Second Generation of Eurocode 7 - A modern code and toolbox for the design of geotechnical structures

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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 has been published 2024/2025 and represents a significant step forward towards further harmonization and efficient guidance for geotechnical design. The revision is performed focusing on the user´s need with the main goals of ease-of-use and harmonization, to meet new demands in geotechnical engineering looking at the coming 20 to 25 years. The second generation covers new basic aspects like numerical methods, probability and reliability-based verification, rock on an equal basis as soil, etc. In addition, geotechnical structures like reinforced fill structures, soil nailing and ground improvement were included for the first time. The paper presents an overview of some of the key revisions compared to the first generation of Eurocode, that will affect the practicing geotechnical engineer and explains the application on example of piles foundations. The paper concludes that the 2nd generation of Eurocode will be a modern standard for all kind of geotechnical structures and a useful tool for engineers in practice.

1 INTRODUCTION

In 2012, the European Commission decided on the M515 mandate, giving the responsibility to CEN to further develop the Eurocodes. In 2015 the first project teams were established to start the drafting process of the second generation of all structural Eurocodes. The aim has been that the first parts of new generation will be published in 2022 and the last in 2027, a timeline that still applies to this day.

In this context, also Eurocode 7, the basis for the geotechnical design was transferred from first edition to second generation including fundamental reorganisation and extensions. In its 2nd 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 1st generation´s EN 1997-1 together with new clauses on reinforced fill structures, ground reinforcing elements, ground improvement and groundwater control.

The reorganization of the second generation of Eurocode 7 is illustrated in Figure 1.

2 EUROCODE 7 PART 1 – GENERAL RULES

The scope of part 1 has been reduced since the basis of geotechnical design has been moved to EN 1990 and specific considerations for different geotechnical structures has been moved to part 3. However, the table of content has introduced some new concepts, and the strive to include all common topics in part 1, instead of repeating them in each clause in part 3, has given a part with a similar amount of text as in 1st generation.

The concept of the geotechnical category (GC) has been revised so that it is systematically determined with the consideration of the consequence of failure (CC) and geotechnical complexity (GCC). This revised concept is used as the base of classification to achieve geotechnical reliability (Franzén & van Seters 2022). The term ´representative value´ is introduced and replace the old characteristic value. The representative value is determined either as a cautious estimate or with a statistical approach.

EN 1997-1:2024 provides further guidance on the four methods for verification of limit states, on the use of numerical methods for design and verification, on the concept of the zone of influence and on the implementation of design during execution and service life focussing on supervision, inspection, monitoring, and maintenance applied to ensure that the design is implemented correctly.

