Design of piles according to Eurocode 7 – Expected evolutions

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ABSTRACT

In progress of preparing the next generation of Eurocode 7 the Evolution Group EG 7 ´Pile Design´ of TC250/SC7 has focused on the evoultion of Design of piles according to Eurocode 7 in the period 2011 to 2015. Based on the results of this period of collaboration and bringing together European experiences in pile design the expected evolutions for the section ´Pile Foundations´ of the upcoming EC7-3are presented in this contribution whereby several issues are still subject of ongoing dicussions and developments. It is obvious that especially the design of pile foundations is still related to national experiences resulting from diffferent geological conditions, different methods of soil investigation, different type of piles commonly used as well as a wide field of different calculations methods often related to the soil conditions/investigations and the pile type used. Nevertheless there is epecially for pile design a realistic chance to achieve a further harmonizaton of the design principles even if the exploration and calculation methods might differ still in future.

1. GENERAL

From 2011 to 2015 Evolution Group EG 7 ´Pile Design´ of TC250/SC7 had focused on the evoultion of the existing design principles according to Eurocode 7 in order to prepare proposals for the further evolution and improvement of the present section 7 of EC 7-1 called ´Pile Foundation´ for the next generation of EC 7. Participants of this Evolution Group had been fifteen European experts representing consulting, industry and universities from overall Europe.

The work of EG 7 was focused on:

a) Editing, changing and improving text of EN 1997-1, section 7 (mainly editorial task, e.g. cancel doublings, resetting mistakes). Aim was to make the document much clearer and more user-friendly.

b) Review of values for correlation factors, partial factors, model factors and action factors and their combination in each country as this was considered to be of major interest for further revision of EN 1997-1 in order to reduce the number of nationally determined parameters (NDP).

c) Comparing and identification of proposals for harmonizing different design approaches for pile design.

d) Comparing calculation methods for pile foundations for selected applications like axially loaded piles, downdrag etc.

e) elaborate proposals for new aspects being relevant for engineering practice

In this context it was general understanding that the next generation of Eurocode 7 should focus on the principles of design and safety concepts whereas recommendations might provide more detailed support for engineering practice e.g. with different calculation methods, background information, continuative literature etc.

After a preparatory two-year-period of more general and fundamental discussions and considerations EG 7 had worked on the present text of section 7 "Pile Foundations" since summer 2013 in order to make the outcome of EG 7´s efforts as effective and valuable as possible and to result in a proposal of a revised section for pile design.

The most relevant aspects of this working period of EG 7 are presented in this paper combined with some general consideration for the further evolution of pile design according to Eurocode 7.

2. HARMONISATION

Beside others activities EG 7 had focussed on harmonizing different design approaches and nationally determined parameters like correlation factors, partial factors, model factors or action factors as this issue is considered to be probably the most relevant one.

An analysis by Bond (2013) shows that the predominant number of countries is using the same design approach (DA2 or DA2*) at least for the design of axially loaded piles (Figure 1). Therefore a general harmonization in this regard is likely to be achieved.

Figure 1: Design approaches used for (axial) pile design in Europe (Bond 2013).

Nevertheless an analysis of the partial safety factors, model factors and correlation factors indicate relevant differences even concerning the principal. As an example many countries do not follow the proposal of EC 7-1 to apply different sets of partial safety factors on the pile resistance depending on the type of pile. As well the approach for the correlation factors differs from country to country as discussed in section 5.2 of this paper.

A comparison of the differing national approaches is reliably possible only on the basis of design examples as all nationally determined parameters as well as the calculation methods used in engineering practice influence the final pile design.

Whereas for axially loaded piles a harmonization of the design approach used might be achieved the need for further discussion is greater in cases where the pile design is influenced by the displacement behavior and therefore by the stiffness of the soil layer and the pile foundation. Typical examples are pile subjected by negative skin friction, by horizontal soil movements (see Figure 2) or buckling. In such cases either DA 2 or DA 3 is applied in different countries.

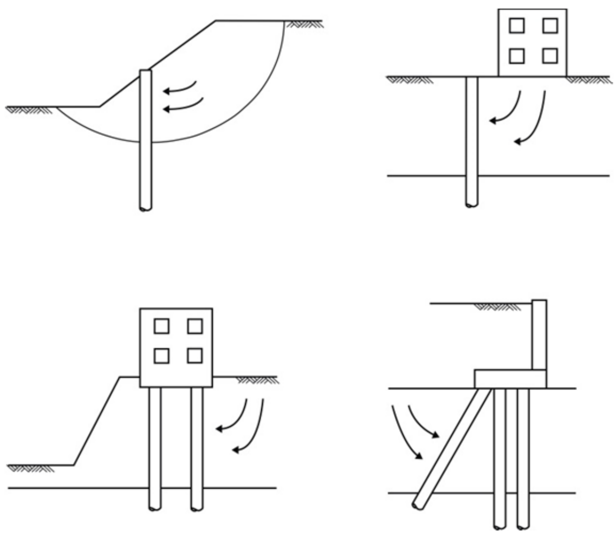

Figure 2: Design situations for piles stressed by lateral soil movements: a) piled slopes (dowels), b) heavy surcharge loads, c) excavations, d) piled bridge abutments with inclined piles.

