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Tomorrow's geotechnical toolbox: EN 1997-3:202x Geotechnical structures

La boîte à outils géotechnique de demain: EN1997-2:202x Structures géotechniques

A. J. Bond / primary author
Geocentrix Ltd, Banstead, United Kingdom; Chair TC250/SC7

C. Jenner
United Kingdom; Leader of SC7 Project Team 5

C. Moormann
University of Stuttgart, Institute for Geotechnical Engineering, Stuttgart, Germany; Leader of SC7 Project Team 4

ABSTRACT: This paper presents an overview of the contents of the proposed new Eurocode 7 Part 3. The paper explains how the principals in EN 1990, combined with the general rules in EN 1997-1, allow more detailed rules to be developed in EN 1997-3 for specific geotechnical structures. Examples showing how EN 1997-3 can be applied in practice are included.

RÉSUMÉ: Ce document présente une vue d'ensemble du contenu de la nouvelle proposition d'Eurocode 7, partie 3. Il explique comment les principes de l'EN 1990, combinés aux règles générales de l'EN 1997-1, permettent de développer des règles plus détaillées dans l'EN 1997-3 pour des structures géotechniques spécifiques. Des exemples montrant comment la norme EN 1997-3 peut être appliquée dans la pratique sont inclus.

Keywords: Eurocodes, geotechnical design; geotechnical structures; minimum ground investigation; calculation models

1 INTRODUCTION

In 2017, work started on preparing a new part to Eurocode 7, sub-titled *Geotechnical structures*, that would provide detailed design rules separate from the general rules of Eurocode 7 Part 1.

The aim of this work is to improve the presentation of existing design rules, to provide more details about suitable geotechnical calculation models, and to eliminate the need for separate Design Approaches for the verification of ultimate limit states.

Detailed plans for the evolution of Eurocode 7 (EN 1997-1:2004 and EN 1997-2:2007) were prepared by CEN/TC 250/SC 7 and have been reported previously by Bond et al. (2015).

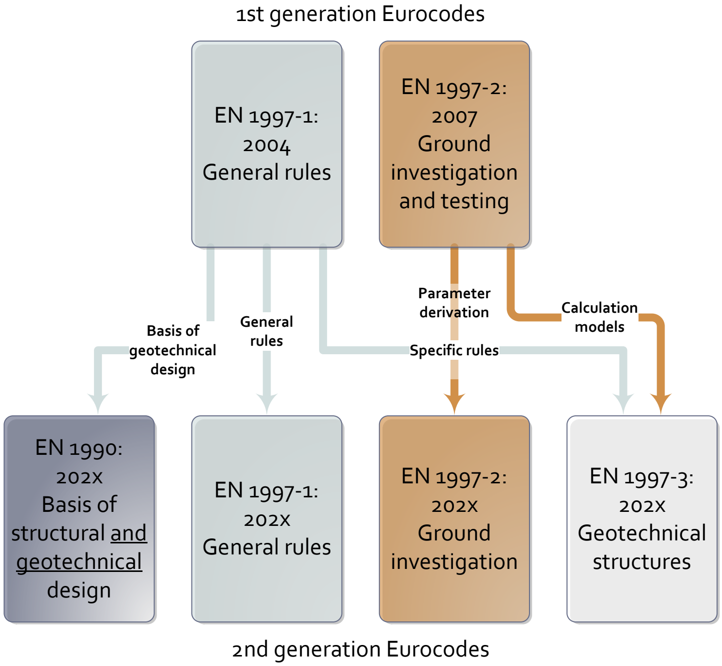

Figure 1 Division of the 1st generation of Eurocode 7 into parts and redistribution to other standards

2 RESTRUCTURING EUROCODE 7

The contents of the existing Eurocode 7 have been divided into separate parts and transferred to the most appropriate standard in the second generation Eurocodes, as illustrated in Figure 1.