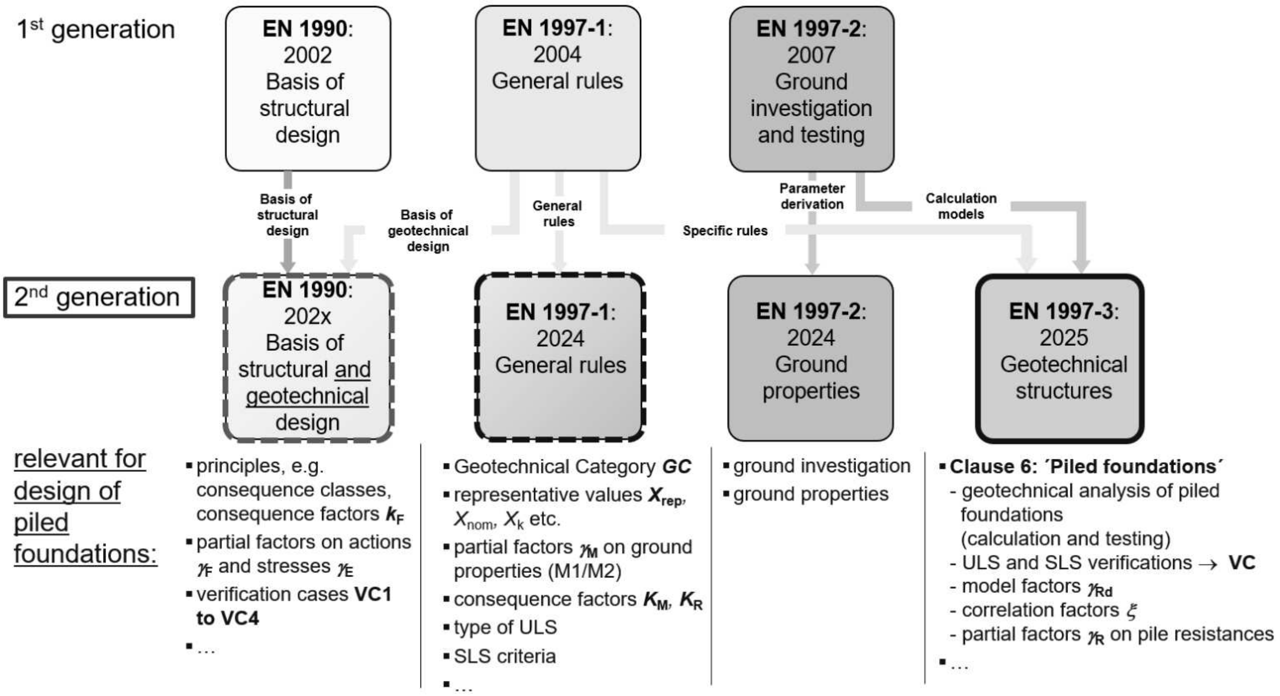

Figure 1. Division and redistribution of the 1st generation of Eurocode 0 and Eurocode 7 into the standards of the second generation (acc. to Bond et al. 2019); at the bottom: contents of these standards being relevant for design of piled foundations.

3 EUROCODE 7 PART 2 – GROUND PROPERTIES

The contents of the existing Eurocode 7, Part 2 ´Ground investigation and testing´ (EN 1997-2:2007) were also being revised to focus in the new Part 2 ´Ground parameters´ (EN 1997-2:2024) on the derivation of design parameters. Thus, while EN 1997-2 was in 1st generation focusing on ground investigation and testing, for the 2nd generation, this part has been turned 90 degrees and is now focusing on the need of the engineer to derive appropriate ground properties as input to the design instead as previous, on the output from ground investigations.

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.

4 EUROCODE 7 PART 3 – GEOTECHNICAL STRUCTURES

Eurocode 7 part 3 consists of the specific rules for each type of geotechnical structure. General requirements applicable for more than one structure has been moved to part 1. Therefore, the main content for each clause is focused on geotechnical analyses giving the calculation models, ultimate limit state and serviceability limit state.

The chapters known from 1st generation of EN 1997-1. i.e. the clauses on slopes, cuttings and embankments (Clause 4), spread foundations (5), piled foundations (6), retaining structures (7) and anchors (8) were revised. In addition, the following new clauses have been added: on reinforced fill structures (9), soil nailed structures (10), rock bolts and rock surface support (11), ground improvement (12) and groundwater control measures (13). Thus, the range of geotechnical structures covered by the new EN 1997-3 has been increased significantly.

5 EXAMPLE: CLAUSE ON PILED FOUNDATIONS

In the following the application of 2nd generation of EN 1997 has exemplarily been in more detail for the design of piled foundations.

5.1 *Introduction*

Relevant for the design of piled foundations is predominantly Clause 6 ´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 regulations 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 follows a common structure, also Clause 6 comprises the following subsections 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 consequence 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 presented in more detail.

5.2 *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.

5.3 *Verification of axial resistance of single piles (ULS)*

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

$$F_{cd} \leq R_{cd} \tag{1}$$

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:

$$F_{cd} = 1.35G_{rep} + 1.5Q_{rep} \tag{2}$$

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:

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

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 $R_{\text{c,rep}}$ resp. of the base and shaft resistance $R_{\text{b,rep}}$ and $R_{\text{s,rep}}$ 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

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

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

Pile resistance based on CPT or PMT data

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

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

pile resistance based on CPT profiles:

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

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

pile resistance from PMT profiles:

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

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

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)	$q_{\text{s,rep}}$ (kPa)[a, b]	Mean cone resistance q (MPa)	$q_{\text{s,rep}}$ (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.)	$R_{\text{rep}} = R_{\text{calc}}$
Model Pile Method: R_{calc} from N field test profiles (N CPTs, N PMTs, N SPTs, etc.)	$R_{\text{rep}} = \min\left\{\frac{R_{\text{calc,mean}}}{\xi_{\text{mean}}}; \frac{R_{\text{calc,min}}}{\xi_{\text{min}}}\right\}$
Pile tests: R_{test} from static, dynamic impact or rapid load tests	$R_{\text{rep}} = \min\left\{\frac{R_{\text{test,mean}}}{\xi_{\text{mean}}}; \frac{R_{\text{test,mean}}}{\xi_{\text{min}}}\right\}$

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.