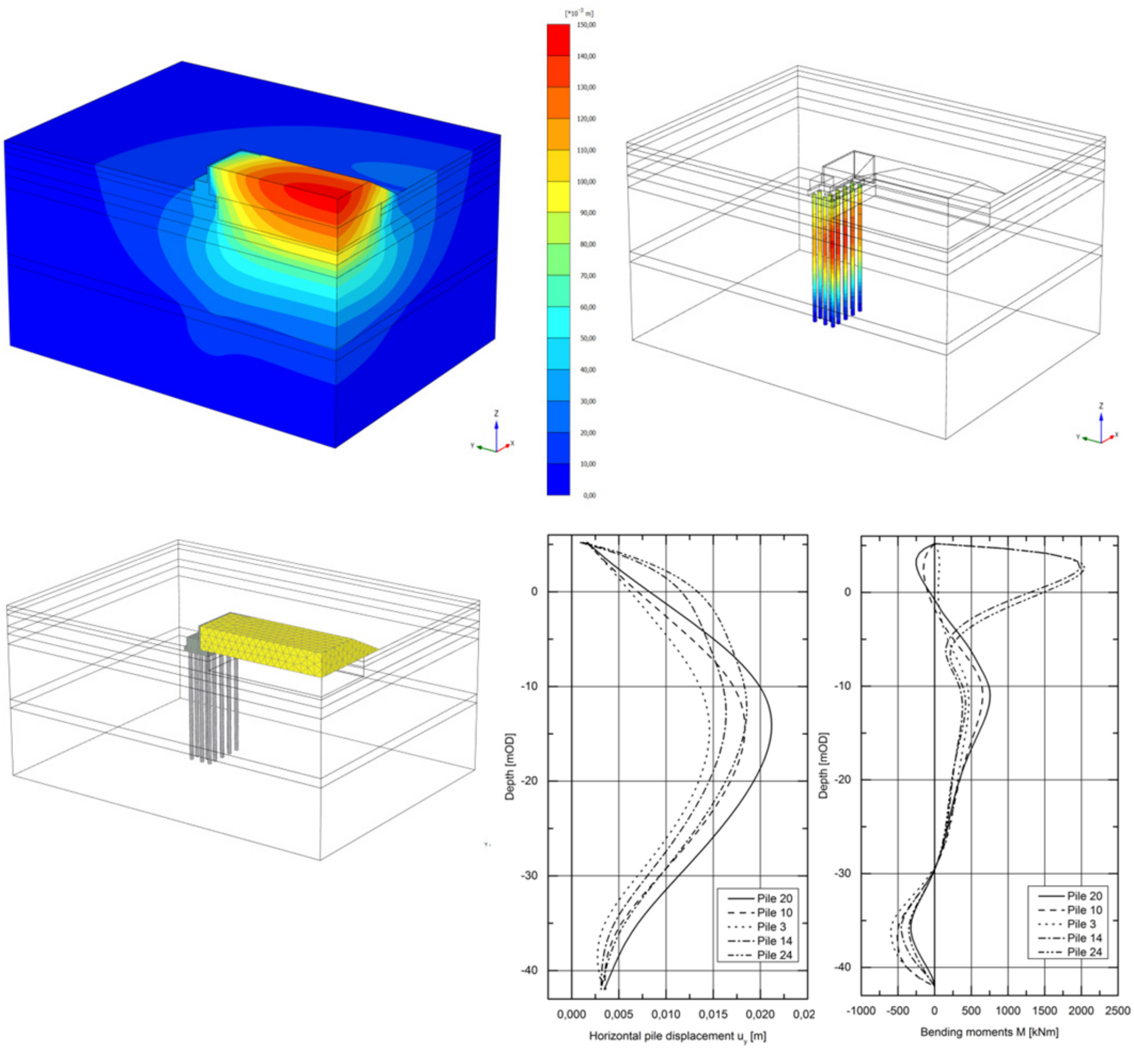

Figure 3: Numerical calculation of a pile foundation for a bridge abutment influenced by horizontal soil movements with application of Design Approach DA2 (simulation with characteristic values).*

DA 2 provides the benefit that with the characteristic values used for soil stiffness and strength and for the pile stiffness as well as for the loads/stresses the characteristic displacements as well as the characteristic inner forces of the pile foundation is calculated, but does involve the shortcoming that the variability of soil conditions can only be covered when a range is considered for the input parameter. DA 2 has also advantages when numerical simulations are applied (Figure 3).

DA 3 on the other hand has the benefit that the influence of the variability of the soil parameter is considered when calculating the displacements and inner forces, but is related to the shortcoming that there are actually no partial safety factors available to be applied on soil or pile stiffness. The application of DA 3 might also be difficult in cases where numerical approaches are used with advances soil models depending on stress and strain rates.

In summary major efforts is requested in evaluating, harmonizing and further developing these issues for the next generation of EC 7.

3. NEW STRUCTURE FOR SECTION ´PILE FOUNDATIONS´

Within the framework of EG 7 a new structure for the section ´Pile Foundations´ of EC 7 was elaborated which is documented in Figure 4 in comparison to the structure of present Section 7.

The revised structure is adjusted on the first level to the principal structure of future EC 7-3 dealing with geotechnical structures. The new structure is characterized by the basic idea to distinguish between single standing piles, pile groups and piled rafts on the second level and on a third level between axially and transversely loaded piles. The present differentiation between compressive and tensile resistance of axially loaded piles will be relinquished and integrated in the subsections for axially loaded piles; this helps to shorten the text of the standard.

