

2nd generation of Eurocode 7 - Foundations

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ABSTRACT: The second generation of Eurocode 7, part 3, focuses on the limit state design of geotechnical structures. Spread foundations are dealt with in Clause 5 whereas piled foundations are addressed in Clause 6. In these Clauses, regulations for the verification of ultimate (ULS) and serviceability (SLS) limit states are provided for soils and fills but also for rock mass. In comparison to the current version of Eurocode 7 the regulations have been improved not only by a unified structure which is consistent with all other Clauses in this part and follows the design-path defined in part 1. Moreover, design principles have been sharpened and various aspects of the design have been emphasized more clearly. Among these are in case of spread foundations the implementation of the Terzaghi-Buisman method for calculating the bearing resistance in the main text, which is an example for the increased harmonization achieved. Further, a widely extended annex includes various calculation models for ULS and SLS verification. For piled foundations, methods to evaluate the axial pile resistance are now clearly distinguished with a focus on design by calculation and design by testing together with a more stringent concept of model, correlation and partial factors. Moreover, guidance on the design of pile groups and piled rafts and the use of numerical models is provided. Together with new provisions on ground improvement in Clause 12, the new Eurocode 7, part 3 now allows a smooth transition in foundation design from spread foundations via ground improvement with rigid inclusions, piled rafts to conventional piled foundations.

KEYWORDS: Second generation Eurocode 7, spread foundations, piled foundations, design, ultimate limit state, serviceability limit state.

1 INTRODUCTION

The geotechnical design of foundations is covered by Part 3 of the second generation Eurocode 7 (CEN 2025), where Clause 5 addresses spread foundations and Clause 6 deals with piled foundations. Both Clauses are organized in a unified way following the basic design principles established in Eurocode 7, Part 1 (CEN 2024a), see Figure 1.

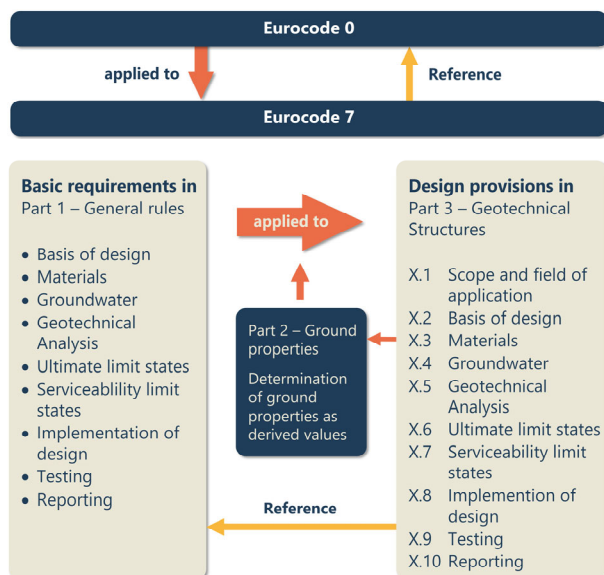


Figure 1. General structure of second generation EN 1997-3, Clauses 5 and 6 including linking with EN 1997-1/-2 and prEN 1990-1.

The overall goal of foundation design is to reach a sufficient level of reliability with regard to safety, serviceability and durability, which is defined in Eurocode 0, Part 1 (prEN 1990-1 - CEN 2023). Hence, Clauses 5 and 6 refer to prEN 1990-1 where the principles of limit state design with the partial factor concept are established. Further, Clause 5 and 6 both refer to Eurocode 7, Part 2 (CEN 2024b) in regard to the ground

properties needed for design which are to be derived from ground investigations (i.e. *derived values*).

Besides typical spread foundations, i.e. pad, strip and raft foundations, Clause 5 is also applicable to deep foundations such as caissons, which behave as spread foundations, and to unreinforced working platforms. Moreover, cross-references to Clause 5 exist in various other Clauses, e.g. in Clause 7 for gravity retaining walls, in Clause 9 for reinforced fill structures and in Clause 11 for soil-nailed walls in regard to aspects related to the bearing behavior of a spread foundation.

