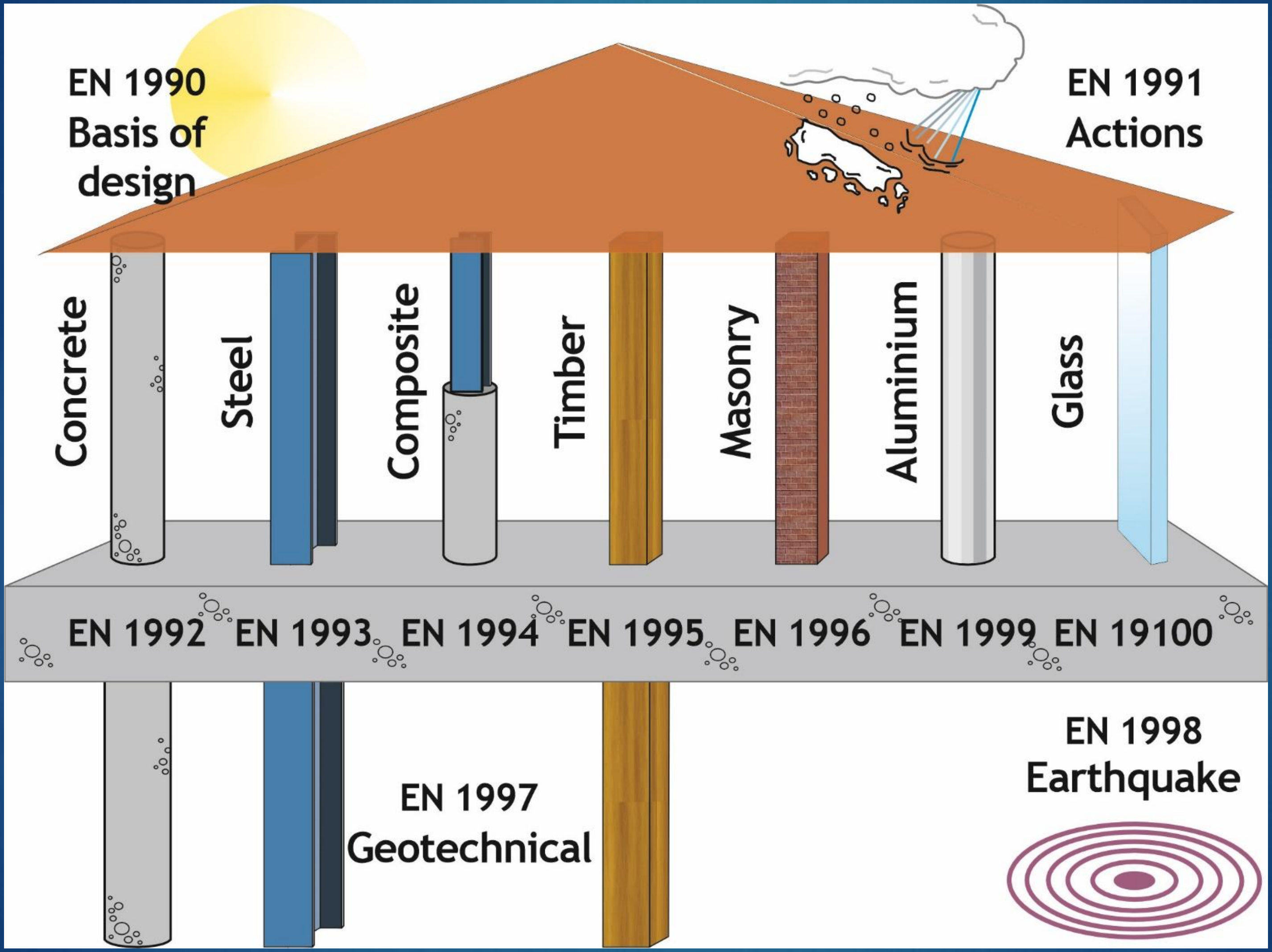
Reinforcing the 2nd generation Eurocode 7

- What are the 2nd generation Eurocodes?
- What's in the new Eurocode 7?
- Does the new code cover reinforced fill structures?
- How does this affect existing UK practice?
- Summary of key points

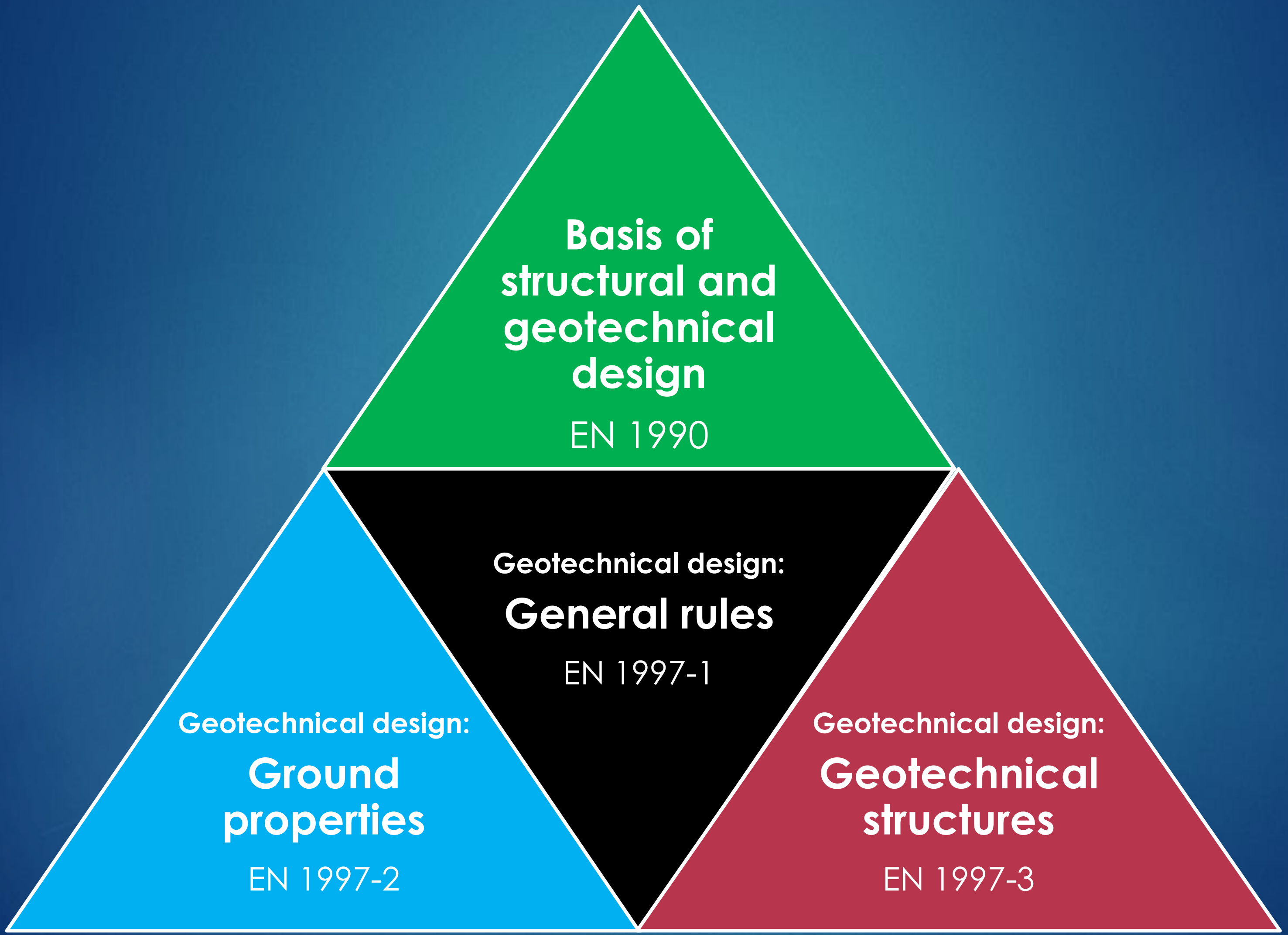
What are the 2nd generation Eurocodes?