Several new subsections as e.g. for ´Pile resistance due to cyclic, dynamic and impact loads´ are planned and will have to be elaborated and incorporated into the new structure.

4. EASE OF USE: REVISION OF SECTION ´PILE FOUNDATIONS

From August 2013 on the work of EG 7 had been focused on preparing a revised section 7 “Pile Foundations” with concrete and detailed recommendations for making this section more user-friendly as well as for the further evolution of this chapter. In this context stepwise the present text of section 7 was reviewed and complemented analysing the four questions:

- Which clauses should remain unchanged in the next edition?
- Which clauses should be deleted from the next edition 7? And why?
- Which of those clauses should be changed in the next edition? What changes should be made? And why?
- What new clauses or even subsections should be added in the next edition? And why?

The review has followed the idea that a code - in sense of improving ease-of-use - should focus on principles for design and safety concepts as well as basics rules for pile design avoiding textbook-like explanations and description. Figure 5 shows an excerpt as example.

It looks quite promising that the aim to come up with a more user-friendly version of the section “Pile Foundations” could be reached as the clauses revised could be focused on the essential principals.

These proposals and recommendations will later be used by the Project Team which will be mandated with writing this section of the new code.

Present	Proposal
1 General **2 Limit states** **3 Actions and design situations** **3.1 General** **3.2 Actions due to ground displacement** 3.2.1 General 3.2.2 Downdrag (negative skin friction) 3.2.3 Heave 3.2.4 Transverse loading **4 Design methods and design considerations** **4.1 Design methods** **4.2 Design considerations** **5 Pile load tests** **5.1 General** **5.2 Static load tests** 5.2.1 Loading procedure 5.2.2 Trial piles 5.2.3 Working piles **5.3 Dynamic load tests** **5.4 Load test report** **6 Axially loaded piles** **6.1 General** 6.1.1 Limit state design 6.1.2 Overall stability **6.2 Compressive ground resistance** 6.2.1 General 6.2.2 Ultimate compressive resistance from static load tests 6.2.3 Ultimate compressive resistance from ground test results 6.2.4 Ultimate compressive resistance from dynamic impact tests 6.2.5 Ultimate compressive resistance by applying pile driving formulae 6.2.6 Ultimate compressive resistance from wave equation analysis 6.2.7 Re-driving **6.3 Ground tensile resistance** 6.3.1 General 6.3.2 Ultimate tensile resistance from pile load tests 6.3.3 Ultimate tensile resistance from ground test results **6.4 Vertical displacements of pile foundations (Serviceability of supported structure)** 6.4.1 General 6.4.2 Pile foundations in compression 6.4.3 Pile foundations in tension **7 Transversely loaded piles** **7.1 General** **7.2 Transverse load resistance from pile load tests** **7.3 Transverse load resistance from ground test results and pile strength parameters** **7.4 Transverse displacement** **8 Structural design of piles** **9 Supervision of construction**	**1 General** **2 Limit states** **3 Actions and design situations** **3.1 General** **3.2 Dynamic and cyclic loading** *[NEW]* **3.3 Actions due to ground displacement** 3.3.1 General 3.3.2 Downdrag (negative skin friction) 3.3.3 Heave 3.3.4 Transverse loading **4 Design methods and design considerations** **4.1 Design by calculation** *[NEW]* 4.1.1 General *[NEW]* **4.1.2 Single standing piles** 4.1.2.1 Axially loaded piles 4.1.2.2 Transversely loaded piles **4.1.3 Pile Groups** *[NEW]* 4.1.3.1 Axially loaded piles *[NEW]* 4.1.3.2 Transversely loaded piles *[NEW]* **4.1.4 Piled Rafts** *[NEW]* **4.1.5 Pile resistance due to cyclic, dynamic and impact loads** *[NEW]* **4.2 Design by testing** 4.2.1 General *[NEW]* **4.2.2 Axially loaded piles** 4.2.2.1 Ultimate resistance from static load tests 4.2.2.2 Ultimate resistance from dynamic impact tests 4.2.2.3 Ultimate resistance by applying pile driving formulae 4.2.2.4 Ultimate resistance from wave equation analysis 4.2.2.5 Re-driving **4.2.3 Transversely loaded piles** *[NEW]* **4.2.4 Pile resistance due to cyclic, dynamic and impact loads** *[NEW]* **5 Ultimate limit state design** *[NEW]* **5.1 General** *[NEW]* **5.2 Single standing piles** *[NEW]* 5.2.1 Axially loaded piles 5.2.2 Transversely loaded piles **5.3 Pile Groups** *[NEW]* 5.3.1 Axially loaded piles *[NEW]* 5.3.2 Transversely loaded piles *[NEW]* **5.4 Piled Rafts** *[NEW]* **6 Serviceability limit state design [NEW]** **6.1 General** *[NEW]* **6.2 Single standing piles** *[NEW]* 6.2.1 Axially loaded piles 6.2.2 Transversely loaded piles **6.3 Pile Groups** *[NEW]* 6.3.1 Axially loaded piles 6.3.2 Transversely loaded piles **6.4 Piled Rafts** *[NEW]* **7 Testing and Instrumentation** **7.1 General** **7.2 Static load tests** 7.2.1 Loading procedure 7.2.2 Trial piles 7.2.3 Working piles **7.3 Dynamic load tests** **7.4 Load test report** **8 Structural design** **9 Execution (supervision, monitoring and maintenance)**

Figure 4: Present (left) and proposal for new (right) structure of section ´Pile Foundations´ of EC 7

5. FURTHER EVOLUTION OF PILE DESIGN ACCORDING TO EC 7

5.1. Proposals for new subjects of section ´Pile Foundations´

By preparing a revised section ´Pile Foundations´ stepwise the present text of section 7 of EC 7-1 is reviewed and concrete and detailed recommendations for the evolution of this section are formulated. As outcome of this evolution process it was agreed that for some aspects of pile design more guidance is needed for engineering practice.

