Recommendations of the Committee for Waterfront Structures Harbours and Waterways
EAU 2004

8th Edition

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Preface to the 8th Revised Edition

This, the 8th English edition of the Recommendations of the Committee for Waterfront Structures, in the translation of the 10th German edition of the recommendations, which was published at the end of 2004. Now the full revision of the collected published recommendations which began with EAU 1996 is concluded. The concept of partial safety factors stipulated in EC 7 and DIN 1054 has been incorporated in the EAU's methods of calculation. At the same time, the revised recommendations also take account of all the new standards and draft standards that have also been converted to the concept of partial safety factors and had been published by mid-2004. Like with EAU 1996, further details concerning the implementation of the partial safety factor concept can be found in section 0.

The incorporation of the partial safety factor concept of DIN 1054 called for a fundamental reappraisal of the methods of calculation and design for sheet piling structures contained in sections 8.2 to 8.4 and the methods of calculation for sheet piles contained in section 13. Extensive comparative calculations had to be carried out to ensure that the established safety standard of the EAU was upheld when using methods of analysis according to the concept of partial safety factors. This has been achieved by adapting the partial safety factors and by specifying redistribution diagrams for active earth pressure. The use of the new analysis concept for the design of sheet piling structures therefore results in component dimensions similar to those found by designs to EAU 1990.

Now that the inclusion of the European standardisation concept has been concluded, the 10th German edition of the EAU (and hence also the 8th English edition) satisfies the requirements for notification by the EU Commission. It is therefore registered with the EU Commission under Notification No. 2004/305/D.

A component of the notification is the principle of "mutual recognition", which must form the basis of contracts in which the EAU or individual provisions thereof form part of the contract. This principle is expressed as follows:

"Products lawfully manufactured and/or marketed in another EC Member State or in Turkey or in an EFTA State that is a contracting party to the Agreement on the European Economic Area that do not comply with these technical specifications shall be treated as equivalent – including the examinations and supervisory measures carried out in the country of manufacture – if they permanently achieve the required level of protection regarding safety, health and fitness for use."

The following members of the working committee have been involved with the German edition EAU 2004 since the summer of 2000.

Prof. Dr.-Ing. Dr.-Ing. E. h. Victor Rizkallah, Hannover (Chairman)
Dipl.-Ing. Michael Behrendt, Bonn (since 2001)
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The fundamental revisions contained in EAU 2004 also made detailed discussions with colleagues and specialists outside the committee necessary, even to the extent of setting up temporary study groups for specific topics. The committee thanks all those colleagues who in this way made significant contributions to EAU 2004.

In addition, numerous contributions presented by the professional world and recommendations from other committees and international technical–scientific associations have been incorporated in these recommendations.

These contributions and the results of the revision work mean that EAU 2004 now conforms with the current international standard. It provides the construction industry with an adapted, updated set of recommendations brought into line with European standards that will continue to act as a valuable aid for design, tendering, placing orders, technical processing, economic and ecological construction, quality control and settlement of contracts, and will thus enable harbour and waterway construction projects to be carried out according to the state of the art and according to uniform conditions.

The committee thanks all those whose contributions and suggestions have helped to bring the recommendations up to their present state, and wishes the EAU 2004 the same success as its earlier editions.

Vote of thanks goes to Prof. Dr.-Ing. Dr.-Ing. E. h. Victor Rizkallah, who was chairman of the committee until the end of 2004 and thus the 10th German edition of the recommendations have been prepared and published under his responsibility. In the translation works very valuable advices and help came from Prof. Dr.-Ing. Martin Hager, who was chairman of the committee up to the end of 1996. Finally a very special vote of thanks goes to my co-worker, Dipl.-Ing. Carsten Pohl, who assisted me in the extensive preparation of this edition and in the review of the text with great dedication and diligence.

Further special thanks are owed to the publisher Ernst & Sohn for the good cooperation and the meticulous care with which all drawings, tables and equations were prepared, providing once again an excellent printing quality and layout of the 8th revised English edition of EAU 2004.

