Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-344

Eurocode 7 – second generation – piled foundations

Eurocode 7 – deuxième génération – pieux

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ABSTRACT: Eurocode 7 is known as the European standard for geotechnical engineering design and is widely considered as a great success story. The second generation of the standard recently being finally drafted by CEN/TC250 SC7 will be published 2024/2025 and will represent a significant step forward towards further harmonization and efficient guidance for geotechnical design. Besides other geotechnical structures this is the case also and especially for piled foundations. In comparison to the first generation the clause on piled foundations in EN 1997-3 ´Geotechnical Structures´ has been fundamentally revised and improved including new rules for pile design. For example, in the second generation pile groups and piled rafts will be covered equivalently to single piles. Detailed guidance is provided to consider actions due to ground displacements like downdrag. Revised sets of correlation, model and partial factors were specified. The design approaches for axial and lateral loaded piled foundations were harmonized. As the authors have been involved in the evolution of the revised clause on pile foundations since 2011 this paper aims to inform first-hand about the upcoming changes and to present the improvements and challenges.

RÉSUMÉ: L'Eurocode 7 en tant que norme européenne pour la conception géotechnique est largement considéré comme une grande réussite. La deuxième génération de la norme récemment rédigée par le CEN/TC250 SC7 sera publiée en 2024/2025 et constituera une avancée significative vers une harmonisation plus poussée avec des orientations efficaces pour la conception géotechnique: c'est notamment le cas des fondations sur pieux. Par rapport à la première génération, le chapitre relatif aux fondations sur pieux a été fondamentalement révisé et amélioré, avec de nouvelles règles pour la conception des pieux. Par exemple, dans la deuxième génération, les groupes de pieux et radiers dur pieux seront traités avec un niveau de détails similaire à ceux des pieux isolés. Des recommandations détaillées sont fournies pour prendre en compte les actions dues aux déplacements du sol comme le frottement négatif. Les ensembles de facteurs de corrélation, de modèle et partiels ont été révisés. Les approches de conception pour les fondations sur pieux chargés axialement et latéralement ont été harmonisées. Comme les auteurs ont été impliqués dans l'évolution de la clause révisée sur les fondations sur pieux au cours des 12 dernières années, cet article vise à présenter simplement les changements à venir ainsi que les améliorations et les défis qui se profilent.

Keywords: Eurocode 7; piled foundations; pile groups; piled rafts; partial factor; axial and transversal loading.

1 EURCODE 7, PART 3 (2025)

In its second generation the new Eurocode 7 comprises three parts 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 ´Basis of structural and geotechnical design´, a revised Part 1 (EN 1997-1:2024) ´General rules´; and a new Part 3 (EN 1997-3:2025) ´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 fill structures, ground reinforcing elements, ground improvement and groundwater control (Bond et al. 2019). In this context the Section 7 ´Pile foundation´ of EN 1997-1:2024 formed the basis for the new Clause 6 ´Piled foundations´.

The contents of the existing Eurocode 7, Part 2 ´Ground investigation and testing´ (EN 1997-2:2007) are also being revised to focus in the new Part 2 ´Ground parameters´ (EN 1997-2:2024) on derivation of design parameters. Calculation models that currently reside in Annexes to EN 1997-2:2007, e.g. on CPT-based calculation of axial pile resistances, have been moved to the new Part 3, as illustrated in Figure 1.

Relevant for the design of piled foundations according to the second generation of Eurocodes are therefore mainly EN 1990, EN 1997-1 and EN 1997-3 whereby the relevant design aspects are illustrated in Figure 1.