These aspects which are presently not covered appropriately should be included in more detail or even for the first time in a future version of EC 7. Beside others such relevant aspects have been identified as follows:

- calculation and design methods for transversally loaded piles,
- consideration of downdrag / negative skin friction (proposal elaborated, see section 6),
- ground heave,
- piles effected by lateral ground movements,
- calculation methods and design of pile groups for axial and horizontal loads,
- design of piled rafts including cases where piles are used as ´settlement-reducer´,
- pile resistance and design for dynamic, cyclic and impact loads,

4 Design methods and design considerations	4 Design methods and design considerations
	4.1 Design by calculation
4.1 General	4.1.1 General
(1)P The design shall be based on one of the following approaches: — the results of ~~static~~ load tests~~, which have been demonstrated, by means of calculations or otherwise, to be consistent with other relevant experience~~; — empirical or analytical calculation methods ~~whose validity has been demonstrated by static load tests in comparable situations~~; — ~~the results of dynamic load tests whose validity has been demonstrated by static load tests in comparable situations~~; — the observed performance of a comparable pile foundation~~, provided that this approach is supported by the results of site investigation and ground testing~~. *Validation to address in specific subsection.* ~~(2) Design values for parameters used in the calculations should be in general accordance with Section 3, but the results of load tests may also be taken into account in selecting parameter values.~~ *Comment: Clause is self-evident.* ~~(3) Static load tests may be carried out on trial piles, installed for test purposes only, before the design is finalised, or on working piles, which form part of the foundation.~~ *Comment: Clause is dispensable.*	(1)P The design shall be based on one of the following approaches: — the results of load tests; — empirical or analytical calculation methods; — the observed performance of a comparable pile foundation.

Figure 5: Example for revised clauses of earlier section 7 ´Pile Foundations´ as part of review work of TC 250/SC 7/EG 7: focusing on design basics in sense of improving ease-of-use.

- seismic design of pile foundations,
- proof of the serviceability of pile foundations,
- structural design of piles for lateral loading and buckling.

As an example section 6 of this paper presents a new approach for designing piles in case of downdrag / negative skin friction.

Some considerations concerning the issue whether (most commonly used) calculation methods for axially and transversally loaded single piles should be included in the next generation of EC 7-3 are addressed in the following section 5.3.

Additionally to these issues which are not covered appropriately by the present EC 7-1 other issues were identified which needs major revision. An example is the present approach for the correlation factors ξ_i as actually requested by EC 7-1.

5.2. Revised approach for correlation factors ξ_i

In determining the design values of a pile resistance from the results of static and dynamic pile load testing as well as from results from ground investigation the measured resp. calculated values $R_{c;m}$ of the pile capacity have to be initially mitigated by correlation factors ξ_i to derive the characteristic pile resistance $R_{c;k}$. With the correlations factors, the influence of the spatial variability of the subsoil, but also of the uncertainties arising from the execution and evaluation of the pile load tests on the derivation of the characteristic pile resistance from the measured values of a single or limited number of test loads is taken into account. An analysis of the existing approach implemented in EC 7-1 indicates shortcomings particularly with respect to the sole dependency of the correlation factors on the number of performed load tests. Whereas correlation factors ξ_i to derive characteristic pile resistances from static and dynamic pile load tests are used quite frequently, correlation factors to derive characteristic pile resistances from ground tests results (Table A.10 of EC7-1) are used only in a few countries (Table 1).

In this regard approaches used in different European countries were reviewed and proposals for an evolution of the present regulations were discussed.

Beside countries using just the correlation factors proposed by EC 7-1 some countries have adaptions which base on this EC 7-1 approach but consider additional aspects like the German approach that specifies the correlation factors $\xi_{5,6}$ for dynamic pile load tests in dependency of the calibration of the dynamic pile load tests with static pile load tests (DGGT 2012).

Table 1: Correlation factors ξi to derive characteristic pile resistances from static pile load tests (Table A.9 of EC7-1) and from ground tests results (Table A.10 of EC7-1).

Table A.9 - Correlation factors ξ to derive characteristic values from static pile load tests (*n* - number of tested piles)

ξ for *n* =	1	2	3	4	≥ 5
ξ_1	1,40	1,30	1,20	1,10	1,00
ξ_2	1,40	1,20	1,05	1,00	1,00

Table A.10 - Correlation factors ξ to derive characteristic values from ground test results (*n* - the number of profiles of tests)

ξ for *n* =	1	2	3	4	5	7	10
ξ_3	1,40	1,35	1,33	1,31	1,29	1,27	1,25
ξ_4	1,40	1,27	1,23	1,20	1,15	1,12	1,08

Other national standards have approaches for the correlation factors which do not only consider the number of test piles or of ground tests but also the area ("surface") for which this tests have been executes. Thus the French code for pile foundations NF P 94-262 does refer the correlation factors to a reference area of S_{ref} = 2,500 m² and allows to reduce the correlation factors for smaller areas (Figure 6). Such an approach does consider as appropriate that the spatial variability of pile resistances decrease for smaller pile foundations when the same number of piles is tested.