REINFORCING THE 2ND GENERATION EUROCODE 7

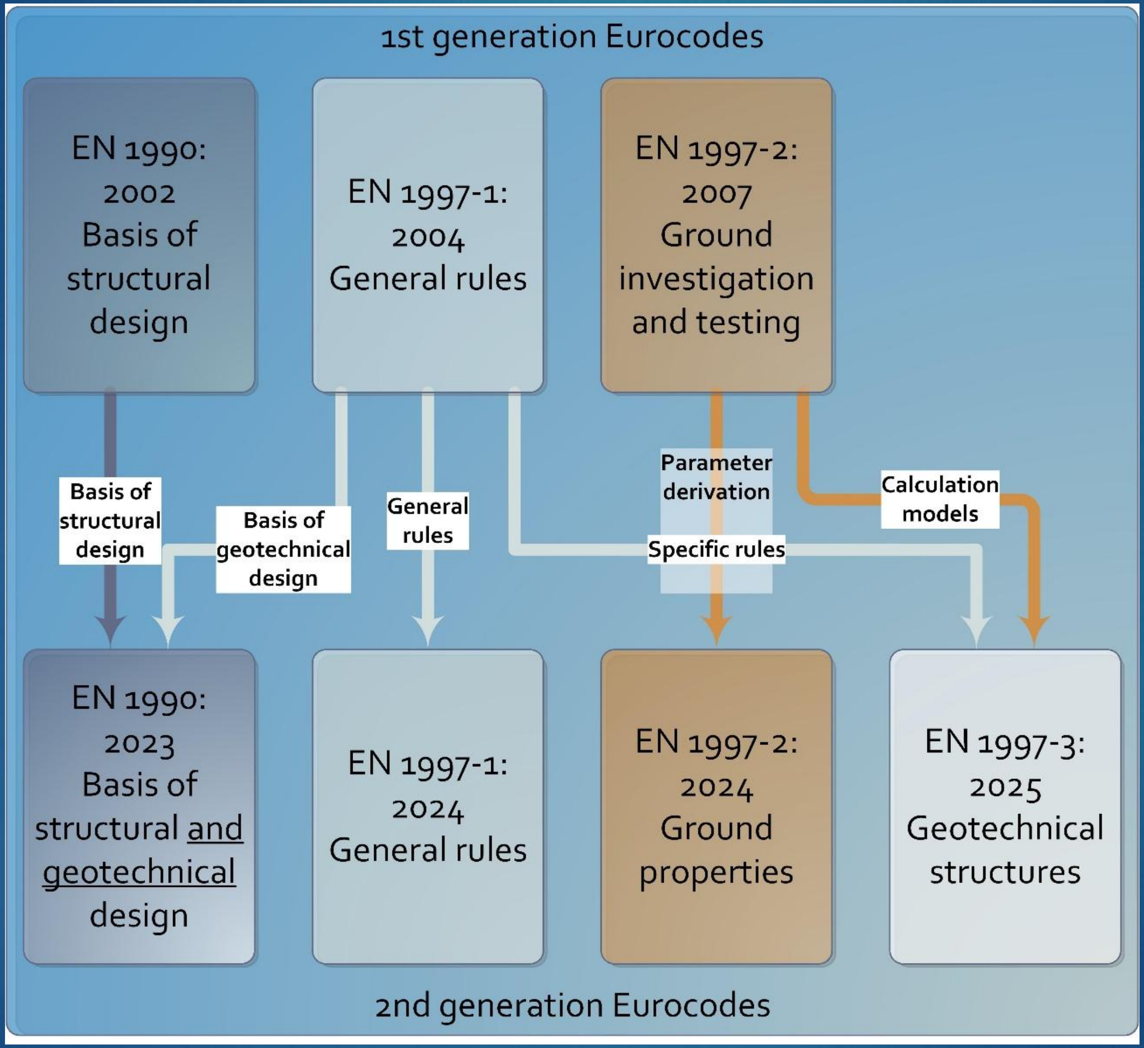
Overview of the 2nd generation Eurocode suite



2nd generation Eurocodes
Core geotechnical design standards



2nd generation – transformation of Eurocode 7 into 3 Parts



What's in the new Eurocode 7?

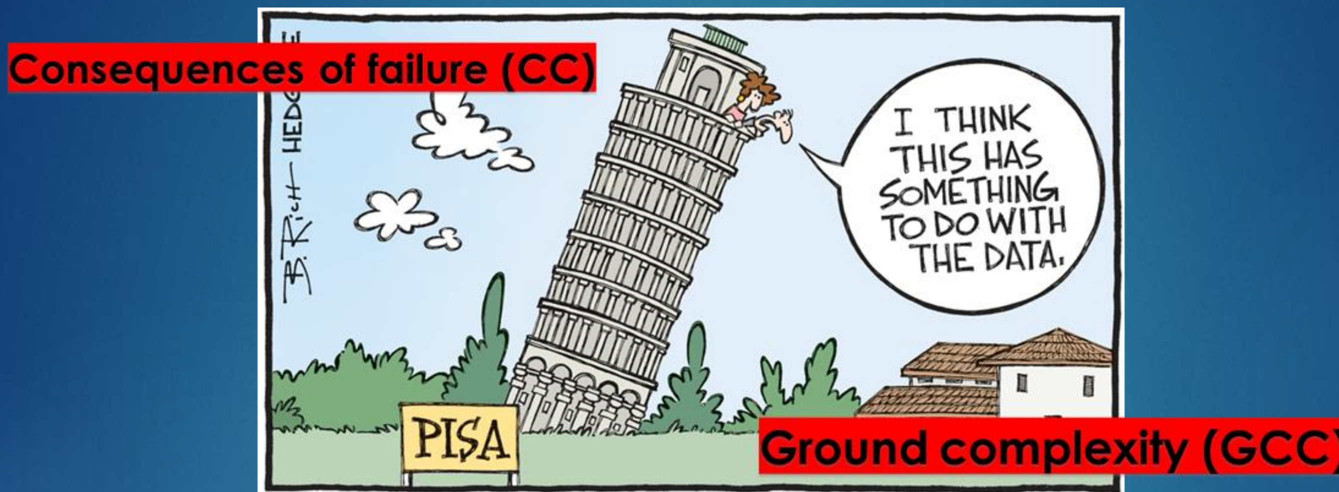
REINFORCING THE 2ND GENERATION EUROCODE 7

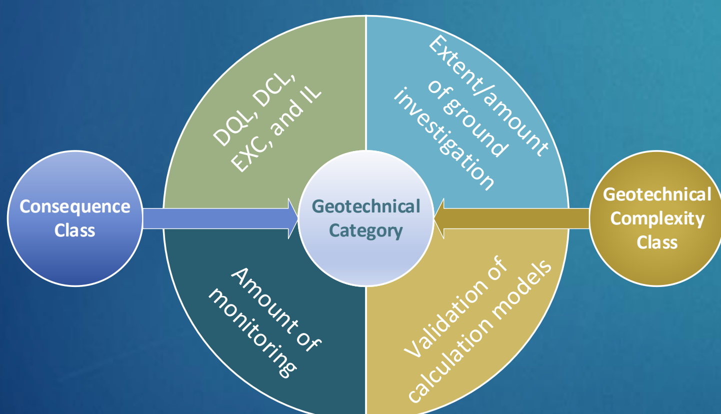
Assumptions made by EN 1997

In addition to the assumptions given in EN 1990, EN 1997 (all parts) assumes:

- **ground investigations** are planned by individuals or organizations **knowledgeable about potential ground and groundwater conditions** — New
- ground investigations are executed by individuals with appropriate skill and experience
- evaluation of test results and derivation of ground properties from ground investigation are carried out by individuals with **appropriate geotechnical experience and qualifications** — New
- data required for design are collected, recorded, and interpreted by appropriately qualified and experienced individuals
- geotechnical structures are designed and verified by individuals with **appropriate qualifications and experience in geotechnical design** — New
- adequate continuity and communication exist between individuals involved in data-collection, design, verification and execution

Revised definition of the Geotechnical Category





Consequence Class	Geotechnical Complexity Class (GCC)		
	Lower (GCC1)	Normal (GCC2)	Higher (GCC3)
CC3			**GC3**
CC2		**GC2**	
CC1	**GC1**		

Consequences of failure

New

New

Consequence class/ Description		Loss of human life*	Economic, social or environ-mental*	Examples of buildings where…	Factor k_F	Reliab-ility index, β_{50}	Prob-ability of failure, $P_{f,50}$
CC4	Highest	Extreme	Huge	Additional provisions can be needed			
CC3	Higher	High	Very great	people assemble e.g. grandstands, concert halls	1.1	4.3	$\sim 10^{-5}$
CC2	Normal	Medium	Consider-able	people normally enter e.g. residential and office buildings	1.0	3.8	$\sim 10^{-4}$
CC1	Lower	Low	Small	people do not normally enter e.g. agricultural buildings, storage buildings	0.9	3.3	$\sim 10^{-3}$
CC0	Lowest	Very low	Insignificant	Alternative provisions may be used			
*CC is chosen based on the more severe of these two columns							

Basic requirements of EN 1997-1

The following models shall be used to verify the requirements for safety, serviceability, robustness, and durability of geotechnical structures:

- **Ground Model** ← New
- **Geotechnical Design Model** ← New

Ground Model

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

Geotechnical Design Model

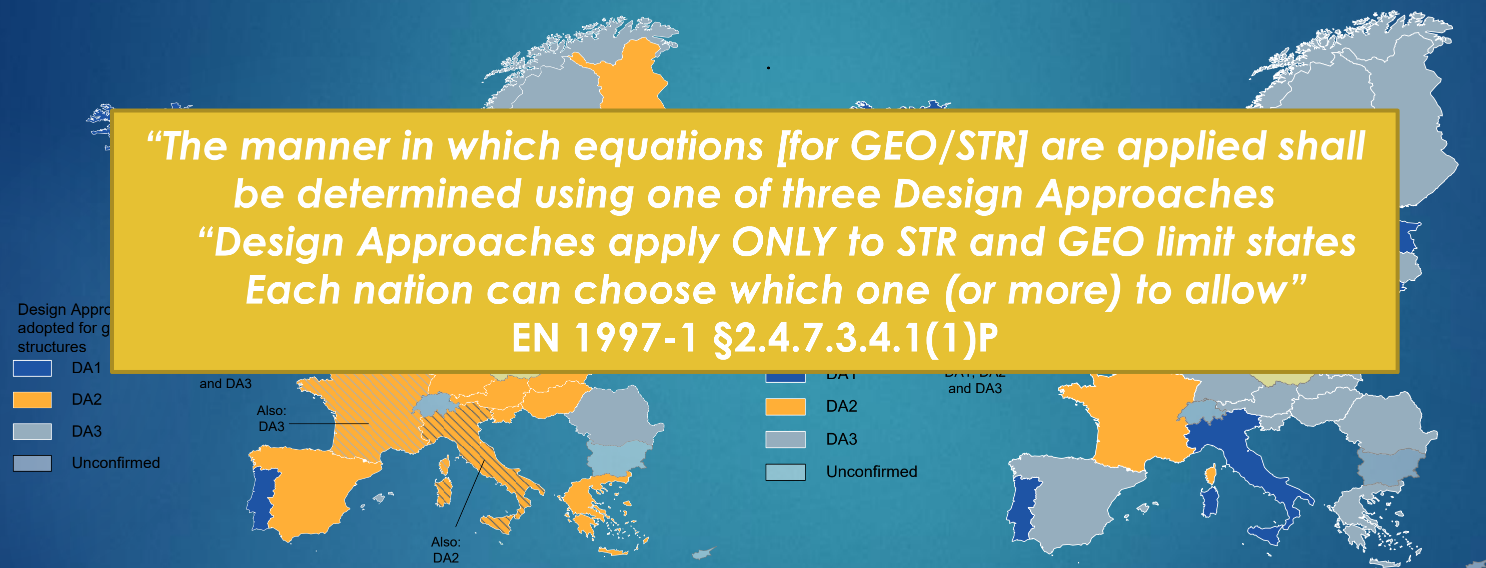
- conceptual representation of the site derived from the ground model for the verification of each appropriate design situation and limit state

Limit states

The following ultimate limit states shall be verified, as relevant:	**1st-gen**
failure of the structure or the ground, or any part of them including supports and foundations, by • **rupture** • **excessive deformation** • transformation into a mechanism • buckling	STR/GEO
loss of static equilibrium of the structure or any part of it	EQU
failure of the ground by **hydraulic heave, internal erosion, or piping** caused **by excessive hydraulic gradient**	HYD
failure caused by fatigue	FAT
failure caused by vibration	
failure caused by other time-dependent effects	

Jargon removed

No single Design Approach – even in a country! (Bond and Harris, 2008)



"The manner in which equations [for GEO/STR] are applied shall be determined using one of three Design Approaches

"Design Approaches apply ONLY to STR and GEO limit states Each nation can choose which one (or more) to allow"

EN 1997-1 §2.4.7.3.4.1(1)P

Verification of ultimate limit states

Ultimate limit states must be verified using:

$$E_{\mathrm{d}} \leq R_{\mathrm{d}}$$

For ultimate limit states caused by excessive deformation:

$$E_{\mathrm{d}} \leq C_{\mathrm{d,ULS}}$$

Factor may be applied to **actions**:

Verification Cases 1-3
(Factored actions)

or to **effects of actions**:

Verification Case 4
(Factored effects)

Factors may be applied to **material properties**:

Material factor approach
(MFA)

or to **resistance**:

Resistance factor approach
(RFA)

Partial factors for fundamental design situations (general application)

Action or effect				Partial factors γ_F and γ_E for Verification Cases 1-4				
Type	Group	Symbol	Resulting effect	Struct-ural*	Static equilibrium and uplift**		Geotechnical design	
				VC1	VC2(a)	VC2(b)	VC3	VC4
Permanent action (G_k)	All	γ_G	unfavourable/ destabilizing	**On actions**				G_k is not factored
	Water	$\gamma_{G,w}$						
	All	$\gamma_{G,stb}$	stabilizing					
	Water	$\gamma_{Gw,stb}$						
	(All)	$\gamma_{G,fav}$	favourable					
Prestressing (P_k)		γ_P						**On effects**
Variable action (Q_k)	All	γ_Q	unfavourable					
	Water	γ_{Qw}						
	(All)	$\gamma_{Q,fav}$	favourable					
Effects-of-actions (E)		γ_E	unfavourable	γ_E is not applied				
		$\gamma_{E,fav}$	favourable					

*Also used for geotechnical design; **Less favourable outcome of (a) and (b) applies
Values taken from EN 1990:2023, Annex A.1

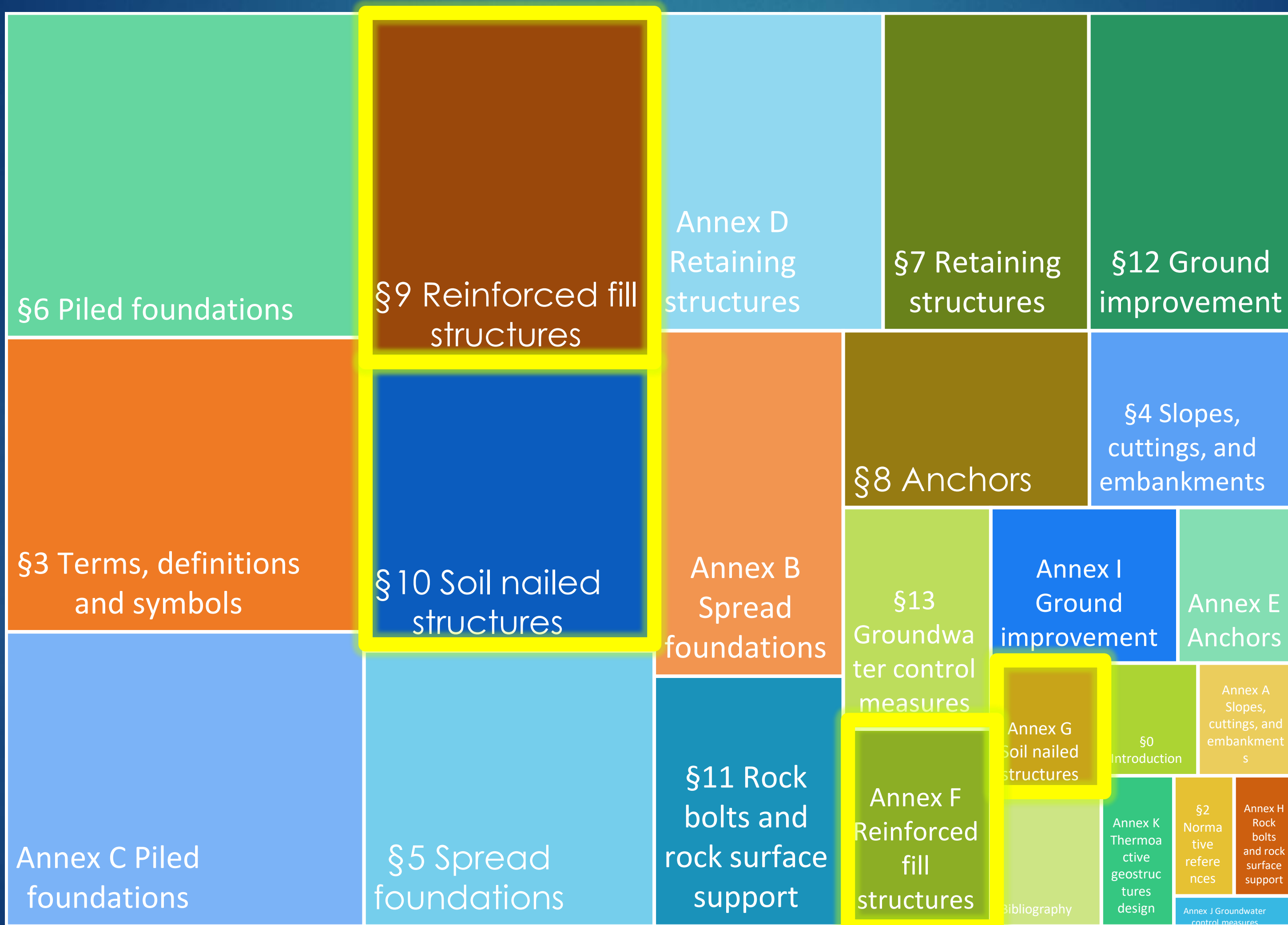
Partial factors for fundamental design situations (ground properties)

Ground property	Symbol	M1	M2
Soil			
Shear strength in effective stress analysis (τ_f)	$\gamma_{\tau f}$	1.0	1.25 k_M
Coefficient of peak friction (tan φ'_p)	$\gamma_{\tan\varphi,p}$		
Peak effective cohesion (c'_p)	$\gamma_{c,p}$		
Coefficient of friction at critical state (tan φ'_{cs})	$\gamma_{\tan\varphi,cs}$		**1.1 k_M**
Coefficient of residual friction (tan φ'_r)	$\gamma_{\tan\varphi,r}$		
Shear strength in total stress analysis (c_u)	γ_{cu}		1.4 k_M
Rock			
Unconfined compressive strength (q_u)	γ_{qu}	Same as γ_{cu}	
Shear strength of rock (τ_r)	$\gamma_{\tau r}$	1.0	1.25 k_M
Unconfined compressive strength of rock (q_u)	γ_{qu}		1.4 k_M
Discontinuities			
Shear strength of rock discontinuities (τ_{dis})	$\gamma_{\tau dis}$	1.0	1.25 k_M
Coefficient of residual friction (tan $\varphi'_{dis,r}$)	$\gamma_{\tan\varphi,dis,r}$		1.1 k_M

Does the new code cover reinforced fill structures?

