1 Introduction to the Recommendations and their Application Principles

1.1 National and International Regulations for Piling Works

(1) Since the implementation of DIN EN 1997-1:2009-09: Eurocode 7: Geotechnical Design – Part 1: General Rules, pile analysis and design in Germany is governed by

- Section 7 of Eurocode EC 7-1 (Eurocode 7), in conjunction with
- DIN 1054:2010-12: Subsoil – Verification of the Safety of Earthworks and Foundations – Supplementary Rules to the German version DIN EN 1997-1, and the
- National Annex to EC 7-1, namely DIN EN 1997-1/NA:2010-12: National Annex – Nationally Determined Parameters – Eurocode 7: Geotechnical Design – Part 1: General Rules.

These three coordinated documents are summarised in the German Eurocode 7 Handbook, Volume 1 [44].

Note: In case amendments or corrections are made to the standards included in the German Eurocode 7 Handbook, Volume 1 [44], the changes must be adopted even when not yet incorporated in [44].

(2) In addition, the individual pile systems are governed by the following execution standards:

DIN EN 1536:	Execution of special geotechnical works – Bored piles.
DIN SPEC 18140:	Supplementary provisions to DIN EN 1536.
DIN EN 12699:	Execution of special geotechnical works – Displacement piles.
DIN SPEC 18538:	Supplementary provisions to DIN EN 12699.
DIN EN 14199:	Execution of special geotechnical works – Micropiles.
DIN SPEC 18539:	Supplementary provisions to DIN EN 14199.
DIN EN 12794:	Precast concrete products – Foundation piles.
DIN EN 1993-5:	Design of steel structures – Part 5: Piling.

(3) Because diaphragm wall elements are often employed in the same way as pile foundations, the respective execution standard must also be considered:

DIN EN 1538:	Execution of special geotechnical works – Diaphragm walls

in conjunction with:

DIN 4126:	Stability analysis of diaphragm walls.

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(4) In addition, several ISO standards are being compiled for a number of special topics relating to piles. They are however not likely to be implemented as building regulations in Germany. Currently, these include:

DIN EN ISO 22477-1:	Geotechnical investigation and testing – Testing of geotechnical structures – Part 1: Pile load test by static axially loaded compression.

On a national basis, the regulations in Section 9 should be adopted for static pile testing.

1.2 Types of Analysis and Limit States using the Partial Safety Factor Approach

1.2.1 New standards generation and their application to pile foundations

(1) By European Commission decision national building design and execution standards either already have been or will in future be replaced by European standards. Actually numerous European standards have been published for geotechnical design and execution of special geotechnical works.

(2) The European standards governing pile execution are listed in 1.1.

(3) Analysis and design of pile foundations is dealt with in the European standard DIN EN 1997-1: Geotechnical Design (Eurocode 7) in conjunction with DIN 1054 and DIN EN 1997-1/NA, see 1.1. These three standards were implemented by the German Building Authorities for use in Germany as of 01.07.2012.

(4) Until the time of implementation of the Eurocodes as binding building regulations a new generation of national standards using the partial safety factor approach served as temporary solution for all fields of structural engineering. The following standards in particular represented the governing standards for pile foundations:

DIN 1055-100:2001-03:	Basis of structural design;
DIN 1054:2005-01:	Verification of the safety of earthworks and foundations;
DIN 18800:1990-11:	Steel structures and;
DIN 1045-2:2001-07:	Concrete, reinforced and prestressed concrete structures – Part 2: Concrete – Specification, properties, production and conformity – Application rules for DIN EN 206-1.

(5) These Recommendations on Piling (EA-Pfähle) are based on the standards listed in 1.1 above and, for design in particular, on Eurocode EC 7-1, in conjunction with DIN 1054 and the NA as stipulated in 1.1 (1).

1.2.2 Actions, effects and resistances

(1) The partial safety factor approach has its origins in probability theory, as used to specify the requisite safety factors from a probabilistic perspective. In contrast to this, with the implementation of DIN 1054:2005-01, the new geotechnical standards generation follows a more pragmatic split of the previously common global safety factors into partial safety factors for actions or effects, and partial safety factors for resistances.

(2) The basis for stability analyses is represented by the characteristic values for actions and resistances. The characteristic value, represented by the index ”k”, is a value of which the specified probability is assumed not to be exceeded or fallen short of during the reference period, taking into consideration the design working life of the structure or the corresponding design situation. Characteristic values are generally specified based on testing, measurements, analyses or empiricism.

(3) If the “internal” or “external” pile capacity needs to be analysed, the effects at the pile head or at given depths are required:

- As action effects, e.g. normal force, shear force, bending moment;
- As stresses, e.g. compression, tension, bending stress, shear stress or equivalent stress.

In addition, further effects of actions can occur:

- As dynamic or cyclic loads;
- As change to the structural element, e.g. strain, deformation or crack width;
- As change in the position of isolated piles or pile groups, e.g. displacement, settlement, rotation.

(4) The cross-section and the internal resistance of the material are the governing factors in the design of individual components. Specific standards are to be applied for this purpose.