The contents of the existing Eurocode 7 Part 1 *General rules* (EN 1997-1:2004) have been split between EN 1990:202x *Basis of structural and geotechnical design*; a revised Part 1 (EN 1997-1:202x) *General rules*; and a new Part 3 (EN 1997-3:202x) *Geotechnical structures*.

The new Part 3 comprises text from Sections 5-9 and 11-12 of the original Part 1 together with new Clauses on reinforced soil structures and ground improvement.

The contents of the existing Eurocode 7 Part 2 *Ground investigation and testing* (EN 1997-2:2007) are also being revised to focus on derivation of design parameters. Calculation models that currently reside in Annexes to EN 1997-2:2007 have been moved to the new Part 3, as illustrated in Figure 1.

Companion papers by Bond et al. (2019), Franzen et al. (2019), and Norbury et al. (2019) describe in more detail the contents of EN 1990:202x, EN 1997-1:202x, and EN 1997-2:202x, respectively. Guidelines for navigating through the second generation of ENs 1990 and 1997 are given by Estaire et al. (2019).

3 CONTENTS OF EN 1997-3

The titles of the main clauses in EN 1997-3:202x broadly follow those of the old sections in EN 1997-1:2004:

1. Scope
2. Normative references
3. Terms, definitions, and symbols
4. Slopes, cuttings, and embankments (old Sections 11 and 12)
5. Spread foundations (old Section 6)
6. Piled foundations (old Section 7)

7. Retaining structures (old Section 9)
8. Anchors (old Section 8)
9. Reinforced soil structures (new)
10. Ground improvement (old Section 5.5)

Each Clause (from 4 onwards) follows a common structure, as detailed below:

1. Scope
2. Basis of design
3. Materials
4. Groundwater
5. Geotechnical analysis
6. Ultimate limit states
7. Serviceability limit states
8. Execution
9. Testing
10. Reporting

4 BASIS OF DESIGN

In EN 1997-3:202x, sub-clauses x.2 *Basis of design* provide additional requirements and recommendations to those given in Clause 4 of EN 1997-1:202x, with regards to:

1. Design situations
2. Geometrical data
3. Actions
4. Limit states
5. Design considerations
6. Minimum ground investigations
7. Geotechnical Complexity Classes

The sub-clauses on minimum ground investigation are based on the former Annex B.3 of EN 1997-2:2007. They provide detailed recommendations for the depth and extent of boreholes and trial pits for each specific geotechnical structure, taking account of the Geotechnical Category of the structure.

5 MATERIALS

The primary source of information about ground properties in the new Eurocode 7 will be EN 1997-2:202x, *Ground investigation*. Sub-clauses x.3 *Materials* of EN 1997-3:202x provide the information needed to specify other materials commonly used in geotechnical design but not covered by other Eurocodes.

For concrete, reference is made to Eurocode 2 (EN 1992:202x) for design parameters and exposure classes; and to EN 206 for the specification, performance, production, and conformity of concrete.

For steel, reference is made to Eurocode 3 (EN 1993:202x) for design parameters; to ENs 10025, 10083, and 10149 for the properties of hot rolled steel products; and to ENs 10210 and 10219 for cold formed hollow steel sections. For steel piling, reference is made to Eurocode 3 Part 5 (EN 1993-5) for design parameters; to EN 10248 for hot rolled sheet piling; and to EN 10249 for cold formed sheet piling.

For anchors, reference is made to EN 10138-1 for pre-stressing steel and to EN 10080 for weldable reinforcing steel for the reinforcement of concrete.

For geosynthetics, reference is made to EN 13251 for the characteristics of geotextiles and geotextile-related products for use in earthworks, foundations, and retaining structures; to EN ISO 10319 for determining the short-term strength of geosynthetic reinforcement; and to ISO/TR 20432 for determining the long-term strength of geosynthetic reinforcement. For steel reinforcement comprising strips, bars, or rods, reference is made to ENs 10025 and 10080; for welded wire ladders or meshes to ENs 10218 and 10080; for polymer coated woven wire mesh to ENs 10218 and 10223. Standards for galvanizing steel strips, rods, bars, ladders or welded wire meshes are also given.