REINFORCING THE 2ND GENERATION EUROCODE 7

Eurocode 7 – Geotechnical design – Part 3: Geotechnical structures



EN 1997-3 Geotechnical structures Reinforced fill structures

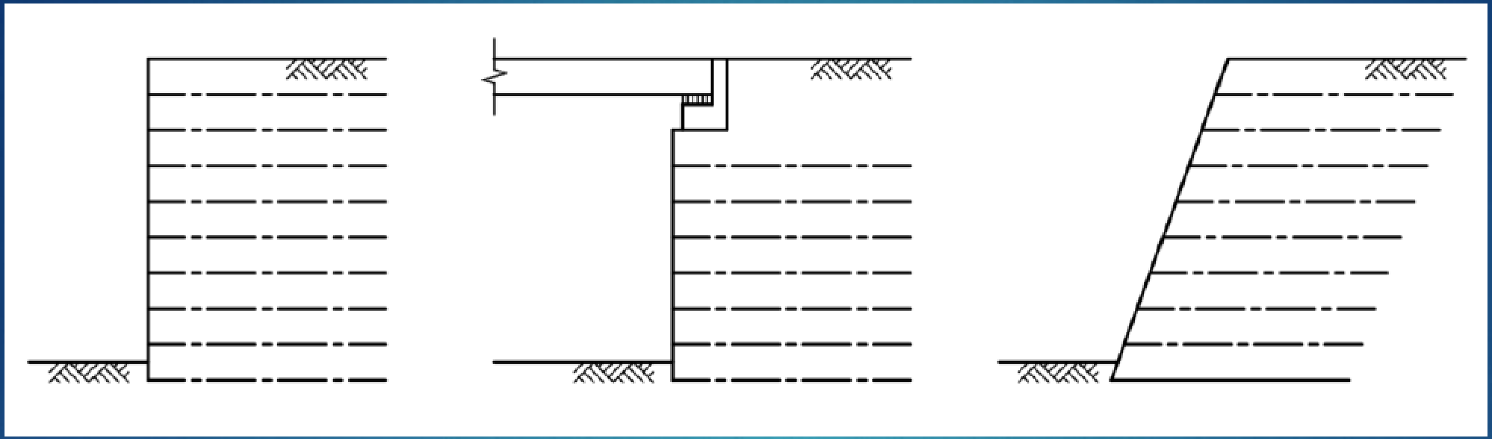
Clause 9 applies to reinforced fill structures:

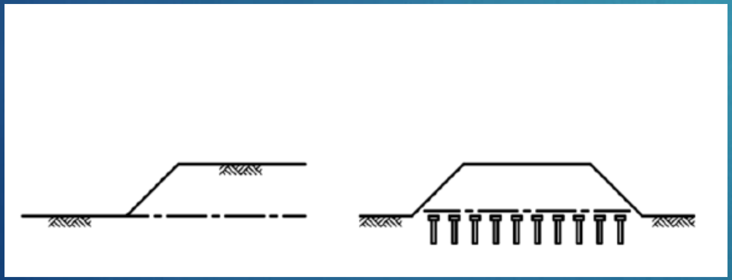
- reinforced walls and abutments
- reinforced slopes
- basal reinforcement for embankments (including load transfer platforms over inclusions and areas prone to development of voids)
- veneer reinforcement

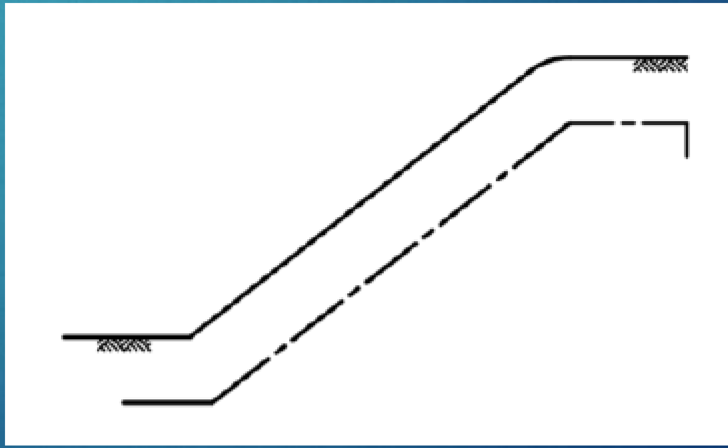
Annex F provides complementary guidance to Clause 9 and covers:

- calculation models for reinforced fill structures

Reinforced fill structures illustrated

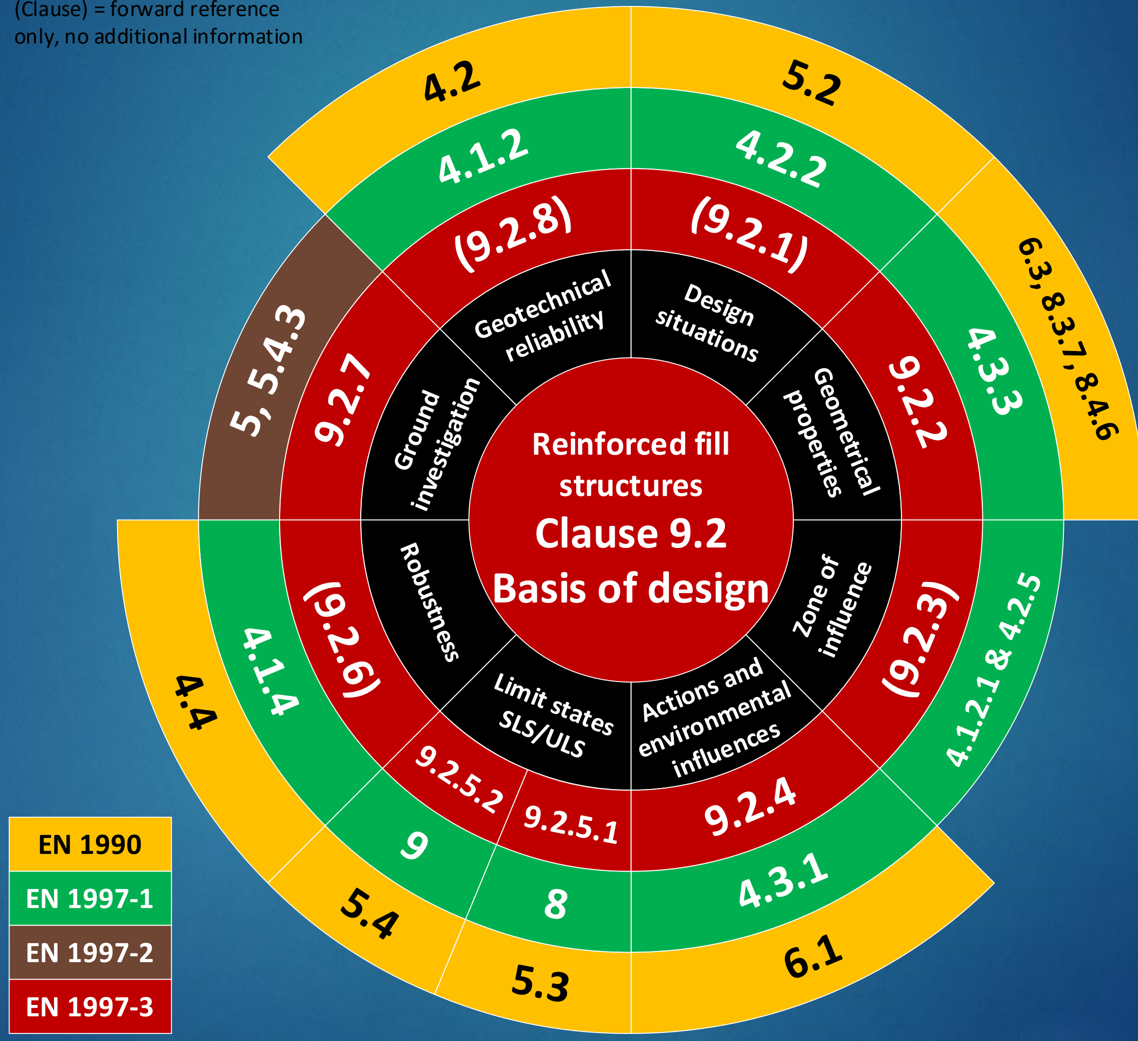




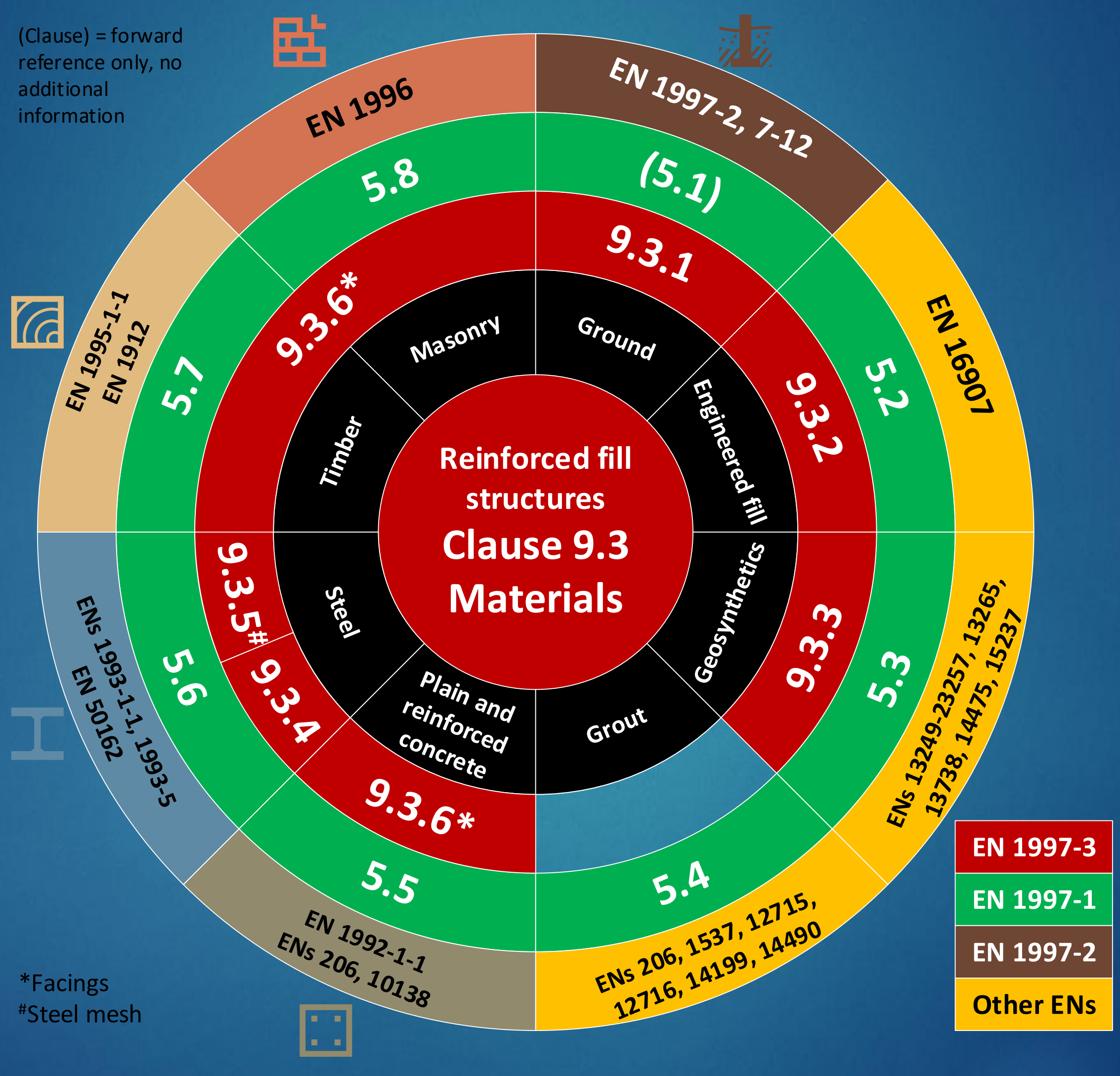


Basis of design clauses appliable to reinforced fill structures

(Clause) = forward reference only, no additional information



Materials for reinforced fill structures



Tensile resistance of geosynthetic reinforcing elements

The representative **tensile resistance of a geosynthetic reinforcing element** is given by:

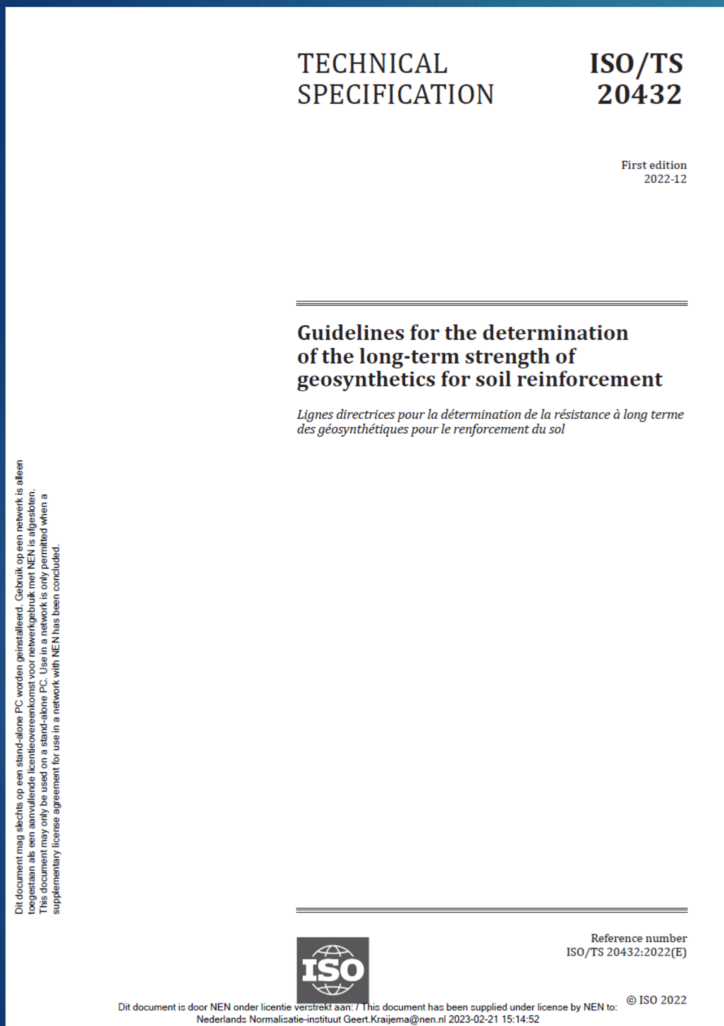
$$\overbrace{R_{\mathrm{t,el,rep}}}^{\substack{tensile\\resistance\\of\ element}} = \overbrace{\eta_{\mathrm{gs}}}^{\substack{reduction\\factor}} \times \overbrace{T_{\mathrm{k}}}^{\substack{characteristic\\tensile\\strength}}$$

where:

$$\overbrace{\eta_{\mathrm{gs}}}^{\substack{reduction\\factor}} = \overbrace{\underbrace{\eta_{\mathrm{cr}}}_{\frac{1}{F_{\mathrm{R,CR}}}}}^{creep} \times \overbrace{\underbrace{\eta_{\mathrm{dmg}}}_{\frac{1}{F_{\mathrm{R,ID}}}}}^{\substack{mechanical\\damage}} \times \overbrace{\underbrace{\eta_{\mathrm{w}}}_{\frac{1}{F_{\mathrm{R,W}}}}}^{weathering} \times \overbrace{\underbrace{\eta_{\mathrm{ch}}}_{\frac{1}{F_{\mathrm{R,CH}}}}}^{\substack{chemical\\and\\biological}} \times \overbrace{\underbrace{\eta_{\mathrm{cyn}}}_{\frac{1}{A_5}}}^{fatigue} \times \overbrace{\eta_{\mathrm{js}}}^{\substack{joints\\and\\seams}}$$

where the factors $F_{R,x}$ *and* A_5 are given in ISO TR 20432 and EBGEO, respectively

Guidance for geosynthetics ISO/TS 20432 and EBGEO



TECHNICAL SPECIFICATION

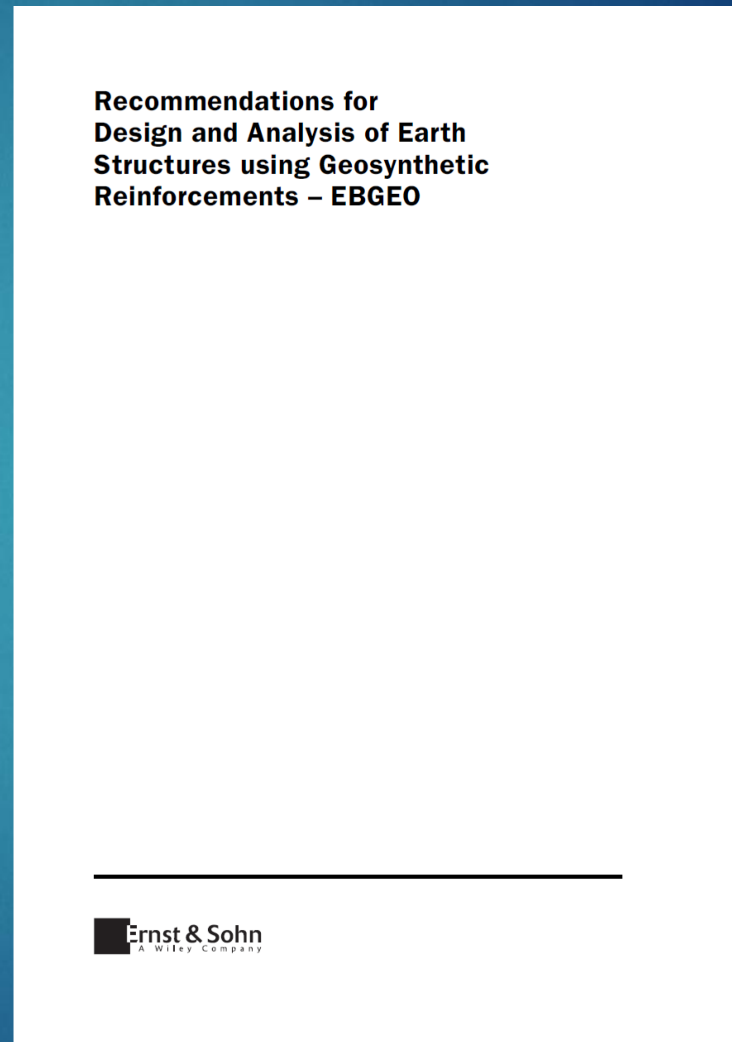
ISO/TS 20432

First edition
2022-12

Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

Lignes directrices pour la détermination de la résistance à long terme des géosynthétiques pour le renforcement du sol