The Dutch standard *NEN 6743:1991* and the Belgian BBRI-Report 12 propose approaches for the correlation factors $\xi_{3,4}$ which consider both the intensity of soil improvement as well as the number of foundation piles for which this evaluation is applied (Table 2).

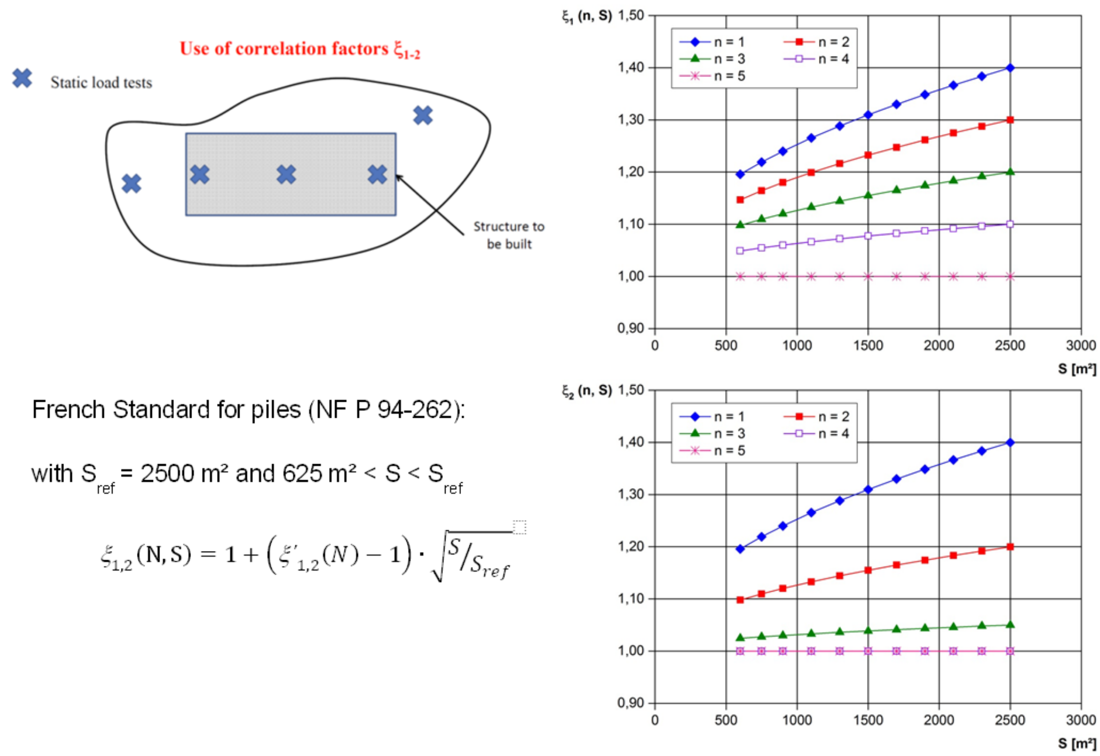

Figure 6: Correlation factors ξ_1 and ξ_2 for deriving the characteristic pile resistance from static pile load tests depending according to the French standard NF P 94-262 depending on the number of tested piles (n) and on the ground area S of the pile foundation.

Table 2: Values of the correlation factors ξ_3 and ξ_4 to derive characteristic values from CPT-tests according to Belgian guidelines (BBRI-Report 12).

a) correlation factor ξ_3

Number of piles	1 CPT / 10 m²	1 CPT / 50 m²	1 CPT / 100 m²	1 CPT / 300 m²	1 CPT / 1000 m²
1-3	1.25	1.29	1.32	1.36	1.40
4-10	1.15	1.19	1.21	1.25	1.29
> 10	1.14	1.17	1.20	1.24	1.27

b) correlation factor ξ_4

Number of piles l	1 CPT / 10 m²	1 CPT / 50 m²	1 CPT / 100 m²	1 CPT / 300 m²	1 CPT / 1000 m²
1-3	1.08	1.17	1.23	1.31	1.40
4-10	1.00	1.07	1.13	1.21	1.29
> 10	1.00	1.06	1.12	1.20	1.27

Based on this experiences the improvement planned for the approach of correlation factors ξ_i can be summarized as follows:

- relate $\xi_{3/4}$ (ground test results) to investigations per area
- relate $\xi_{1/2}$ and $\xi_{5/6}$ (load tests) to percentage of piles tested ./. total number of piles or to the area of the pile foundation

It has also to be discussed whether correlation factors should vary in dependency of the pile type. Generally the reliability of dynamic load tests is considered to be lower than for static pile load tests and therefore higher correlation factors have to be applied for dynamic pile load tests, a fact that is covered by the present regulation of EC 7-1 already with $\xi_{1,2}$ being significantly smaller than $\xi_{5,6}$ already. But results of a round robin test with dynamic pile load tests executed recently on bored piles conditions in sandy soil near Berlin (Baeßler et al. 2012; Herten et al. 2013) indicated also that in this case a quite large scattering due to the analysis of the results of dynamic pile load tests may occur, which makes dynamic pile load tests more reliable for prefabricated driven piles than for cast-in-situ driven or bored piles.