Clause 6 not only includes provisions for single piles but has been significantly extended to also cover pile groups and piled rafts. In addition, several new regulations for the design of piled foundations e.g. considering the adverse effects of moving ground, cyclic loading etc. were included.

Both Clauses, 5 and 6, are strongly connected to Clause 12 on ground improvement (GI) whereby Clause 12 covers all kind of GI considering the diffused (Classes AI and AII) or discrete (Classes BI and BII) character of the GI and the possibility to measure the unconfined compressive strength (UCS) of the improved ground. A concept close to piled foundations are rigid inclusions which represent structural elements with stiffness and strength both significantly higher than the ground in which they are installed. With that, a stringent foundation design and verification concept for all types of foundation has been established by the new Eurocode 7. As indicated in Figure 2, this allows a smooth transition from conventional spread foundations via ground improvement without and with rigid inclusions to piled rafts and finally conventional piled foundations with a comparable equivalent global safety level.

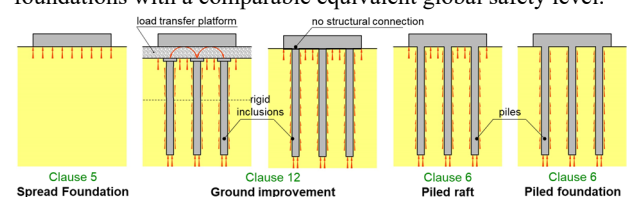


Figure 2. Transition between conventional spread and piled foundations using concepts of ground improvement.

In the following an overview of the important changes and improvements in the design of spread and piled foundations according to the new Eurocode 7 as compared to its 1st generation is presented.

2 DESIGN OF SPREAD FOUNDATIONS

2.1 Basis of design

According to Figure 1, subclause 5.2 of Clause 5 addresses the basic design information. These include design situations, geometrical properties, actions and environmental influences as well as the limit states and the required ground investigations.

An important accompanying measure to achieve the required level of reliability in a design following Eurocode 7 is the requirement of a minimum extent of ground investigations. Whereas the ground investigation methods and their arrangement are subject of Part 2, the minimum investigation depths are defined in Part 3 for each geotechnical structure depending on their specific bearing behavior. Table 1 shows the minimum depth values given in subclause 5.2 for spread foundations. These values are comparable to the recommendations in Annex B of the current Eurocode 7, Part 2 (CEN 2007). The table is defined as a *Nationally Determined Parameter* (NDP), hence its content and structure can be modified in the National Annexes.

Table 1. Minimum depth of ground investigations according to Table 5.1 of EN 1997-3:2025.

Type of spread foundation	Minimum depth
Square or circular footing	$d_{\min} = \max(3B; 6\text{m})$
Strip footing	$d_{\min} = \max(5B; 6\text{m})$
Raft or structure supported by a group of footings	$d_{\min} = \max(1.5B; 6\text{m})$

B = either width of a single foundation or width of a foundation group, depending on the system considered

The ultimate (ULS) and serviceability (SLS) limit states to be verified for spread foundations are summarized in Figure 3. In case of rotational failure of the structure, the new Eurocode 7 clearly distinguishes between toppling, which is a loss of static equilibrium without failure of the ground, and overturning, which results from a rotational bearing failure of the ground. Whereas toppling is to be verified according to Part 1 together with prEN 1990-1 by a comparison of stabilizing and destabilizing moments around an anticipated point of rotation, overturning is implicitly covered by the verification against bearing resistance failure according to Clause 5.

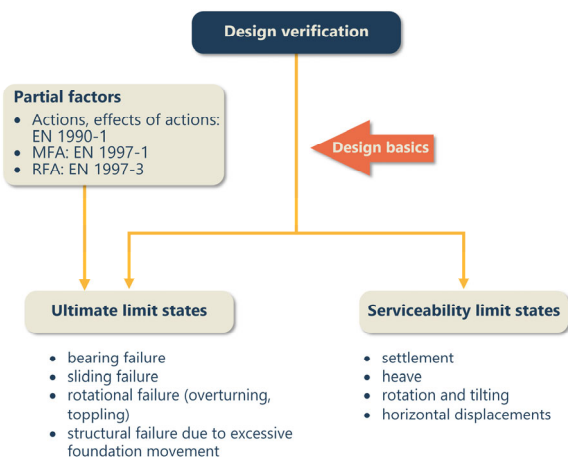


Figure 3. Ultimate and serviceability limit states of spread foundations.