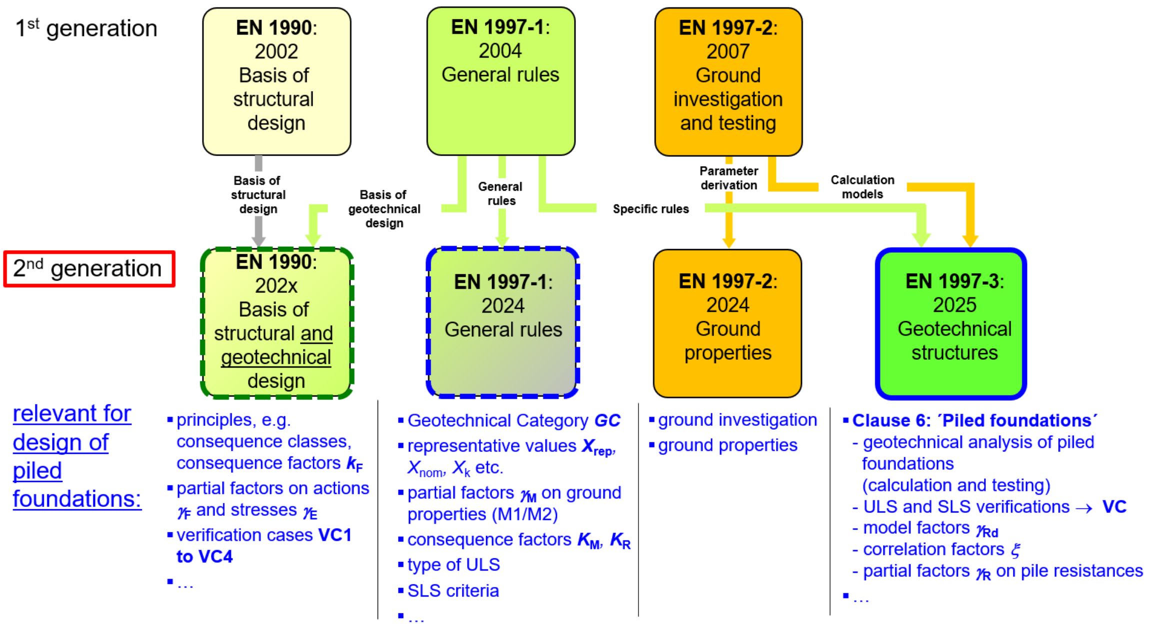

Figure 1. Division and redistribution of the 1st generation of Eurocode 0 and Eurocode 7 into the standards of the second generation; at the bottom: contents of these standards being relevant for design of piled foundations.

2 CLAUSE 6: PILED FOUNDATIONS

2.1 Introduction

Relevant for the design of piled foundations is predominantly Clause 6 ´Piled foundations´ of EN 1997-3:2025 which was elaborated on basis of Section 7 ´Pile foundation´ of EN 1997-1:2024 whereby the previous regulations were fundamentally revised, improved and supplemented including new resp. additional rules for pile design. Fundamentally, in the second generation pile groups and piled rafts will be covered equivalently to single piles whereby the regulation of the first generation focused solely on single piles. Detailed guidance is provided to consider actions on piles due to ground displacements like downdrag. Revised sets of correlation, model and partial factors were specified. The design approaches for axially and laterally loaded piled foundations were harmonized.

As each Clause of EN 1997-3 (Clauses 4 to 12) follows a common structure, also Clause 6 comprises the following sub-sections which have the same order as the Clauses in EN 1997-1:2024 and which provide structure-specific rules in addition to the general rules specified in Part 1 of Eurocode 7:

6.1 Scope
6.2 Basis of design
6.3 Materials
6.4 Groundwater
6.5 Geotechnical analysis
6.6 Ultimate limit states
6.7 Serviceability limit states
6.8 Execution
6.9 Testing
6.10 Reporting

These sections of Clause 6 provide specific regulations for the analysis and design of piled foundations. In this context the detailed information documented in Clause 6 includes for example the following aspects:

- requirements on the minimum extent of ground investigations;
- analysis of piled foundations due to structural loads and effects of ground displacements;
- design of piled foundations by testing, calculation, prescriptive measures;
- the specification of ultimate limit state (ULS) and serviceability limit state (SLS) verifications for single piles, pile groups and piled rafts including a definition of the verification cases (VC) being relevant for those verifications;
- the specification of the sets of model factors γ_{Rd}, correlation factors ξ as well as partial factors γ_R for the evaluation of the design value of pile resistances.

Besides the structure-specific regulations documented in Clause 6 of EN 1997-3, information needed for the design of piled foundations are provided also by EN 1990 and EN 1997-1 as illustrated in Figure 1.

EN 1990 specifies the principles of classification of structures according to consequences classes and the consequences factors k_F for actions as well as the principles of limit state design and of the verification by the partial factor method including specification of partial factors on actions γ_F and stresses γ_E. EN 1990 also specifies the ´Verification Cases´ VC1 to VC4 being relevant for different design situations like structural resistance, static equilibrium and geotechnical design and the related sets of partial factors. The partial factors can either be applied on material properties, i.e. the ´Material Factor Approach´ (MFA), or to resistances, i.e. the ´Resistance Factor Approach´ (RFA).