Generally the basis concept of correlation factors which consider the extent and intensity of soil investigation when defining the requested safety factor is considered to be a motivation for adequate soil investigation programs. Therefore it might be an example for other applications (slope stability …) as well.

5.3. Calculation methods for pile design

In process of future evolution of the section ´Pile Foundation´ for the next generation of Eurocode 7 it will have to be discussed in more detail whether calculation methods might be added as an informative annex to EC 7-3.

Such information would enable engineers in practice under ideal circumstances to calculate and design pile foundations just on basis of using EC7-3. On the other hand especially for pile design it has to be considered that due to different geological conditions, different type of piles used and different long-term design practice even for frequently used types of pile like bored piles or precast driven piles many different calculations methods are presently used in Europe, which differ concerning their basic approaches, their range of proven application, the input parameters needed etc.

Therefore – if possible at all - the documentation of calculation methods for piles in an informative annex to EC 7-3 could be realized only for simple tasks like calculation the axial pile resistance for usual pile systems (to be identified) and for most frequently calculation methods used in Europe (and not only in a single country).

A benefit of selected calculation methods documented in an informative annex to EC 7-3 could be that model factors related to these methods could be stated as well (at least in a range) what would be a contribution to a further harmonization of pile design in Europe. As already mentioned this issue will have to be discussed in more detail in future. In any case joint efforts on a European basis might become necessary to identify and to validate such calculation methods once a positive decision for such an informative annex is taken.

6. EXAMPLE: NEW SECTION FOR NEGATIVE SKIN FRICTION

An example for a new subject identified and subsicently elaborated by EG 7 in preparation of the next generation of the section `Pile Foundation´ of Eurocode 7 is the new subsection on negative skin friction resp. downdrag. The new approach considers both serviceability and ultimate limit state design and is part of the proposal of EG 7 for a revised section ´Pile Foundations´. The subsection has been drafted by EG 7 as follows:

(1) *Negative skin friction has to be regarded as a permanent action F_n, originating from relative axial movement between the ground and the pile, when the ground settles more than the pile.*

(2) *The pile continues to settle until the actions from negative skin friction τ_n, together with the actions imposed on the pile by the superstructure, and the pile resistances resulting from the pile end bearing capacity and supporting skin friction qs, are in equilibrium.*

(3) *Negative skin friction should be taken into account for the justification at SLS and ULS.*

(4) *Both for SLS and ULS, the characteristic values of negative skin friction should be estimated by considering the pile loading level with appropriate calculation models, see (5), accounting for relevant strain mechanisms between the pile and the soil surrounding. For simple cases approximates approach can be used, see (6).*

(5) *An appropriate model to calculate negative skin friction is to take into account up to the neutral point marking the boundary between positive and negative skin friction. Two separate neutral points should be considered for the ULS and SLS (Figure 7). In the case of SLS the neutral point is the point of the theoretical zero relative movement between the pile and the settling soil considering total possible settlement (e.g. primary and secondary consolidation). In the case of the ULS the neutral point should be moved up relative to the SLS neutral point.*

To calculate the negative skin friction $\tau_{n,k}$ information are required on:
- *pile settlements with depth;*
- *soil strata settlements with depth;*
- *the resulting relative movements and*
- *any mobilisation functions of $\tau_{n,k}$ and $q_{s,k}$.*

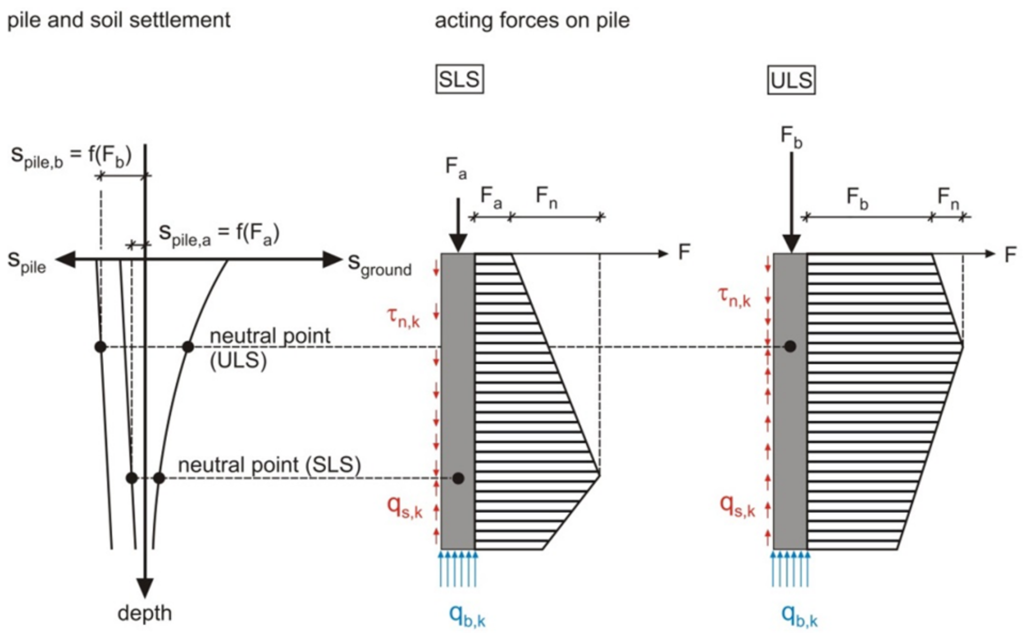

Figure 7: Evaluation of negative skin friction for ultimate limit state (ULS) and serviceability limit state (SLS).