Figure 3 also mentions structural failure due to excessive foundation movements. However, Clause 5 does not include any provisions on how to verify this ultimate limit state, but refers to the general requirements in Part 1. Hence, specific rules are subject to the National Annexes.

The materials involved in the design are the topic of subclause 5.3. Reference is made to Part 2 for determination of the necessary ground properties. The use of either effective or total stress ground properties is recommended depending on the design situation. Further, subclause 5.4 explicitly demands consideration of groundwater conditions and resultant pressures, which could affect the foundation bearing behavior.

2.2 Geotechnical analysis

Clause 5, subclause 5.5 provides rules for selection and application of calculation models for verifying the ULS and SLS of a spread foundation. Whereas the rules for calculating the sliding resistance as well as settlement or heave have not significantly changed in comparison to the current Eurocode 7, several modifications can be identified for the bearing resistance calculation.

A clear indication of an increased harmonization reached by the new Eurocode 7 is that the well-known Terzaghi-Buisman formulae for the bearing resistance of soils and fills for drained and undrained analysis (Terzaghi, 1943) are recommended in the main code text and no longer in an informative annex. However, the parameters for the bearing resistance formulae are defined in the new Annex B.4 as they may vary due to national design practices.

The bearing resistance formulae for soil and fill now also include depth factors and ground inclination factors. For the depth factors the formulae proposed by Brinch Hansen (1970) and adopted by Vesic (1973) and for the ground inclination factors the formulae provided by Vesic (1975) are recommended. However, the depth factors should only be used with great care and only, if the strength of the soil or fill in the embedment zone is equal to or greater than the strength of the soil below foundation level. The cohesion term in the load inclination factor is no longer considered. The bearing resistance factor N_γ has been modified as well to adapt to internationally used formulations. Accordingly, the formula provided by Caquot & Kérisel (1953) and Vesic (1973) is now recommended in Annex B.4, i.e. $N_\gamma = 2 \cdot (N_q + 1) \cdot \tan \phi^*$, whereas Annex D of the current Eurocode 7 (CEN 2004) defines the following: $N_\gamma = 2 \cdot (N_q - 1) \cdot \tan \phi^*$. Figure 4 indicates that both formulae lead to very similar results for friction angles greater than $\approx 25^\circ$. It further illustrates the big scatter, which is involved with different formulations for N_γ indicating a significant uncertainty in this parameter. Against this background, this change is, thus, acceptable.

Clause 5.5 further provides additional guidance for determining the bearing resistance of rock mass. It also allows the derivation of the bearing resistance from empirical models if verified by comparable experience. Besides, rules for selecting appropriate distributions of bearing pressures for structural analysis are now available. Clause 5 is supplemented by a significantly extended Annex B where additional calculation models for bearing resistance calculation and settlement evaluation are provided.

2.3 ULS verification

According to subclause 5.6, either the Material Factor Approach (MFA) or the Resistance Factor Approach (RFA) may be used for the ULS verification of spread foundations. As already indicated in Figure 3, the partial factors for the design ground properties in the MFA are given in Part 1, Table 4.8, whereas the partial resistance factors for the design resistances

in the RFA are provided in subclause 5.6 of Part 3, Table 5.2. The partial factors on actions and effects of actions are defined for different verification cases (VC) in prEN 1990-1, Table A.1.8. All tables are NDP. Hence, it is up to the National Annexes to decide which factoring approach and partial factors to be used.