EN 1997-1 as well provides relevant specifications and regulations needed for the design of piled foundations. Besides specifications of the Geotechnical Category (GC) which should be determined by a combination of the Consequence Class (CC) of the structure and the Geotechnical Complexity Class (GCC), the evaluation of representative values X_{rep} as well as partial factors γ_M on ground properties and consequence factors both on ground properties k_M and resistances k_R are specified in Part 1 of Eurocode 7.

In the following some of the most relevant modifications for the design of piled foundations according to second generation of Eurocode 7 are explained in more detail.

2.2 Ground investigations

In addition to EN 1997-2:2024 which includes fundamental requirements on ground investigation and evaluation of ground properties section 6.2 of EN 1997-3 provides additional specific regulations, e.g. specifications on the minimum depth d_{min} of field investigation on piled foundations (Table 1).

Table 1. Minimum depth of ground investigation for piled foundations.

Application	Minimum depth
Single piled foundation	d_{min} = max (5 m; 3·$B_{n,eq}$)
Pile groups or piled rafts in soils and in very weak and weak rock masses	d_{min} = max (5 m; 3·$B_{n,eq}$; p_{group})
Pile groups or piled rafts in strong rock masses	d_{min} = max (3 m; 3·$B_{n,eq}$)

d_{min} is the minimum investigation depth beneath pile base level.

$B_{n,eq}$ is the equivalent size of the pile base, equal to B_b (for square piles), D_b (for circular piles), or p_b/π (for other piles);

B_b is the base width of the pile with the largest base (for square piles);

D_b is the base diameter of the pile with the largest base (for circular piles);

P_{group} is the smaller dimension of a rectangle circumscribing the group of piles forming the foundation, limited to the depth of the zone of influence.

2.3 Verification of axial resistance of single piles (ULS)

For axially loaded single piles the axial (compression) resistance shall be verified using:

$$F_{cd} \leq R_{cd} \quad (1)$$

Thereby, the verification for axial loaded piles (single piles, pile groups and piled rafts) could be harmonized as solely the Resistance Factor Approach (RFA), where the partial factors are applied on the pile resistance, shall be used in combination with Verification Case VC1, where the partial factors are applied on the actions. Thus, the design value of actions is defined as follows:

$$F_{cd} = 1.35G_{rep} + 1.5Q_{rep} \quad (2)$$

with Q_{rep} as caractersitic value, combination value, frequent value or quasi-permanent value.

The design value of the axial pile resistance is defined as follows:

$$R_{\mathrm{cd}} = \frac{R_{\mathrm{c,rep}}}{\gamma_{\mathrm{Rc}} \cdot \gamma_{\mathrm{Rd}}} \ or \ \left(\frac{R_{\mathrm{b,rep}}}{\gamma_{\mathrm{Rb}} \cdot \gamma_{\mathrm{Rd}}} + \frac{R_{\mathrm{s,rep}}}{\gamma_{\mathrm{Rs}} \cdot \gamma_{\mathrm{Rd}}}\right) \quad (3)$$

where γ_{Rc}, γ_{Rb}, γ_{Rs} are partial factors for pile resistrances and γ_{Rd} is a model factor.

The representative values of the pile resistance in axial compression $R_{\mathrm{c,rep}}$ resp. of the base and shaft resistance $R_{\mathrm{b,rep}}$ and $R_{\mathrm{s,rep}}$ can be obtained by testing, by calculation or by prescriptive rules. The use of prescriptive rules is very rare for piles. For the determination of the axial resistances of single piles by calculation either the ´Ground Model Method´ or the ´Model Pile Method´ can be applied. In case of the Ground Model Method the axial resistance of a single pile is calculated based on ground properties determined from both field and laboratory tests, accounting for horizontal variability of the ground in the piled area. The Model Pile Method is a calculation method to determine the axial resistance of a single pile based on individual pile resistance profiles determined from correlations with field test results or ground properties from field or laboratory tests. Methods of calculating base and shaft resistance are included in Annex C of EN 1997-3 for ground parameters as well as for cone penetration methods and for pressuremeter methods. Figure 2 provides an overview about these calculation methods.

The axial resistance of a single pile at ultimate and serviceability limit state may be also determined from the results of static load tests. Dynamic impact and rapid load tests may be used to determine the ultimate limit state of a single pile in compression.