As the list of documents above demonstrates, civil, structural, and geotechnical engineers refer to a lot of standards when designing geotechnical structures.

6 GROUNDWATER

Sub-clauses x.6 *Groundwater* provide detailed recommendations for dealing with groundwater, as it affects particular geotechnical structures. These sub-clauses extend the more general advice given in Clause 6 of EN 1997-1:202x.

7 GEOTECHNICAL ANALYSIS

According to EN 1997-1:202x, limit states must be verified by one of the following methods:

- calculation
- prescriptive measures
- testing
- application of the Observational Method

The sub-clauses in EN 1997-3:202x that deal with geotechnical analysis specify particular design methods that should be used for each type of geotechnical structure, in order to satisfy this requirement.

For example, Sub-Clause 4.5 gives the designer permission to use limit-equilibrium methods, numerical methods, or limit analysis as a form of calculation for slopes, embankments, and cuttings.

Sub-Clause 5.5 provides calculation models to determine the bearing resistance and settlement of spread foundations from soil parameters and from pressuremeter test results. (Later drafts of the code will probably extend the number of methods given.)

Sub-Clause 6.5 provides design methods for axially loaded single piles based on calculation, results of pile loading tests, prescriptive measures, and the Observational Method. Methods are given for designing laterally loaded single piles, pile groups, and piled rafts.

Sub-Clause 7.5 provides guidance on the determination of earth pressures against retaining structures, including limiting (active and passive) and at-rest values.

Sub-Clause 8.5 provides a detailed calculation model for verifying both the geotechnical and the structural resistance of grouted anchors, under ultimate and serviceability conditions.

Sub-Clause 9.5 recommends which methods should be used to analyse reinforced soil structures: the coherent gravity, tie-back wedge, and two-part wedge methods; slope stability methods; or numerical analysis. Details of some of these methods are given in Annex F.

Finally, Sub-Clause 10.5 provides general guidance for the analysis of diffused and discrete ground improvement techniques.

8 ULTIMATE LIMIT STATES

The sub-clauses in EN 1997-3:202x that cover ultimate limit states serve two main purposes:

- To identify the ultimate limit states that must be verified for each particular type of geotechnical structure
- To provide partial resistance factors (where needed) to enable that verification

8.1 Identification of limit states

It is impossible for EN 1997-3:202x to identify all ultimate limit states that could affect a particular geotechnical structure. However, the most commonly encountered limit states are covered and less frequently encountered limit states are mentioned when they are known to be particularly problematic.

For example, sub-clause 6.6 on ultimate limit states for piled foundations deals with compressive, tensile, and lateral loading of piles as well as down-drag on piles (less common).

8.2 Partial factors

A key principle in drafting the second generation of Eurocodes is the need to avoid duplication of information.

A consequence of this principle is that the values of the partial load factors (γ_G, γ_Q, and γ_E) given in EN 1990:202x cannot be duplicated in Eurocode 7. Instead, they must be called up by reference only, in this instance by reference to a particular Design Case (DC1- 4) specified in one of the Annexes to EN 1990:202x.

A major benefit of this approach is that EN 1990 can specify different values of γ_G, γ_Q, and γ_E for different structures (e.g. buildings, bridges, towers and masts, silos and tanks, etc.) without invalidating the text of other Eurocodes, provided that they refer solely to Design Cases.

In the same way, the values of the partial material factors ($\gamma_{\tan\varphi}$, γ_c, γ_{cu}, etc.) that are given in the second generation of Eurocode 7 Part 1 cannot be duplicated in the new Part 3. Instead, the values must be called up by reference to sets M1, M2, or M3 specified in Annex A of EN 1997-1:202x.

The task of sub-clauses x.6 of EN 1997-3 is to choose the appropriate partial factors to use for each geotechnical structure and to provide values of any resistance factors that are needed.