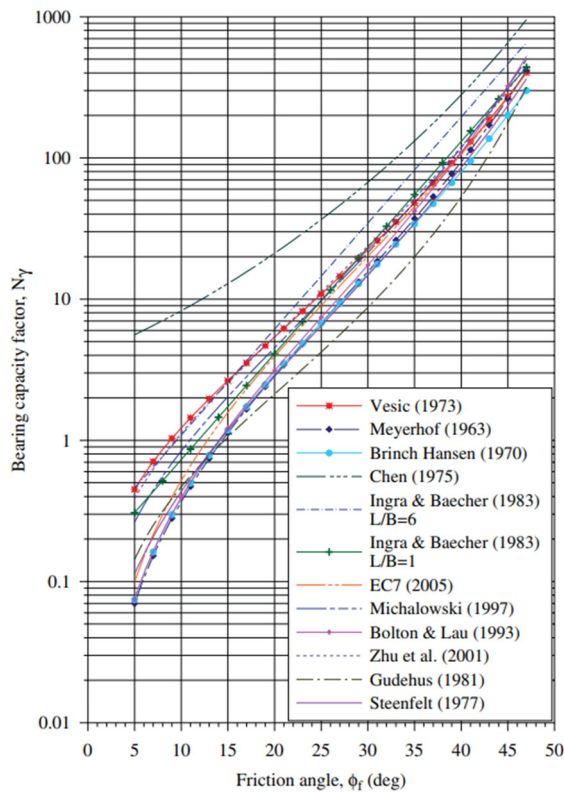


Figure 4. Scatter involved with bearing resistance factor N_f according to various solutions from the literature (adopted from Paikowsky et al., 2011).

In general, the two approaches result in the possible combinations (a) to (c) for MFA as well as (d) and (e) for RFA, for which the relevant partial factors for persistent and transient design situations are summarized in Table 2. EN 1997 and prEN 1990-1 allow to reduce the partial factors for transient design situations. In the MFA, either combination (a) and (b) or combination (c) must be verified. In RFA verifications combination (e) is limited to design situations where the representative load inclination does not exceed 20%.

Table 2. Partial factors for the ULS verification of spread foundations for persistent and transient design situations (Table 5.2, EN 1997-3:2025).

	MFA			RFA	
	a	b	c	d	e
	VC1	VC3	VC1	VC1	VC4
γ_G	1.35	1.0	1.35	1.35	1.0
$\gamma_{G, fav}$	1.0	1.0	1.0	1.0	1.0
γ_Q	1.5	1.3	1.5	1.5	1.11
γ_E	1.0	1.0	1.0	1.0	1.35
$\gamma_{tan^{\phi, p}}$	1.0	1.25	1.25	1.0	1.0
$\gamma_{tan^{\delta}}$	1.0	1.25	1.25	1.0	1.0
γ_{RN}	1.0	1.0	1.0	1.4	1.4
γ_{RT}	1.0	1.0	1.0	1.1	1.1

The verification procedures for undrained and drained bearing and sliding resistances themselves have not changed. As already mentioned in section 2.1 the limit state of overturning is verified via the bearing resistance verification using the formulae provided in subclause 5.5 (see section 2.2). In this regard, it needs to be ensured that the load eccentricity remains in a moderate range which is covered by the bearing resistance formulae. Therefore subclause 5.6 emphasizes, among other things, to limit the reduction of the foundation base area A to the effective area A' so that rotation does not cause a limit state in the foundation or the overlying structure. It further allows National Annexes to provide limiting values for the design eccentricity in the ULS. Finally, it is pointed out that numerical methods can be more appropriate if the eccentricity is large.

In regard to the verification of the undrained sliding resistance an additional check is required that the design undrained base resistance is not larger than 0.4 of the representative force acting normal to the foundation base which is considered as a favorable action. This requirement is also included in the current version of Eurocode 7. The purpose is to limit the load inclination when there is an irregular bearing surface with poor contact between the base of the foundation and the ground and, thus a reduced contact area, to ensure that simultaneous shearing and bearing failure does not occur.

Besides the rules for design verification via the partial factor concept, subclause 5.6 also provides guidance on ULS verification by prescriptive rules, testing and the observational method.