Pile resistance based on ground parameters

$q_{s,rep}$ with $\alpha \cdot c_u$ or $\beta \cdot \sigma'_v$

$q_{b,rep}$ with N_c or N_q

Pile resistance based on CPT or PMT data

$q_{s,rep}$ = f (soil type, pile type, q_c or p^*_{LM})

$q_{b,rep}$ = f (soil type, pile type, q_c or p^*_{LM})

pile resistance based on CPT profiles:

$q_{s,rep}$ with $c_s \cdot q_c$

$q_{b,rep}$ with $c_b \cdot k_{shape} \cdot q_c$

pile resistance from PMT profiles:

$q_{s,rep}$ with $\alpha_{pile\text{-}ground} \cdot f(p^*_{LM})$

$q_{b,rep}$ with $k_{b,PMT} \cdot p^*_{LM}$

Pile resistance based on empirical tables

Example: Representative values of unit shaft resistance $q_{s,rep}$ for bored piles in soils

Fine soils		Coarse soils	
Undrained shear strength c_u (kPa)	$q_{s,rep}$ (kPa)[a, b]	Mean cone resistance q (MPa)	$q_{s,rep}$ (kPa)[a,b]
60	30-40	7,5	55-80
150	50-65	15	105-140
≥ 250	65-85	≥ 25	130-170

[a] The lower value represents the 10 % quantile and the upper value the 50 % quantile

[b] Intermediate values can be obtained by linear interpolation

Figure 2. Available calculation methods for evaluation of axial pile resistances.

Table 2 specifies the evaluation of representative values of axial pile resistances from calculated or measured values.

Table 2. Evaluation of representative axial resistances of single piles based on calculation or testing.

Ground Model Method: R_{calc} from ground parameters (c_u, φ´ and c´, p_{LM}*, q_c, N_{SPT}, etc.)	$R_{rep} = R_{calc}$
Model Pile Method: R_{calc} from N field test profiles (N CPTs, N PMTs, N SPTs, etc.)	$R_{rep} = \min\left\{\frac{R_{calc,mean}}{\xi_{mean}}; \frac{R_{calc,min}}{\xi_{min}}\right\}$
Pile tests: R_{test} from static, dynamic impact or rapid load tests	$R_{rep} = \min\left\{\frac{R_{test,mean}}{\xi_{mean}}; \frac{R_{test,mean}}{\xi_{min}}\right\}$

Figure 3 visualizes the possible procedures to evaluate design values of axial pile resistances from testing and calculation. Tables 3 and 4 document the model factors γ_{Rd} for verification of axial pile resistance assisted by testing and calculations.

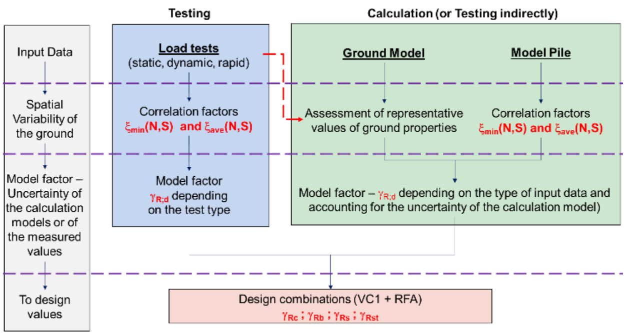

Figure 3. Calculation procedures for piles.

Correlation factors ξ allows to consider the spatial variability of the ground alternatively to the selection of the representative values of the ground parameters which is always related to subjective interpretation. Correlation factors ξ as documented in section 6.2.4 of EN 1997-3 continues to be dependent form number of executed pile tests or ground profiles. The correlation factors given reflect an average uncertainty corresponding to a coefficient of variation of about 12%; other approaches are therefore acceptable if spatial variation is lower or higher.

The correlation factors for the Model Pile Method can be adjusted according to the density of the field test profiles (CPTs, PMTs, etc.) considering the ratio of the average horizontal spacing d_{avg} between the N

Table 3. Model factors γ_{Rd} for verification of axial pile resistance assisted by testing.

Verification by		Model factor γ_{Rd}		
		Fine soils	Coarse soils	Rock mass
Static load tests		1.0	1.0	1.0
Rapid load tests (multiple load cycles)		1.4	1.1	1.2
Rapid load tests (single load cycle)		1.4	1.1	1.2
Dynamic impact tests (signal matching)	Shaft bearing	1.5	1.1	1.2
	End bearing	1.4	1.25	1.25
Dynamic impact tests (multiple blow)	Shaft bearing	1.5	1.1	1.2
	End bearing	1.4	1.2	1.2
Dynamic impact tests (closed form solutions)	Shaft bearing	Not permitted	Not permitted	Not permitted
	End bearing	Not permitted	1.3	1.3
Wave equation analysis		Not permitted	1.6	1.5
Pile driving formulae		Not permitted	1.8	1.7

Table 4. Model factors γ_{Rd} for verification of axial pile resistance by calculation.