Comparing the relative displacements from pile settlement spile and the settlement of the surrounding soil sground gives the location of the neutral point and thus the value of the characteristic action Fn,k in the serviceability limit state and in the ultimate limit state.

(6) *For simple cases the following approximate approaches can be used alternatively to (5):*

a) *In case that at ultimate limit state the settlements of the pile can be assumed to be greater than the settlement of the surrounding soil the neutral point can be assumed to be located at the ground surface resp. at top of the pile. Thus the pile resistance can be proven for the ultimate limit state without calculating a negative skin friction.*

b) *In case that at ultimate limit state the settlements of the pile has to be considered to be smaller than the settlement of the surrounding soil (example: "rock socket piles") the neutral point can be assumed to be located at the bottom of the settling soil layer. Thus the pile resistance can be proven for the ultimate limit state by assuming characteristic values of negative skin friction for the settling soil layers.*

c) *For serviceability limit state the calculation of the neutral point can be substituted by assuming characteristic values of negative skin friction for the settling soil layers, thus considering the neutral point to be located at the bottom of the settling soil layers. This value* $\tau_{n,k}$ *should be an upper bound value and be determined on the safe side.*

(7) *Approaches for deriving the characteristic negative skin friction* $\tau_{n,k}$ *are given in Annex A.*

(8) *Normally, downdrag and transient loading need not be considered simultaneously in load combinations.*

(9) *The pile resistance has to be proven analysing the ultimate and serviceability limit state:*

a) *Serviceability limit state (SLS): the characteristic action* $F_{n,k}(SLS)$ *and the location of the neutral point have to be calculated by the deformation behaviour associated with the pile settlement spile and the settlements in the soft stratum sground. The design value of the effects is:*

$$F_d = F_k = F_{G,k} + F_{n,k}(SLS) + F_{Q,rep} \quad (1)$$

Additionally it should be proven that the pile displacements are compatible with the supported structures.

b) *Ultimate limit state (ULS): the characteristic action Fn,k(ULS) and the location of the neutral point have to be calculated by comparing the deformations associated with the pile settlement spile = sultin the ultimate limit state and the settlements in the soft stratum sground. The location of the neutral point is normally higher than in the serviceability limit state, because the pile settlement sult is greater than s(SLS). The design value of the effects is:*

$$F_d = (F_{G,k} + F_{n,k}(ULS)) \cdot \gamma_G + F_{Q,rep} \cdot \gamma_Q \quad (2)$$

(10) *For the structural analysis of the pile shaft the action resulting from negative skin friction at serviceability limit state, i.e.* $F_{n,k}(SLS)$*, has to be considered as permanent characteristic action beside permanent and transient loading from the structure. The design value of the action relevant for the internal pile design has to be calculated as*

$$F_d = (F_{G,k} + F_{n,k}\,(SLS)) \cdot \gamma_G + F_{Q,k} \cdot \gamma_Q. \quad (3)$$

(Note: It might be further discussed whether the same partial factor should be applied for structural loads and negative skin friction.)

Annex A (Informative)

Two principle approaches for deriving the characteristic negative skin friction $\tau_{n,k}$ *are given in the literature dealing with negative skin friction:*

- *Using total stresses for cohesive soils*

$$\tau_{n,k} = \alpha \cdot c_{u,k} \quad (A.1)$$

where:

α *factor for specifying the value of the characteristic negative skin friction for cohesive soils;*

$c_{u,k}$ *characteristic value of the shear strength of the undrained soil.*

Depending on the soil type and pile type the factor α generally ranges between 0.15 and 1.60, whereby $\alpha = 1$ is often adopted in approximation, which is generally recommended for cohesive soils.

More detailed information on the value of α can be taken from [Literature].

- *Using effective stresses for non-cohesive and cohesive soils:*

$$\tau_{n,k} = K_0 \cdot \tan\delta_k \cdot \sigma'_v = \beta \cdot \sigma'_v \qquad (A.2)$$

where:

σ'_v *effective vertical stress;*

K_0 *coefficient of at-rest earth pressure;*

δ_k *characteristic value of the interface friction angle, whereby*

$\delta_k = \varphi'_k$ *for concrete cast in situ piles,*
$\delta_k = 0.75\,\varphi'_k$ *for concrete precast and steel piles,*
but $K_0 \cdot \tan\delta_k \geq 0.25$

φ'_k *characteristic value of the friction angle;*

β *factor for specifying the value of the characteristic negative skin friction for non-cohesive and cohesive soils.*

According to [relevant literature] the factor β generally ranges between 0.1 and 1.0, depending on soil type. For non-cohesive soils β = 0.20 to 0.30 is often used.

7. OUTLOOK

For elaborating the Eurocode text for the next generation of Eurocode 7 the working structure of TC250/SC7 was restructured at autumn of 2015. The new structure with three working groups (WG) is shown in Figure 8. The preparation of revised Eurocode text will be the task of so called Project Teams (PT) whose members are contracted to NEN and who will deliver the Eurocode text. The Project Teams will receive assistance and guidance by Task Groups (TG) who will also review the work of the Project Teams on behalf of SC7.