(5) The characteristic values of the effects are multiplied by partial safety factors, those of resistances are divided. The values acquired in this way are designated as design values of effects or resistances respectively and are characterised by the index “d”. For stability analyses, different limit states are distinguished, also see 1.2.3, 1.2.4 and 3.1.1 (4).

(6) In addition to actions, design situations are also taken into consideration for pile analyses, similar to other structural elements. To this end the previous loading cases LC 1, LC 2 and LC 3, adopted for use in analysis according to DIN 1054:2005-01, have been converted to design situations for use in analyses after DIN EN 1997-1 (EC 7-1) and DIN 1054:2010-12, and DIN EN 1990 as follows:

- BS-P (persistent (design) situation);
- BS-T (transient (design) situation) and;
- BS-A (accidental (design) situation).

In addition, there is the seismic design situation BS-E. More detailed information is given in the EC 7-1 German Handbook [44] and in [133].

1.2.3 Limit states and national application of the EC 7-1 German Handbook

(1) The term “limit state” is used with two different meanings:

a) In soil mechanics, the state of the soil in which displacements of individual soil particles against each other are so great that the mobilisable shear strength achieves its greatest values in either the entire soil mass, or at least in the region of a failure plane, is known as the “limit state of plastic flow”. It cannot become greater even if more movement occurs, but could become smaller. The limit state of plastic flow characterises the active earth pressure, passive earth pressure, bearing capacity, “external” pile failure, slope stability, and global stability.
b) A second limit state in the sense of the new safety factor approach is a state of the load-bearing structure where, if exceeded, the design requirements are no longer fulfilled.

(2) The following limit states are differentiated using the partial safety factor approach:

a) The ultimate limit state is a condition of the structure which, if exceeded, immediately leads to a calculated collapse or another form of failure. It is referred to as “ULS” in EC 7 and DIN 1054. Further distinguishing is described in (5).
b) The serviceability limit state is a condition of the structure which, if exceeded, no longer fulfils the conditions specified for its use. It is referred to as “SLS” in EC 7 and DIN 1054.

(3) For ultimate limit state analysis (ULS), Eurocode EC 7-1 provides three options. With one exception (see (6) and (9)), the supplementary rules of DIN 1054 for use in Germany are based on Analysis Method 2 of EC 7-1. The partial safety factors are applied to both, effects and resistances. To differentiate this from the other permitted scenario, in which the partial safety factors are not applied to the effects but to the actions, this procedure is designated as Analysis Method 2* in [133], also see the EC 7-1 Handbook [44].

(4) The National Annex to EC 7-1 and DIN 1054 represent a formal link between EC 7-1 and national German standards, see EC 7-1 German Handbook [44]. In DIN 1054 and the National Annex it is stated which of the possible analysis methods and partial safety factors are applicable in the respective national domains. In addition, the applicable, supplementary national codes may also be given. The supplementary national codes may not contradict EC 7-1. Moreover, the National Annex may not repeat information already given in EC 7-1.

(5) Eurocode EC 7-1 distinguishes the following subordinate limit states of the ultimate limit state (ULS):

a) EQU: Loss of equilibrium of the structure, regarded as a rigid body, or the ground. The designation is derived from “equilibrium”.
b) STR: Internal failure or very large deformations of the structure or its structural elements, where the strength of the materials governs the resistance. The designation is derived from “structural failure”.
c) GEO: Failure or very large deformation of the structure or the ground, where the strength of the soil or rock governs the resistance. The designation is derived from “geotechnical failure”.
d) UPL: Loss of equilibrium of the structure or the ground due to buoyancy or water pressure. The designation is derived from “uplift”.
e) HYD: Hydraulic ground failure, internal erosion of or piping in the ground, caused by a flow gradient. The designation is derived from “hydraulic failure”.

(6) In the terminology of the EC 7-1 German Handbook [44] the GEO limit state is sub-divided into GEO-2 and GEO-3:

a) GEO-2: Failure or very large deformation of the ground in conjunction with the calculation of the action effects and the dimensions, i.e. when utilising shear strength for passive earth pressure, for sliding resistance and bearing resistance, and when analysing deep slide surface stability for anchored retaining walls, and for base resistance and skin friction of pile foundations. The GEO-2 limit state calculation follows Analysis Method 2*, see (3), as outlined in the EC 7-1 German Handbook [44].
b) GEO-3: Failure or very large deformation of the ground in conjunction with the analysis of the overall stability, i.e. when utilising the shear strength for analysis of the safety against slope failure and global failure and, normally, when analysing slope stabilisation measures, including consideration of structural elements, e.g. anchors or piles. The GEO-3 limit state calculation follows Analysis Method 3 as outlined in the EC 7-1 German Handbook [44].

(7) The EQU, UPL and HYD limit states describe the loss of static equilibrium. These include:

a) Safety analysis against overturning (EQU);
b) Safety analysis against buoyancy or uplift, e.g. of a tension pile group (UPL);
c) Safety analysis against hydraulic heave (HYD).

(8) The limit states EQU, UPL and HYD involve actions only, but no resistances.