Table 1 illustrates the way the partial factors are presented in EN 1997-3:202x, for a selected number of geotechnical structures. Values of the partial factors specified in the Design Cases (for buildings) and material factor sets are given in brackets (but, of course, do not appear in EN 1997-3:202x).

Table 1. Partial factors (provisional) for verification of ultimate limit states in persistent and transient design situations

Sub-clause	Verification of	Partial factor on	Symbol	Material factor approach (MFA)		Resistance factor approach (RFA)
4.6	Overall stability of slopes, embankments, and cuttings	Actions/effects	γ_F / γ_E	DC3 (γ_G = 1.0, γ_Q = 1.3)		Not permitted
		Ground properties	γ_M	M3 ($\gamma_{\tan\varphi}$ = 1.25K_M, γ_{cu} = 1.4K_M)		
		Earth resistance	γ_{Re}	Not factored		
5.6	Spread foundations	Actions/effects	γ_F / γ_E	DC1* (γ_G = 1.35K_F, γ_Q = 1.5K_F)	DC3* (γ_G = 1.0, γ_Q = 1.3)	DC4 (γ_G not used, γ_Q = 1.1) (γ_E = 1.35K_F)
		Ground properties	γ_M	M1 ($\gamma_{\tan\varphi}$ = γ_{cu} = 1.0)	M3 ($\gamma_{\tan\varphi}$ = 1.25K_M γ_{cu} = 1.4K_M)	M1 ($\gamma_{\tan\varphi}$ = γ_{cu} = 1.0)
		Bearing resistance	γ_{Rv}	Not factored		1.4
		Sliding resistance	γ_{Rh}	Not factored		1.1
6.6	Pile foundations in compression or tension	Actions/effects	γ_F / γ_E	Not permitted		DC4 (γ_G not used, γ_Q = 1.1) (γ_E = 1.35K_F)
		Ground properties	γ_M			Not factored
		Base resistance	γ_{Rb}			1.2
		Shaft resistance	γ_{Rs}			1.0
		Total resistance	γ_{Rt}			1.1
		Shaft resistance (in tension)	γ_{Rst}			1.15

*Note: both combinations must be verified

The observant reader will have noticed that, in several places in Table 1, the value of the partial factor includes a 'consequence factor' (K_F or K_M). The value of this factor is linked to the consequences of failure, as specified for a particular structure by the Consequence Class into which it is classified.

Consequence Classes and the corresponding values of K_F are defined in EN 1990:202x (see Table 2); values of K_M and K_R (not shown in Table 1) will be defined in EN 1997-3:202x for specific geotechnical structures.

The reason that DC3 omits K_F from the partial factors on actions and instead includes K_M on material strengths is related to the value of γ_G (= 1.0 in this particular Design Case). A factor of 1.0 is a *do nothing* factor, i.e. reliability is not provided by adjustment of the permanent actions. Instead, reliability is provided through factors on material strength (γ_M > 1.0 in DC3). Hence reliability discrimination based on the consequences of failure can only be applied by adjusting the value γ_M. This is particularly relevant to the design of slopes, embankments, and cuttings.

Table 2 Consequence classes, examples and factors

Consequence class		**Indicative qualification of consequences**		**Examples of buildings**	**Consequence factor K_F**
	Description	**Loss of human life or personal injury***	**Economic, soil, or environmetal loss***		
CC4	Highest	Extreme	Huge	Additional provisions can be needed	
CC3	Higher	High	Very great	Grandstands, large buildings, e.g. a concert hall	1.1
CC2	Normal	Medium	Considerable	Residential and office buildings, small buildings	1.0
CC1	Lower	Low	Small	Agricultural buildings, buildings where people do not normally enter, such as storage buildings, etc.	0.9
CC0	Lowest	Very low	Negligible	Alternative provisions may be used	
*CC is chosen based on the more severe of these two columns					

9 SERVICEABILITY LIMIT STATES

The sub-clauses in EN 1997-3:202x that cover serviceability limit states provide recommendations for calculating settlement, heave – and other forms of displacement – of both the structure and the ground.