2.4 SLS verification

Subclause 5.7 addresses the verification of the SLS. Here, no significant changes have been made compared to the current version of Eurocode 7. Nevertheless, a clearer distinction is now made between settlement and tilting caused by load eccentricity. For eccentrically loaded foundations it shall further be verified that the load eccentricity remains within certain limits to confine the occurrence of a physical gap at the edge of the foundation. Typical values are provided in a table as NDP, which, thus, can be modified by the National Annexes.

2.5 Evaluation of the new regulations in Clause 5

The design of spread foundations according to EN 1997-3, Clause 5 follows a clear and unified procedure which is established in Part 1 of the new Eurocode 7 and adopted by all geotechnical structures covered by Part 3. Whereas, the general design methodology has not changed in comparison to the current version of the code, the verification procedure with new verification cases combined with MFA or RFA requires the engineer to adapt to at least new terminologies.

Moreover, comparative calculations in JRC (2024) or Lesny & Orr (2024) have shown that the different alternatives of combining the partial factors (see Table 2) lead to differences in the design results, i.e. the calculated width of the foundation or the degree of utilization (i.e. the ratio between design resistance and design effect of actions). On the other hand, the calculations in JRC (2024) indicate results that are comparable to a design according to the current Eurocode 7. In the end, the different countries should carefully reflect, based on their national practices and experiences, which design approach should be implemented in their National Annex.

On the other hand, significant improvements and benefits result, beside the stringent design procedure, from an increased harmonization in regard to the bearing resistance calculation, from the explicit consideration of rock and a significantly extended informative Annex B with various calculation models.

3 DESIGN OF PILED FOUNDATIONS

3.1 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 1997-1:2004 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 (Moormann 2025).

3.2 Basis of design

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 3).

Table 3. Minimum depth of ground investigations according to Table 6.2 of EN 1997-3:2025.

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

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.

3.3 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 axially 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 G_{rep} as representative value of permanent action and Q_{rep} as characteristic value, combination value, frequent value or quasi-permanent value. The design value of the axial pile resistance is defined as follows:

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

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

The representative values of the pile resistance in axial compression $R_{c,rep}$ respectively of the base and shaft resistance $R_{b,rep}$ and $R_{s,rep}$ 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 5 provides an overview about these calculation methods.

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			
$q_{s,rep} = f(\text{soil type, pile type, } q_c \text{ or } p_{LM}^*)$		$q_{b,rep} = f(\text{soil type, pile type, } q_c \text{ or } p_{LM}^*)$	
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 $\alpha_{pile-ground} \cdot f(p_{LM}^*)$ $q_{b,rep}$ 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 5. Available calculation methods for evaluation of axial pile resistances.

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.

Table 4 specifies the evaluation of representative values of axial pile resistances from calculated or measured values.

Table 4. 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	$R_{rep} = \min \left\{ \frac{R_{test,mean}}{\xi_{mean}}; \frac{R_{test,min}}{\xi_{min}} \right\}$

Figure 6 visualizes the possible procedures to evaluate design values of axial pile resistances from testing and calculation.

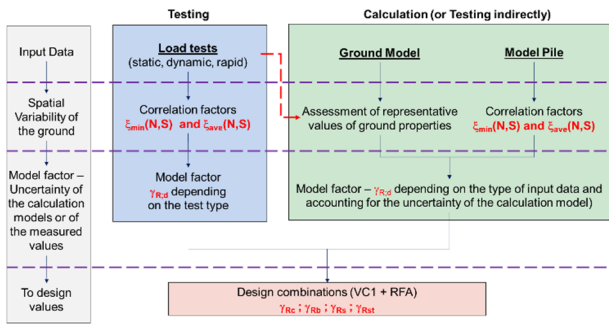


Figure 6. Available calculation methods for evaluation of axial pile resistances.

Tables 5 and 6 document the model factors γ_{Rd} for verification of axial pile resistance assisted by testing and calculation.