Verification by	Based on	Model factor γ_{Rd}	
Ground Model Method	Ultimate pile tests	1.15	
	Extensive comparable experience without site-specific control tests	1.3	
	Serviceability pile tests	1.35	
	No pile load tests and limited comparable experience	1.55	
Model Pile Method		Compressive resistance	Tensile resistance
	Pressuremeter test	1.15	1.4
	Cone penetration test	1.1	1.1
	Profiles of ground properties based on field or laboratory tests	1.2	1.2

tests profiles located in the area S to a reference distance d_{ref} = 30 m:

$$\xi_{mean}(S) = 1 + \frac{d_{avg}}{d_{ref}}(\xi_{mean} - 1) \quad (4)$$

$$\xi_{min}(S) = 1 + \frac{d_{avg}}{d_{ref}}(\xi_{min} - 1) \quad (5)$$

2.4 Verification of axial resistance of pile groups and piled rafts (ULS)

As already mentioned Clause 6 of EN 1997-3:2025 covers not only single piles but equally also pile groups and piled rafts.

Pile group design shall consider that the resistance and load-displacement behaviour of single piles in a group might show significant variation compared to the behaviour of single piles due to pile-pile interaction. Calculation of pile group effects should consider the potential changes in stress and density of the ground resulting from pile installation together with the effects of group behaviour due to the structural loads taking the stiffness of the pile cap and the structure into account. The ultimate vertical resistance of a pile group R_{group} with n piles should be determined from:

$$R_{group} = \min\{\textstyle\sum_i^n R_i ; R_{block}\} \quad (6)$$

where R_i is the ultimate axial resistance of the i-th pile in the pile group, taking full account of the effects of pile interaction, and where R_{block} is the ultimate vertical resistance of the block of ground bounded by the perimeter of the pile group. The design resistance of a pile group $R_{d,group}$ shall be verified using

$$F_d \leq R_{d,group} \quad (7)$$

with

$$R_{d,group} = \frac{R_{rep,group}}{\gamma_{R,group} \cdot \gamma_{Rd,group}} \quad (8)$$

where $\gamma_{R,group}$ is a resistance factor and $\gamma_{Rd,group}$ is a model factor for the pile group.

The design of piled rafts shall consider beside the pile-pile interaction the pile-raft interaction (Figure 4). Considering the compatibility of the displacements of the piles and the raft, the ultimate compressive resistance $R_{piled\text{-}raft}$ of a piled raft should be determined as

$$R_{piled-raft} = \left(\textstyle\sum_i^n R_{c,i} + R_{raft}\right) \quad (9)$$

where R_{raft} is the additional bearing resistance from the raft. The design resistance of a piled raft $R_{d,piled\text{-}raft}$ shall be verified using

$$F_d \leq R_{d,piled-raft} \quad (10)$$

with

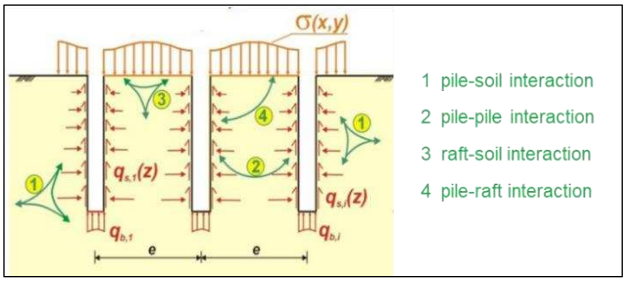

Figure 4. Interaction effects to be considered for the verification of piled rafts according to EN 1997-3, 6.5.6.

$$R_{d,piled-raft} = \frac{R_{rep,piled-raft}}{\gamma_{R,piled-raft} \cdot \gamma_{Rd,piled-raft}} \quad (11)$$

where $\gamma_{R,piled\text{-}raft}$ is a resistance factor and $\gamma_{Rd,piled\text{-}raft}$ is a model factor for the piled raft.

For the ULS-verification of axially loaded pile groups and piled rafts EN 1997-3 pretends the application of verification case VC1 in combination with RFA and partial factors of $\gamma_{R,group}$ = 1.4 resp. $\gamma_{R,piled\text{-}raft}$ = 1.4 leading to a comparable equivalent gloabal safety level as for spread foundations or single piles. For combined axial and transversal loaded pile groups and piled rafts both approaches, MFA or RFA, might be used for ULS-verficiations.