Hannover, November 2005 *Prof. Dr.-Ing. Werner Richwien*

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Recommendations

0 Structural calculations

0.1 General

Up until the 8th German edition (EAU 1990), the basis for the 6th English edition, the earth static calculations in the recommendations of the "Committee for Waterfront Structures", which had been developed in over 50 years of work by the Committee, were based on reduced values of soil properties, known as "calculation values", with the prefix "cal". Results of calculations using these calculation values then had to fulfil the global safety criteria in accordance with R 96, section 1.13.2a, of EAU 1990. This safety concept distinguished between three different load cases (R 18, section 5.4), and proved its worth over the years.

The introduction of EAU 1996 resulted in a changeover to the concept of partial safety factors. Since then, development of the Eurocodes has led to extensive changes to the DIN pre-standards, which have been taken into account in the 2004 edition of the EAU.

As part of the realisation of the Single European Market, the "Eurocodes" (EC) are currently being drawn up and will form harmonised directives for fundamental safety requirements for buildings and structures. These Eurocodes are as follows:

DIN EN 1990, EC 0: Basis of structural design
DIN EN 1991, EC 1: Actions on structures
DIN EN 1992, EC 2: Design of concrete structures
DIN EN 1993, EC 3: Design of steel structures
DIN EN 1994, EC 4: Design of composite steel and concrete structures
DIN EN 1995, EC 5: Design of timber structures
DIN EN 1996, EC 6: Design of masonry structures
DIN EN 1997, EC 7: Geotechnical design
DIN EN 1998, EC 8: Design provisions for earthquake resistance of structures
DIN EN 1999, EC 9: Design of aluminium structures

Verification of structural safety must always be carried out according to these standards. EC 0 to EC 9, but in particular EC 7, are significant for proof of stability to EAU 2004. However, until the aforementioned Eurocodes are adopted, the following national DIN standards should be used in Germany. Some of these DIN standards have already been converted to the concept of partial safety factors on the basis of DIN 1055-100. These include the following standards:

DIN 1054: Subsoil – Verification of the safety of earthworks and foundations
DIN 4017: Soil – Calculation of design bearing capacity of soil beneath shallow foundations
DIN 4019: Subsoil; settlement calculations for perpendicular central loading
DIN 4084: Subsoil – Calculation of embankment failure and overall stability of retaining structures
DIN 4085: Subsoil – Calculation of earth pressure

The previous standards covering design and construction will be superseded by new Eurocodes under the heading of "Implementation of special geotechnical works":

Previous standard	New standard
DIN 4014: Bored piles	DIN EN 1536: Bored piles
DIN 4128: Grouted piles	
DIN 4125: Ground anchors	DIN EN 1537: Ground anchors
DIN 4126: Stability analysis of diaphragm walls	DIN EN 1538: Diaphragm walls
	DIN EN 12 063: Sheet-pile walls
DIN 4026: Driven piles	DIN EN 12 699: Displacement piles
DIN 4093: Ground treatment by grouting	DIN EN 12 715: Grouting DIN EN 12 716: Jet grouting

From now on, EAU 2004 will make reference to the quantitative statements regarding methods of calculation with partial safety factors contained in these Eurocodes and the national standards, DIN 1054 in particular.

Wherever standards are cited in the recommendations, no mention is made of their respective status. However, Annex I.3 contains a list of the standards and their status as of October 2004.

0.2 Safety concept

0.2.1 General

The failure of a structure can occur as a result of exceeding the limit state of bearing capacity (LS 1, failure in the soil or structure) or the limit state of serviceability (LS 2, excessive deformation).

Analyses of limit states (verification of safety) are carried out according to the provisions of DIN EN 1991-1 for actions or action effects and those of DIN EN 1992–1999 for actions or action effects and resistances. DIN EN 1990 has been incorporated into DIN 1055-100, DIN EN 1997-1 into DIN 1054. DIN EN 1997-1 permits three options for assessing the verification of safety. These are designated "methods of verification 1 to 3".

DIN 1054 distinguishes between three cases for analysing limit state 1 (ultimate limit state of bearing capacity):

LS 1A: limit state of loss of support safety
LS 1B: limit state of failure of structures and components
LS 1C: limit state of loss of overall stability
(after EC 7 method of verification 3)

In DIN 1054, method of verification 2 has been incorporated for earth static analyses of LS 1B, and method of verification 3 for analyses of LS 1C. Only one method is given for limit state LS 1A in DIN EN 1997-1; EAU 2004 makes use of this method of analysis.