Table 5. 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
	End bearing	1.4	1.25
Dynamic impact tests (multiple blow)	Shaft bearing	1.5	1.1
	End bearing	1.4	1.2
Dynamic impact tests (closed form solutions)	Shaft bearing	Not permitted	Not permitted
	End bearing	Not permitted	1.3
Wave equation analysis	Not permitted	1.6	1.5
Pile driving formulae	Not permitted	1.8	1.7

Table 6. Model factors γ_{Rd} for verification of axial pile resistance assisted 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

Correlation factors ξ allow 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 from the 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 test profiles located in the area S to a reference distance $d_{ref} = 30$ m:

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

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

3.4 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:

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

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.

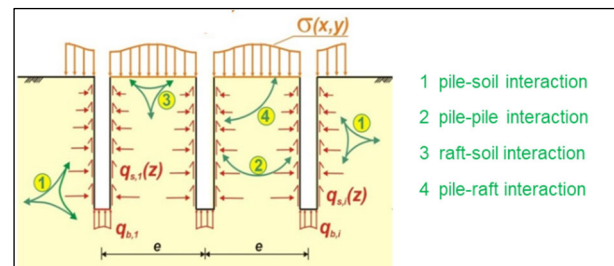


Figure 7. Interaction effects to be considered for the verification of piled rafts according to EN 1997-3, 6.5.6.

The design of piled rafts shall consider beside the pile-pile interaction the pile-raft interaction (Fig. 7). Considering the compatibility of the displacements of the piles and the raft, the ultimate compressive resistance $R_{piled-raft}$ of a piled raft should be determined as

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

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

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

with

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

where $\gamma_{R,\text{piled-raft}}$ is a resistance factor and $\gamma_{Rd,\text{piled-raft}}$ is a model factor for the piled raft. For the ULS-verification of axially loaded pile groups and piled rafts EN 1997-3 specifies the application of verification case VC1 in combination with RFA and partial factors of $\gamma_{R,\text{group}} = 1.4$ respectively $\gamma_{R,\text{piled-raft}} = 1.4$ 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 preferentially by numerical calculation methods.

3.5 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.

3.6 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 8 which also illustrates the approach recommended to be used to calculate the neutral point and the dragforce owing to potential downdrag. The representative drag force D_{rep} should then be determined from

$$D_{\text{rep}} = p \int_0^{L_{dd}} \tau_s \cdot dz \quad (12)$$

where p is the perimeter of the pile and z_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.

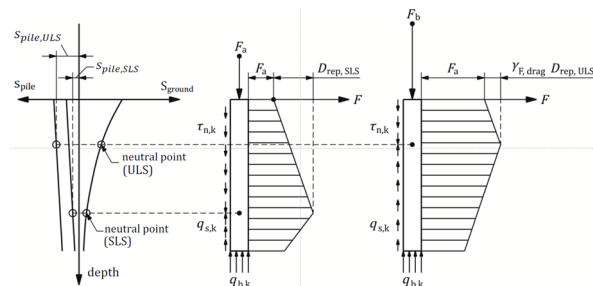


Figure 8. Settlement and force distribution for assessment of negative skin friction and drag force on a pile subject to downdrag acc. to EN 1997-3, C.9.

3.7 Further aspects of piled foundation design

Clause 6 of EN 1997-3 provides guidance to many further aspects being relevant for piled foundations including further calculation and design issues as e.g. lateral loading, buckling, cyclic effects etc., but also execution, testing and reporting. Even aspects of sustainability are addressed as the thermal, geo-technical and structural design aspects of thermo-activated deep foundations are mentioned (Moormann and Burlon 2025).

4 CONCLUSIONS

The 2nd generation of Eurocode 7 is a modern standard developed as useful tool for the design of all kind of foundations that provides 'state of the art'-guidance including many new design aspects being relevant engineering practice and allows to cover even sophisticated structures. It has to be highlighted that the regulations provided by EN 1997-3:2025 provide a stringent foundation design and verification concept for all types of foundation allowing a smooth transition from spread foundations via ground improvement with and without rigid inclusions and with or without load transfer platforms to piled rafts and piled foundations with comparable equivalent global safety level (see Figure 2).

5 REFERENCES

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