Reference number
ISO/TS 20432:2022(E)



Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements – EBGEO

Ernst & Sohn
A Wiley Company

Tensile resistance of wire mesh

The representative **tensile resistance of polymeric coated woven wire mesh reinforcement/wire mesh** is given by:

$$\overbrace{R_{\mathrm{t,el,rep}}}^{\substack{tensile\\resistance\\of\ element}} = \left(\overbrace{\eta_{\mathrm{pwm}} | \eta_{\mathrm{wm}}}^{\substack{reduction\\factor}}\right) \times \overbrace{T_{\mathrm{k}}}^{\substack{characteristic\\tensile\\strength}}$$

where:

$$\overbrace{\eta_{\mathrm{pwm}} | \eta_{\mathrm{wm}}}^{\substack{reduction\\factor}} = \overbrace{\eta_{\mathrm{dmg}}}^{\substack{mechanical\\damage}} \times \overbrace{\eta_{\mathrm{cor}}}^{corrosion}$$

where the sub-factors:

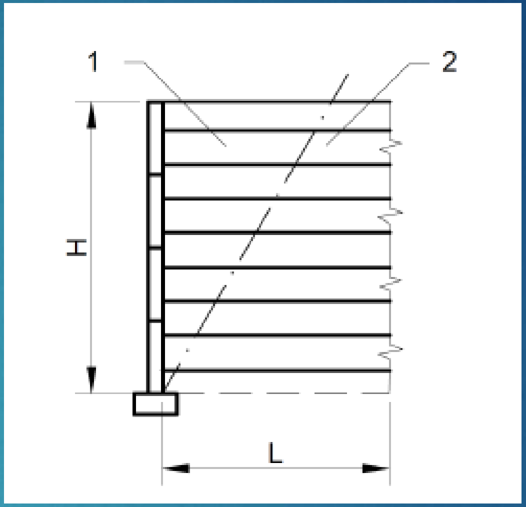
- (for reinforcing elements) can be determined according to EN 17738, *Geotextiles and geotextile-related products – Damage during installation procedure. Full scale test*
- (for facings to soil nailed structures) are 1.0 unless the National Annex or European Assessment Document give different values

Methods of analysing reinforced fill structures (1 of 2)

tie back wedge method

- method of analysis of reinforced soil structures that follows basic design principles currently employed for classical or anchored retaining walls

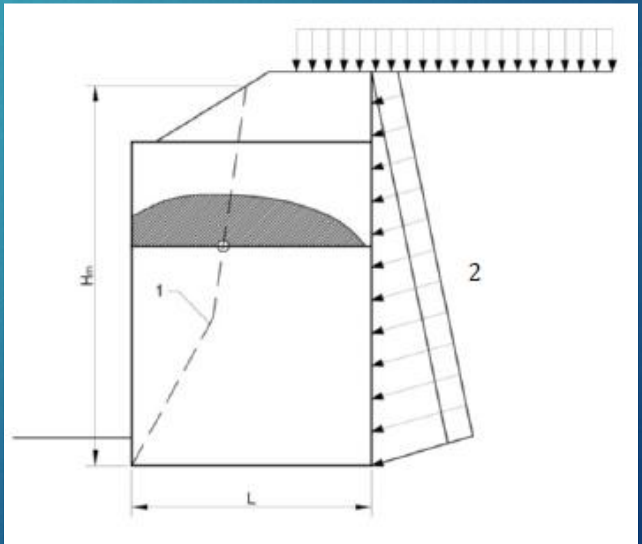
BS 8006-1, 6.3



coherent gravity method

- method of analysis based on the monitored behaviour of a large number of structures using inextensible reinforcements, corroborated by theoretical analysis

BS 8006-1, 6.3

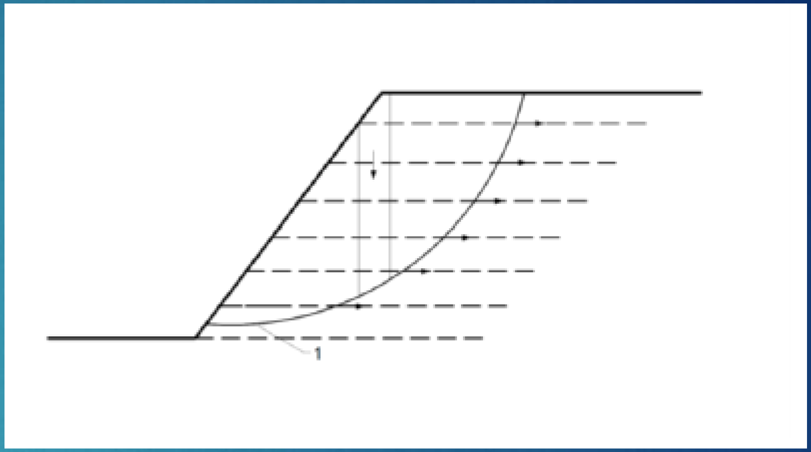


Methods of analysing reinforced fill structures (2 of 2)

method of slices

- assumes that the interslice forces may be ignored because of the complexity of the reinforcement influencing these forces and because the presence of the reinforcement will mean that there is little distortion of the soil mass under consideration

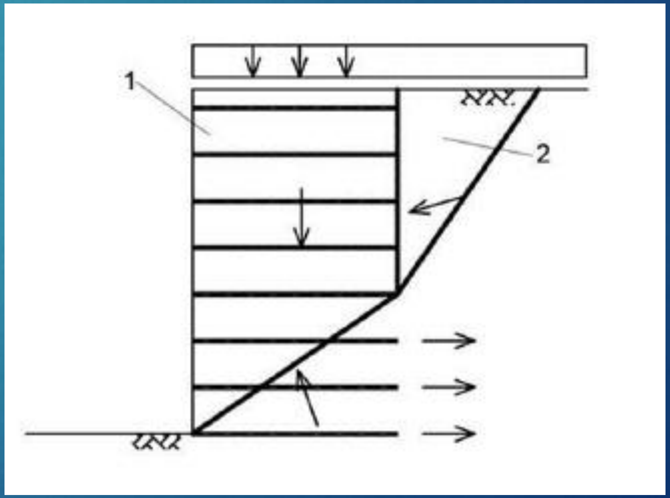
BS 8006-1, 7.4.4.3



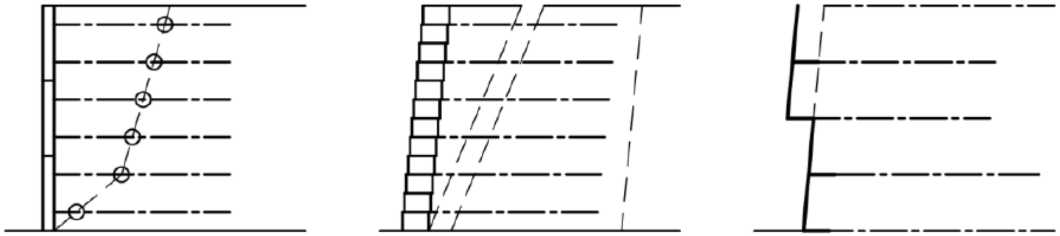
two-part wedge method

- assumes a bi-lineal failure surface that has been shown to provide a reasonable representation of the potential failure surfaces for slopes. It is a logical extension of the Coulomb wedge approach for vertical wall

BS 8006-1, 7.4.4.2



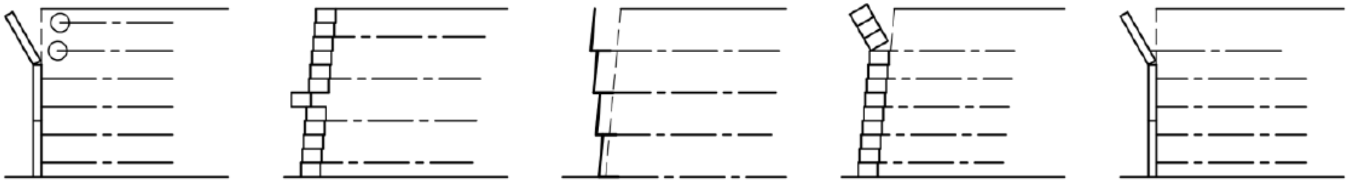
Ultimate limit states for reinforced fill structures



Key

– - – reinforcing element

Figure 9.2 — Examples of ultimate limit states for internal failure mechanisms for reinforced fill structures: (a) tensile failure, (b) pull-out of reinforcing elements, and (c) sliding along the interface between fill and reinforcing elements.