Verification of limit states for pile groups and piled rafts may be carried out by analytical or empirical, but preferential by numerical calculation methods.

2.5 Pile settlements and SLS verifications

Verification of the serviceability limit state for piled foundations should be based on modelling that accounts for non-linear stiffness of the ground, flexural stiffness of the structure, and interaction between the ground, structures, and piles. The non-linearity of the load-displacement curves of axially loaded piles should be considered for the verification of both geotechnical and structural limit states.

The settlement of a single pile may be determined from load tests or calculated using empirical or analytical methods or numerical modelling.

2.6 Downdrag (negative skin friction)

The adverse effects of a drag force caused by moving ground shall be included in the verification of serviceability *and* ultimate limit states of piled foundations when relevant. Thereby the drag force caused by downdrag should be classified as a permanent action. The effects of the downdrag should be modelled by carrying out a ground-pile interaction analysis, to determine the depth of the neutral point L_{dd} corresponding to the point where the pile settlement s_{Pile} equals the ground settlement s_{ground}. This neutral point is different for SLS or ULS conditions as shown in Figure 5 which also illustrates the approach recommended to be used to calculate the neutral point and the dragforce owing to potential downdrag.

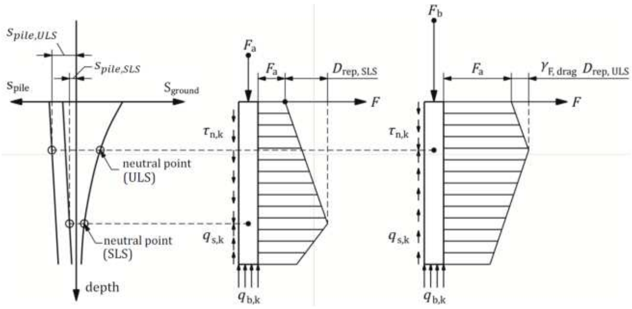

Figure 5. Force distribution for assessment of drag force on a pile subject to downdrag according to EN 1997-3, C.9.

The representative drag force D_{rep} should then be determined from

$$D_{\text{rep}} = p \int_0^{L_{\text{dd}}} \tau_{\text{s}} \cdot \text{dz} \tag{12}$$

where p is the perimeter of the pile and τ_s is the (negative) unit shaft friction causing downdrag at depth z. EN 1997-3 provides in its Annex C a simplified approach for calculating the drag force by adopting a depth to the neutral plane L_{dd} that results in an upper value of the drag force.

2.7 Transversal loading

Clause 6 of EN 1997-3 provides also guidance on the verification of single piles, pile groups and piled rafts due to lateral loading. In Annex C.12 calculation models, mainly based on *p-y* curves from undrained and drained soil properties, are provided to calculate the behaviour of transversely loaded single piles. For the verification of the transverse resistance either the MFA or the RFA can be applied.

2.8 Buckling

The buckling resistance of a slender pile under compression and embedded in soil should be determined by a validated model, either analytic or numerical, according to second order theory considering the support of the soil and initial transverse deflection due to production imperfections, installation etc. EN 1997-3 provides detailed guidance to evaluate the buckling resistance by analytical methods even though other approaches, e.g. by numerical methods can be applied.

2.9 Cyclic effects

Cyclic and dynamic actions can result in reduced ground strength and stiffness leading to additional pile displacements and loss of resistance. Therefore, EN 1997-3 requests to consider the adverse effects of cyclic and dynamic actions on the long-term axial and transverse resistance of piled foundations. In Annex C.14 of EN 1997-3 the concept of ´stability diagram´ based on Poulos (1988) is provided to determine in a simple way whether the axial cyclic loads applied at the pile head can induce any degradation effects to reduce the axial pile resistance.

2.10 Further aspects

Clause 6 of EN 1997-3 provides guidance to many further aspects being relevant for piled foundations including further calculation and design issues but also execution, testing and reporting. Even aspects of sustainability are addressed as the thermal, geotechnical and structural design aspects of thermo-activated deep foundations are mentioned.

ACKNOWLEDGEMENTS

The authors have been involved at various stages in the development of the second generation of Eurocode 7, serving on a range of evolution and working groups or project teams. They are grateful to their colleagues for their contributions to the development of EN 1997-3.

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