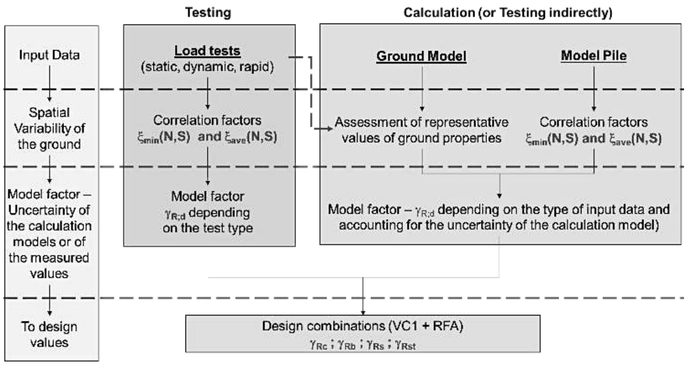

Figure 3. Calculation procedures for piles

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	
		Compressive resistance	Tensile resistance
Model Pile Method	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:

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

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

5.4 *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.

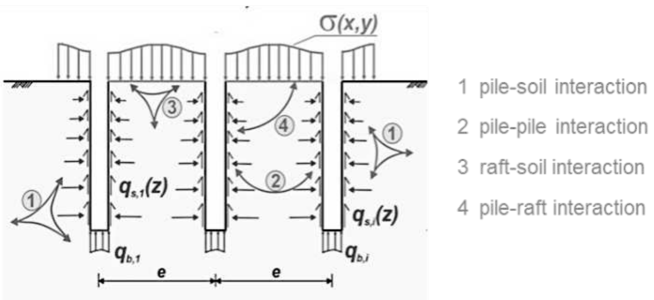

Figure 4. Interaction effects to be considered for the verification of piled rafts according to EN 1997-3, 6.5.6.

The design of piled rafts shall consider beside the pile-pile interaction the pile-raft interaction (Fig. 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

$$F_{\mathrm{d}} \leq R_{\mathrm{d,piled-raft}} \tag{10}$$

with

$$R_{\mathrm{d,piled-raft}} = \frac{R_{\mathrm{rep,piled-raft}}}{\gamma_{\mathrm{R,piled-raft}} \cdot \gamma_{\mathrm{Rd,piled-raft}}} \tag{11}$$

where $\gamma_{\mathrm{R,piled\text{-}raft}}$ is a resistance factor and $\gamma_{\mathrm{Rd,piled\text{-}raft}}$ 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 $\gamma_{\mathrm{R,group}} = 1.4$ resp. $\gamma_{\mathrm{R,piled\text{-}raft}} = 1.4$ leading to a comparable equivalent global 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-verifications.

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

5.5 *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.

5.6 *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 drag-force owing to potential downdrag.

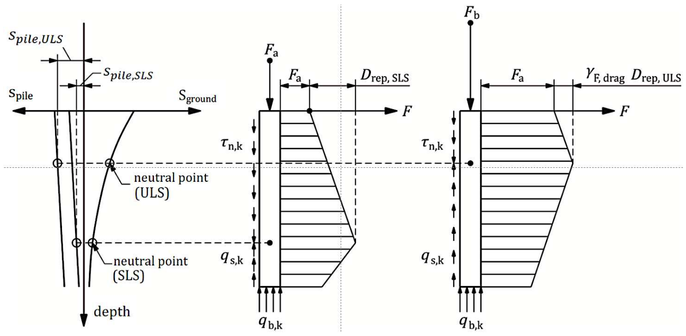

Figure 5. Force distribution for assessment of drag force on a pile subject to downdrag according to EN 1997-3, C.9.

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

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

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.

5.7 *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.

5.8 *Buckling*

The buckling resistance of a slender pile under compression 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.

5.9 *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.

5.10 *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 thermoactivated deep foundations are mentioned.

6 CONCLUSION

The 2nd generation of Eurocode 7 is a modern standard developed as useful tool for the coming decades. Hence the standard tries to include concepts that are foreseen to be important for the future such as sustainability, robustness, impacts within the zone of influence and climate change. The new structure with a clear division between general rules in part 1, ground properties in part 2 and specific rules for different geotechnical structures in part 3, opens the possibility to add on additional specific clauses if ever needed. The new Eurocode 7 will serve as the commonly agreed standard for the future functioning as a toolbox that fulfil the needs of geotechnical engineers worldwide.

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