Key

– - – reinforcing element

Figure 9.3 — Examples of ultimate limit states for reinforced fill structures involving internal failure mechanisms: (a) connection rupture, (b) shear failure between face elements (bulging), (c) shear failure between facing elements and reinforcing elements, (d) toppling of top facing elements not connected to reinforcing elements and (e) rotation of large facing elements connected to reinforcing elements at one elevation only

Values of partial factors for reinforced fill and soil nailed structures

Partial factor on	Symbol	MFA	RFA
Overall stability – See Clause 4, *Slopes, cuttings, and embankments*			
Bearing resistance and sliding – See Clause 5, *Spread foundations*			
Overturning – See Clause 7, *Retaining structures*			
Pull-out and direct shear			
Verification Case		VC3	**VC1**
Actions[$$$]	γ_G γ_Q	1.0 **1.3**	**1.35 k_F** **1.5 k_F**
Effects-of-actions[$$$]	γ_E	×	×
Ground properties[$$]		**M2**	
	$\gamma_{\tan\varphi}$ γ_{cu}	**1.25 k_M** **1.4 k_M**	×
Pull-out resistance[$]	$\gamma_{R,po}$	×	**1.25**
Direct shear resistance[$**]	$\gamma_{R,ds}$		

Values given for fundamental (persistent and transient) design situations
Underlined indicates primary source of reliability; (values = 1.0); × not factored
[$$$]Values given in EN 1990, Annex A; [$$]EN 1997-1; [$]EN 1997-3
☐ Options chosen in the UK National Annex; **Reinforced fill structures only

Values of additional partial factors for reinforced fill and soil nailed structures

Partial factor on tensile resistance of	Symbol	MFA and RFA
Rupture of reinforcing element		
Geosynthetic reinforcement	$\gamma_{M,gs}$	**1.25**
Structural steel to EN 10025 Steel wires or ropes	γ_{M0} γ_{M2}	**1.0*** **1.25***
Reinforcing steel to EN 10080	γ_{S}	**1.15****
Polymeric coated steel wire mesh reinforcement	$\gamma_{M,pwm}$ $\gamma_{M,wm}$	**1.25**
Rupture of connections to facing or wire mesh		
Reinforcing element	$\gamma_{R,con,el}$	**As above**
Connector	$\gamma_{R,con,c}$	**1.25**
Facing element	$\gamma_{R,con,f}$	**from relevant EN**
Connection to soil nail	$\gamma_{R,con}$	**from EN 1993-1-1**
Connection to adjacent wire mesh panels		**1.25**
Values given for fundamental (persistent and transient) design situations *From EN 1993-1-1:2022, **from EN 1992-1-1:2023		

Design tensile resistance of steel reinforcing elements

The design **tensile resistance $R_{t,el,d}$ of a steel reinforcing element** in a reinforced fill structure is given by:

$$\overbrace{R_{t,el,d}}^{design\ tensile\ resistance\ of\ element} = \overbrace{A_r}^{reduced\ area\ of\ element} \times \overbrace{f_{yd}}^{design\ yield\ strength} = A_r \times \begin{cases} \overbrace{\overbrace{f_y}^{yield\ strength} / \overbrace{\gamma_{M0}}^{partial\ factor}}^{hot-rolled\ steel\ to\ EN\ 10025} \\ -\ or\ - \\ \underbrace{\underbrace{f_{0.2k}}_{proof\ strength\ at\ 0.2\%\ strain} / \underbrace{\gamma_S}_{partial\ factor}}_{reinforcing\ steel\ to\ EN\ 10080} \end{cases}$$

Reduced cross-sectional area of steel reinforcement

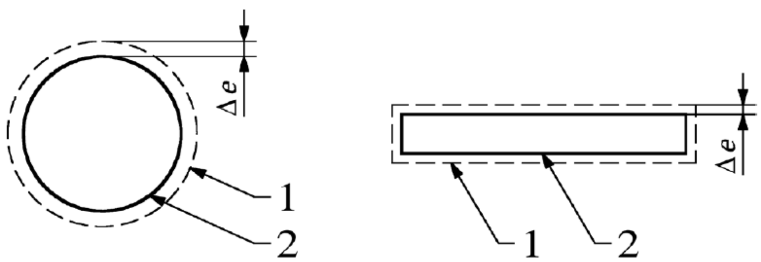


Figure 9.4 — Loss of thickness due to corrosion resulting in reduced cross-sectional area

Key

1 Original section

2 Section after corrosion

The loss of thickness Δe is:

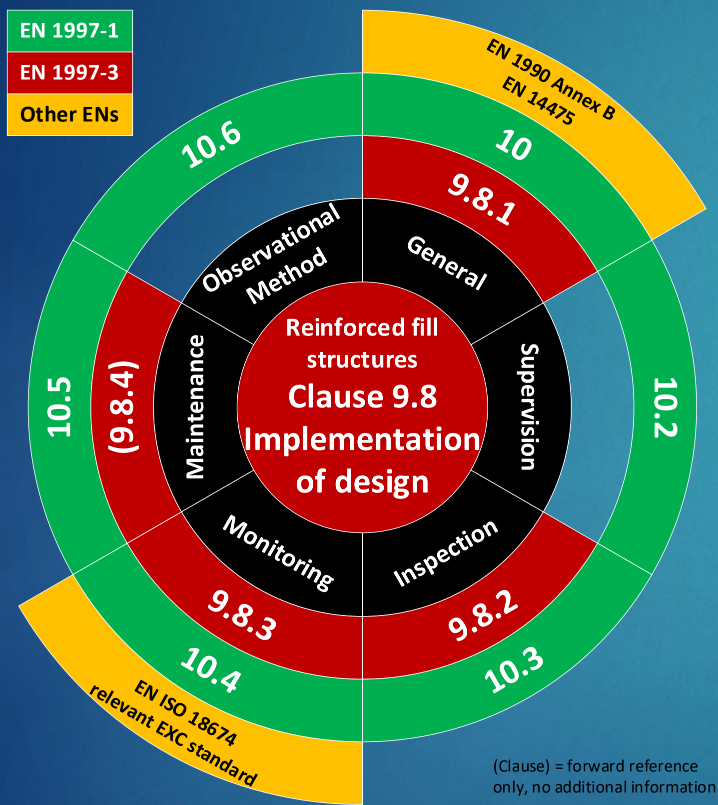
$$\Delta e = \overbrace{k_{\mathrm{cc}}}^{\substack{\text{corrosion}\\ \text{concentration}\\ \text{factor}}} \times \left(\overbrace{A}^{\substack{\text{loss of metal}\\ \text{per face}\\ \text{over first year}}} \times \left(\overbrace{T}^{\substack{\text{design}\\ \text{service}\\ \text{life}}} \right)^{n} - \overbrace{e_{\mathrm{z}}}^{\substack{\text{thickness of}\\ \text{initial zinc}\\ \text{coating}}} \right) \geq 0$$

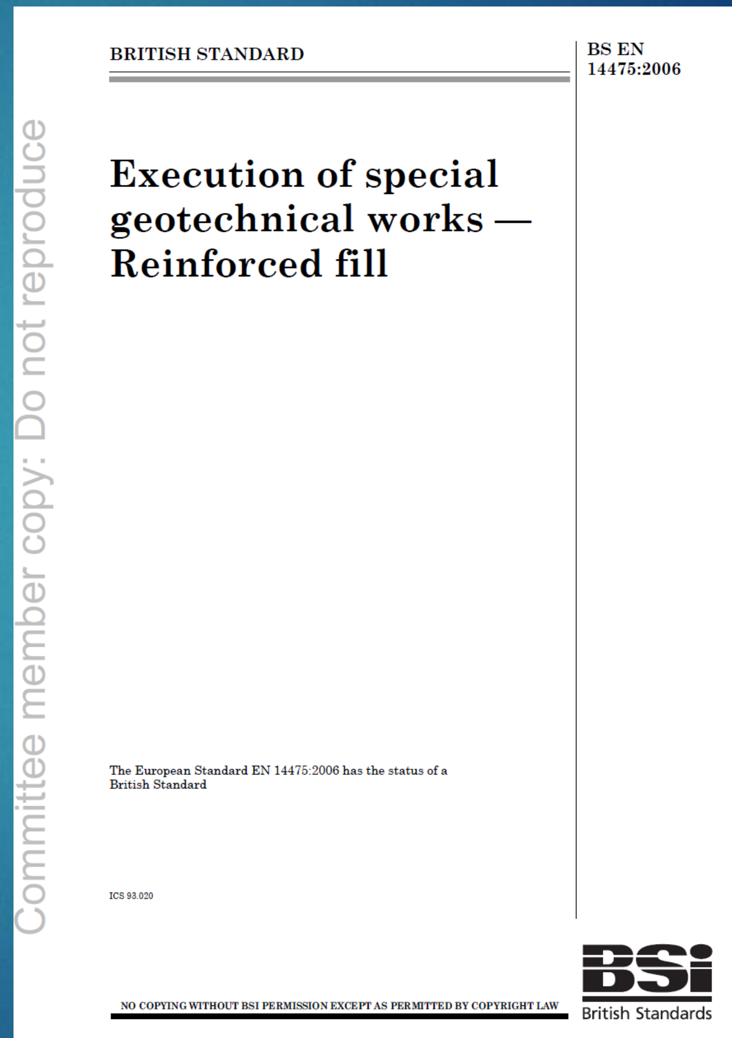
Corrosion parameters for steel reinforcement in fill

Parameter		Steel	
		Galvanized	Non-galvanized
A (μm)	Land-based	25	
	Fresh water	40	
n	Land-based	0.65	0.80
	Fresh water	0.60	0.75