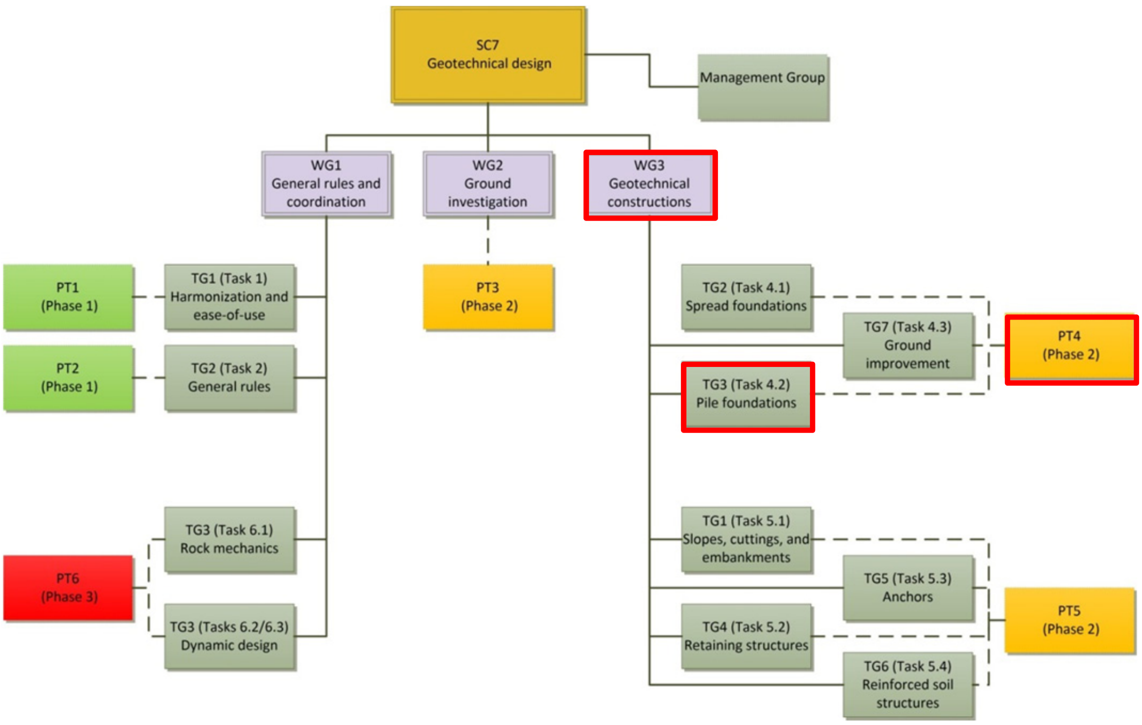

Figure 8: Evaluation of negative skin friction for ultimate limit state (ULS) and serviceability limit state (SLS).

The elaboration of a final proposal for the section ´Pile Foundation´ will be the task of Project Team PT4. They must develop a new proposal implementing new subjects and changes based on:

- M/515 Mandate,
- Evolution Group Reports,
- Systematic Review comments approved by SC7.

Project Team PT4 will start working in the second phase of the program for revising Eurocode 7, i.e. probably from end of 2016 on.

Task group TG 3 of Working Group WG 3 (WG3/TG3) called ´Pile Foundations´ has already started working in autumn 2015 and will focus on the following tasks:

- Review comments received through Systematic Review,
- Respond to the Project Team PT4 request for assistance/guidance,
- Review work of Project Team PT4 on behalf of SC7,
- Recommend acceptance/rejection of Project Team PT4's work.

Beside others probably the following subjects might be addressed by WG 3/TG 3 in a first approach:

- Proposal for evolution and harmonisation of NDP´s (Nationally Determined Parameters) and DA´s (Design Approaches),
- Elaboration of an improved approach for correlation factors ξ,
- Selection and documentation of calculation methods for axially and transversely loaded piles and for other applications as input for a possible informative annex,
- Elaboration of basic design rules and proof concept for pile groups and for piled rafts,
- Guidance for interpretation of pile load tests (e.g. assessment of limit resistance from static pile load tests).

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The progress gained in elaborating proposals for the evolution of the section ´pile foundations´ of EC 7 into the next generation bases on the collaboration and valuable contribution of all delegates (Table 3). of Evolution Group EG 7 "Pile Design" of TC250/SC7 working from 2011 to 2015 on these issues.

The support of these colleagues in developing the next generation of the section ´Pile Foundation´ of EC 7 is highly appreciated.

Table 3: Delegates of TC 250/SC 7/EG 7 ´Pile Design´ of the period 2011-2015

Name	Country	Name	Country
Christian Moormann (Convenor)	Germany	Ole Møller	Denmark
Chris Raison (Secretary)	UK	Panicos Papadopoulos	Cyprus
Gary Axelsson	Sweden	Krzystof Sahajda	Poland
Ioan Boldurean	Romania	Arne Schram Simonsen	Norway
Sébastien Burlon	France	Frits van Tol	Netherlands
Josif Josioivski	Rep. of Mazedonia	Veli-Matti Uotinen	Finland
Boleslaw Klosinski	Poland	Monika de Vos	Belgium
Jan Kos	Czech Republic		

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