The governing limit state condition is:

$$F_d = F_k \cdot \gamma_{dst} \leq G_k \cdot \gamma_{stb} = G_d \, ; \qquad (1.1)$$

i.e. the destabilising actions F_k, multiplied by the partial safety factor $\gamma_{dst} \geq 1{,}0$, may only be as large as the stabilising action G_k, multiplied by the partial safety factor $\gamma_{stb} < 1{,}0$.

(9) The GEO-2 limit state describes the failure of structures and structural elements or the failure of the ground. It includes:

a) Analysis of the bearing capacity of structures and structural elements subjected to loads from the ground or supported by the ground;
b) Analysis of the bearing capacity of the ground to demonstrate that it is not exceeded, e.g. passive earth pressure, bearing resistance, pile resistance or sliding resistance.

The analysis to demonstrate that the bearing capacity of the ground is not exceeded is performed exactly as for any other construction material. The limit state condition is always the governing condition:

$$E_d = E_k \cdot \gamma_F \leq R_k / \gamma_R = R_d; \tag{1.2}$$

i.e. the characteristic effect E_k, multiplied by the partial safety factor γ_F for actions or strains, may only become as large as the characteristic resistance R_k, divided by the partial safety factor γ_R.

(10) The GEO-3 limit state is a peculiarity of earthworks and ground engineering. It describes the loss of overall stability. It includes:

a) Analysis of safety against slope failure;
b) Analysis of safety against global failure.

The limit state condition is always the governing condition:

$$E_d \leq R_d; \tag{1.3}$$

i.e. the design value E_d of the effects may only become as large as the design value of the resistance R_d. The geotechnical actions and resistances are determined using the design values for shear strength:

$$\tan\varphi'_d = \tan\varphi'_k / \gamma_\varphi \quad \text{and} \quad c'_d = c'_k / \gamma_c \quad \text{and, respectively} \tag{1.4a}$$

$$\tan\varphi_{u,d} = \tan\varphi_{u,k} / \gamma_\varphi \quad \text{and} \quad c_{u,d} = c_{u,k} / \gamma_c; \tag{1.4b}$$

i.e. the friction tan φ and the cohesion c are reduced from the outset using the partial safety factors γ_φ and γ_c.

(11) The serviceability limit state (SLS) describes the state of a structure or structural element at which the conditions specified for its use are no longer met, but without loss of its bearing capacity. The analysis is based on the anticipated displacements and deformations being compatible with the purpose of the structure.

1.2.4 Transitional regulations for applying of the Recommendations on Piling in conjunction with the EC 7-1 German Handbook

(1) These Recommendations on Piling are based on the provisions of the EC 7-1 German Handbook [44].

(2) A decisive difference between the provisions of the EC 7-1 German Handbook [44] and DIN 1054:2005-01 is the specification of different partial safety factors γ_P (lower) and the correlation factors ξ (higher) for pile foundations. Overall, however, γ_P and ξ result in a comparable magnitude on the resisting side, like DIN 1054:2005-01, see [59].

(3) The existing limit states to DIN 1054:2005-01 are replaced as follows in the EC 7-1 German Handbook [44]:

a) The previous GZ 1A limit state to DIN 1054:2005-01 corresponds without restrictions to the EQU, UPL and HYD limit states as in the EC 7-1 German Handbook [44].
b) The previous GZ 1B limit state to DIN 1054:2005-01 corresponds without restrictions to the STR limit state as in the EC 7-1 German Handbook [44] as the “internal” pile capacity (material strength). In addition, there is the GEO-2 limit state as in the EC 7-1 German Handbook [44], in conjunction with the “external” design of the foundation elements, e.g. the “external” pile capacity.
c) The previous GZ 1C limit state as in DIN 1054:2005-01 corresponds to the GEO-3 limit state as in the EC 7-1 German Handbook [44], in conjunction with the analysis of the overall stability, i.e. when utilising the shear strength for analysis of safety against slope failure and global failure.

1.3 Planning and Testing Pile Foundations

(1) These Recommendations use the terms “designer” (planner) as the EC 7-1 German Handbook [44] and the EC 7-2 German Handbook [45].

(2) The designer should consult a specialist pile foundation planner if not in possession of the requisite knowledge and experience for pile foundation planning.

(3) A geotechnical design report must be compiled for pile foundations in accordance with the EC 7-1 German Handbook [44], which must make reference to the ground investigation report in accordance with the EC 7-2 German Handbook [45].

(4) Pile foundations are classified as either Geotechnical Category GC 2 or Geotechnical Category GC 3. See 3.2 and the EC 7-1 German Handbook [44] for classification criteria.

(5) Where pile foundations are classified as Geotechnical Category GC 3, a geotechnical expert with requisite experience must be consulted during the

structural engineering appraisal of the ground investigation report and the geotechnical design report. In particular, the geotechnical expert should verify the ground model, the soil parameters and the design approach, and, in agreement with the independent verifier, should carry out comparative analyses.

(6) The execution of pile foundations should be supervised by a specialist planner or a geotechnical expert with the requisite experience and specialist knowledge of pile foundations. Where pile foundations are classified as Geotechnical Category GC 3, the expert mentioned in (5) must also be consulted to check the detailed design and to supervise the pile execution works.