Parameter	Strip thickness [bar diameter] (mm)	Strength distribution	Steel	
			Galvanized	Non-galvanized
Corrosion concentr-ation factor, k_{CC}	4-6 [6-18]	Non-uniform/ unknown	2.0	3.0
		Uniform	**1.7**	**2.5**
	> 12 [> 40]	Any	1.0	1.0
The value of k_{CC} may be determined by testing, provided the test data is certified by a Technical Assessment Body and it is not less than that given for steel with a uniform strength distribution				

Implementation of design for reinforced fill structures





BRITISH STANDARD

BS EN 14475:2006

Execution of special geotechnical works — Reinforced fill

The European Standard EN 14475:2006 has the status of a British Standard

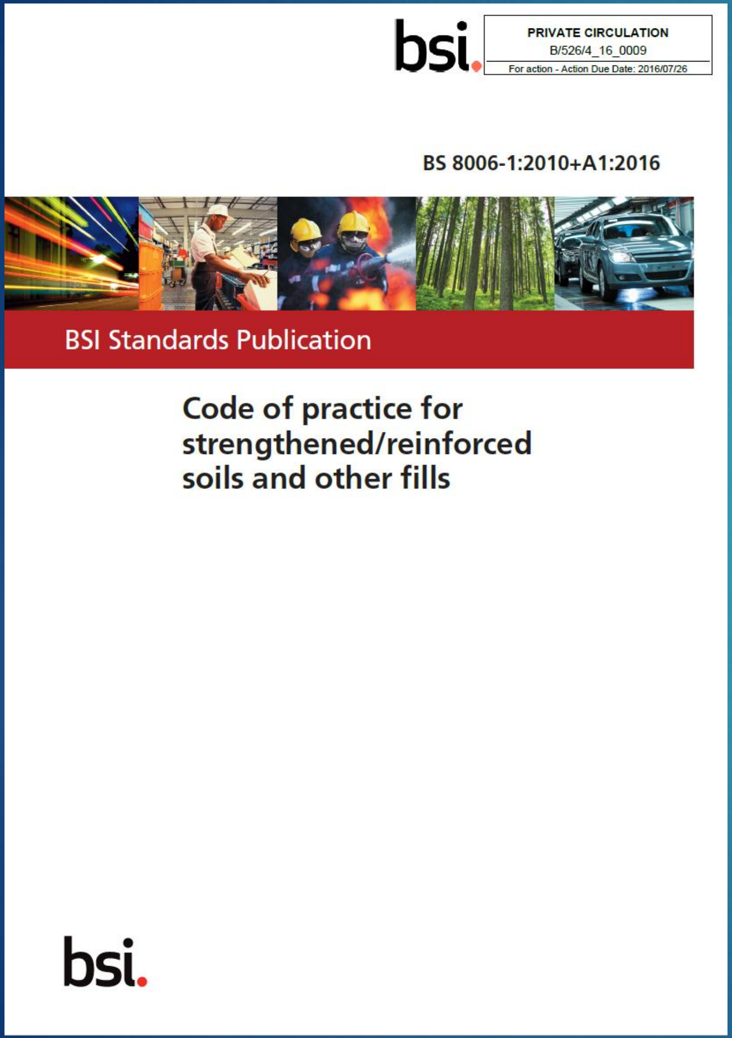
ICS 93.020

BSi British Standards

How does this affect existing UK practice?

REINFORCING THE 2ND GENERATION EUROCODE 7

BS 8006-1:2010+A1:2016 Code of practice for strengthened/reinforced soils and other fills



Section 3. Materials

Section 4. Testing for design purposes

Section 5. Principles of design

Section 6 Walls and abutments

Section 7: Reinforced slopes

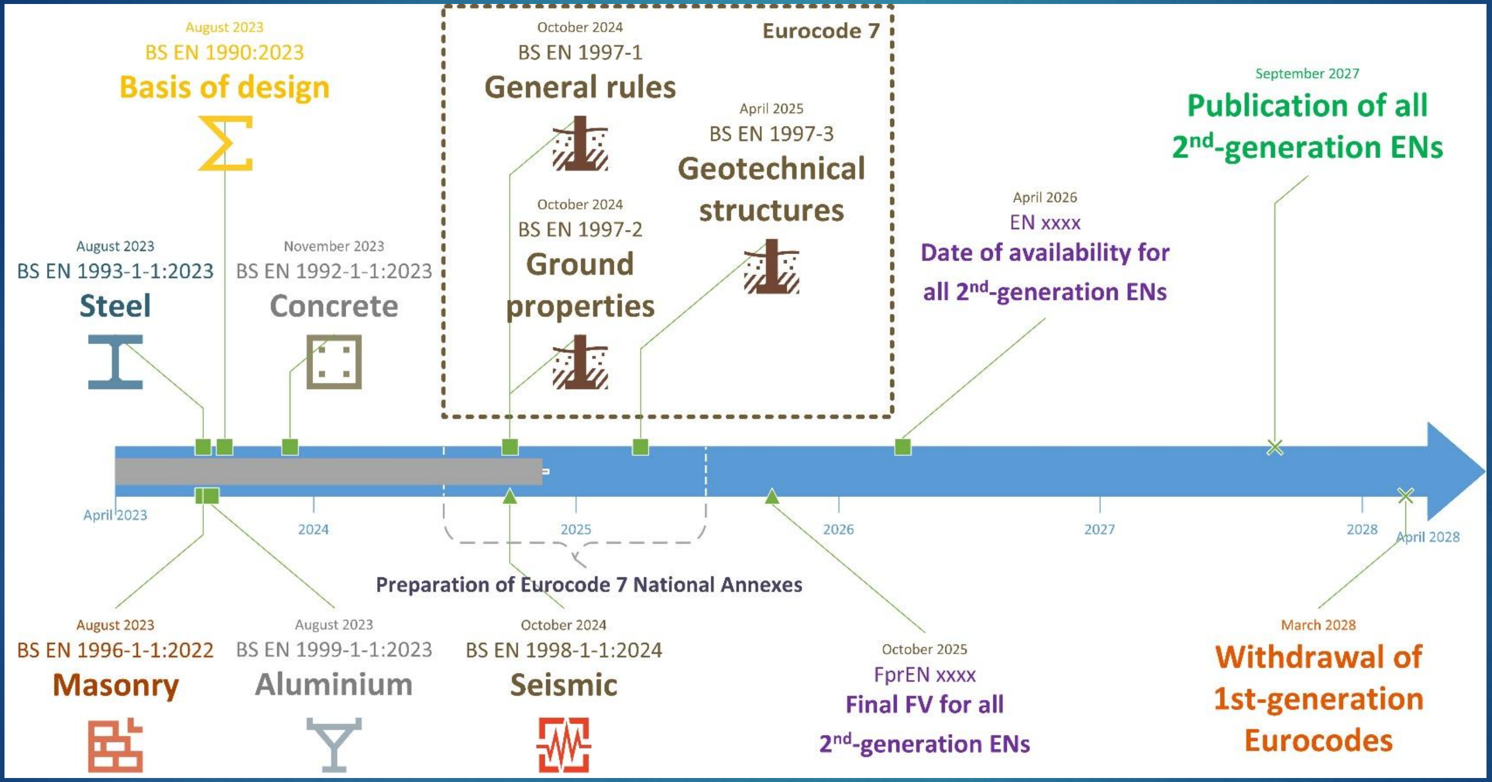
Section 8 Design of embankments with reinforced soil foundations on poor ground

- First published as BS 8006 in 1995
- Re-published as BS 8006-1 in 2010
- Key features
  - Recommendations and guidance for the **application of reinforcement techniques** to soils, as fill or in situ, and to other fills
  - Written in a **limit state format;** guidelines provided in terms of partial material factors and load factors for various applications and design lives

*"**BS EN 1997-1:2004 does not cover the design and execution of reinforced soil structures …** The **partial factors set out in BS 8006-1 cannot be replaced** by … factors in [Eurocode 7]"*

BS 8006-1:2010+A1:2016, 1.1 Scope

Timeline for the second-generation Eurocodes



Summary of key points

REINFORCING THE 2ND GENERATION EUROCODE 7

Improvements in 2nd generation … EN 1997 *Geotechnical design*

- Organizational changes to Eurocode 7
  - Clearer layout aids ease-of-navigation
  - Greater consistency with EN 1990 aids ease-of-use
- No more Design Approaches!
  - Simpler choice of partial factors
  - Material Factor or Resistance Factor Approach
- Catering for different groundwater conditions
  - Better specification of groundwater pressures
- Separating consequence from hazard
  - Clear distinction between consequence of failure and complexity of the ground
  - Geotechnical Categories now drive meaningful decisions

Impact on the design of reinforced fill structures

Design rules for reinforced fill structures:

- are given in Clause 9 of EN 1997-3 (with additional guidance given in Annex F)
- supplement the general rules for geotechnical design given in EN 1997-1
- rely on rules for ground investigation given in EN 1997-2

EN 1997-3 Clause 9 is applicable to:

- reinforced walls and abutments
- reinforced slopes
- basal reinforcement for embankments (including load transfer platforms over inclusions and areas prone to development of voids)
- veneer reinforcement

EN1997-3 Clause 9 does not apply to:

- asphalt reinforcement of pavements
- geotextile encased columns (see Clause 11 instead)

2nd generation

Decoding ^ Eurocodes

Reinforced fill structures

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