Partial factors are not used in the verification of serviceability limit states. Instead, the calculated movement is compared with a design criterion (C_d) specific to the structure.

Guidance on suitable values of C_d for structures of different sensitivity to movement is given in EN 1990:202x, via Structural Sensitivity Classes. The hope is that structural designers will use these classes to provide more realistic design criteria for foundations than in the past.

10 EXECUTION

Between 1999 and 2010, CEN Technical Committee TC288 produced 13 European standards, covering the execution of so-called 'special' geotechnical works, including piles, walls and steep slopes, and ground improvement.

The aim of sub-clauses x.8 *Execution* in EN 1997-3:202x is not to repeat the work of TC288 but instead to ensure that the reader of Eurocode 7 is aware which execution standard is relevant to each type of geotechnical structure.

As Table 3 shows, there are many standards that the new Eurocode 7 Part 3 will refer to. Few geotechnical designers are aware of these standards or the fact that they include clauses covering 'execution design' – i.e aspects of design that affect the construction of the works if not the permanent structure itself.

For example, Clause 10.3 of EN 13670:2009, *Execution of concrete structures*, specifies the position of the centres of the base supports for precast and cast-in-place foundations, including pile caps (see Annex G of that standard for details).

Table 3. Execution standards referenced in EN 1997-3:202x

Sub-clause	Title	Geotechnical structure/process	Execution standard
4.8	Slopes, cutting, and embankments	Earthworks	EN 16907*
5.8	Spread foundations	Concrete foundations	EN 13670*
6.8	Piled foundations	Bored piles	EN 1536
		Displacement piles	EN 12699
		Micropiles	EN 14199
7.8	Retaining structures	Sheet pile walls	EN 12063
		Diaphragm walls	EN 1538
8.8	Anchors	Grouted anchors	EN 1537
9.8	Reinforced soil structures	Reinforced fill structures	EN 14475
		Soil nailing	EN 14490
10.8	Ground improvement	Grouting	EN 12715
		Jet grouting	EN 12716
		Deep mixing	EN 14679
		Deep vibration	EN 14731
		Vertical drainage	EN 15237

*Not part of the suite of execution standards produced by TC288

11 TESTING

The sub-clauses on testing in EN 1997-3:202x provide guidance on the suitability and use of different types of test for specific geotechnical structures. These sub-clauses make reference to appropriate independent testing standards, where they exist – typically in the EN ISO 22477 series of standards for *Testing of geotechnical structures*.

For example, sub-clause 8.9 on testing of anchors gives requirements and recommendations for the use of investigation, suitability, and acceptance tests according to EN ISO 22477-5. This includes specifying parameters such as creep rate, loss of load, and proof load for both ultimate and serviceability verifications.

12 REPORTING

Sub-clauses x.10 *Reporting* provide additional information regarding the preparation of the Geotechnical Design Report (GDR) and the Geotechnical Construction Record (GCR) defined in Clause 12 of EN 1997-1:202x. Whereas Part 1 gives guidance about the general information that must be recorded, Part 3 gives guidance for specific geotechnical structures.

13 CONCLUSIONS

A new – third – part of Eurocode 7 is under development which will provide requirements and recommendations for the design of slopes, spread foundations, pile foundations, retaining structures, anchors, reinforced soil structures, and ground improvement.

Although the contents of this new part are drawn primarily from EN 1997-1:2004 (Sections 5-9 and 11-12), much of the text has either been re-written or created afresh (particularly that for reinforced soil structures and ground improvement). In addition, calculation models from EN 1997-2:2007 have been collected together in one place (in new Annexes) and supplemented by widely accepted calculation models, so that they are readily available to readers of EN 1997-3:202x.

The development of this new European standard provides civil, structural, and geotechnical designers with a comprehensive set of tools for geotechnical design.

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