The partial safety factors associated with these three cases are reproduced in tables R 0-1 and R 0-2 for loading cases 1 to 3 of DIN 1054. In the analysis of limit states 1B and 1C to DIN 1054, adequate ductility of the complete system of subsoil plus structure is assumed (DIN 1054, 4.3.4).

0.2.2 Design situations for geotechnical structures

0.2.2.1 Combinations of actions

Combinations of actions (CA) are permutations of the actions to which a structure may be subjected simultaneously at the limit states according to cause, magnitude, direction and frequency. We distinguish between:

a) Standard combination CA 1:
Permanent actions and those variable actions occurring regularly during the functional lifetime of the structure.

b) Rare combination CA 2:
Seldom or one-off planned actions apart from the actions of the standard combination.

c) Exceptional combination CA 3:
   An exceptional action that may occur at the same time and in addition to the actions of the standard combination, especially in the event of catastrophes or accidents.

0.2.2.2 Safety classes for resistances

Safety classes (SC) take into account the different safety requirements for resistances depending on the duration and frequency of the critical actions. We distinguish between:

a) Conditions of safety class SC 1:
   Conditions related to the functional lifetime of the structure.

b) Conditions of safety class SC 2:
   Temporary conditions during the construction or repair of the structure and temporary conditions during building measures adjacent to the structure.

c) Conditions of safety class SC 3:
   Conditions occurring just once or probably never during the functional life of the structure.

0.2.2.3 Loading cases

The loading cases (LC) for limit state LS 1 are derived from the combinations of actions in conjunction with the safety classes for the resistances. We distinguish between:

- Loading case LC 1:
  Standard combination CA 1 in conjunction with the conditions of safety class SC 1. Loading case LC 1 corresponds to the “permanent design situation” according to DIN 1055-100.

- Loading case LC 2:
  Rare combination CA 2 in conjunction with the conditions of safety class SC 1, or standard combination CA 1 in conjunction with the conditions of safety class SC 2. Loading case LC 2 corresponds to the “temporary design situation” according to DIN 1055-100.

- Loading case LC 3:
  Exceptional combination CA 3 in conjunction with the conditions of safety class SC 2, or rare combination CA 2 in conjunction with the conditions of safety class SC 3. Loading case LC 3 corresponds to the “exceptional design situation” according to DIN 1055-100. The loading case categories for waterfront structures are dealt with in R 18, section 5.4.

0.2.2.4 Partial safety factors

0.2.2.4.1 Partial safety factors for actions and action effects

Table 0-1. Partial safety factors for actions for the ultimate limit states of bearing capacity and serviceability for permanent and temporary situations

Action or action effect	Symbol	Loading case		
		LC 1	LC 2	LC 3
LS 1A: limit state of loss of support safety				
Favourable permanent actions (dead load)	$\gamma_{G,stb}$	0.90	0.90	0.95
Unfavourable permanent actions (uplift/buoyancy)	$\gamma_{G,dst}$	1.00	1.00	1.00
Flow force in favourable subsoil	γ_H	1.35	1.30	1.20
Flow force in unfavourable subsoil	γ_H	1.80	1.60	1.35
Unfavourable variable actions	$\gamma_{Q,dst}$	1.00	1.00	1.00
LS 1B: limit state of failure of structures and components				
General permanent actions	γ_G	1.35	1.20	1.00
Hydrostatic pressure in certain boundary conditions a)	$\gamma_{G,red}$	1.20	1.10	1.00
Permanent actions due to steady-state earth pressure	γ_{E0g}	1.20	1.10	1.00
Unfavourable variable actions	γ_Q	1.50	1.30	1.00
LS 1C: limit state of loss of overall stability				
Permanent actions	γ_G	1.00	1.00	1.00
Unfavourable variable actions	γ_Q	1.30	1.20	1.00
LS 2: limit state of serviceability				
$\gamma_G = 1.00$ for permanent actions or action effects $\gamma_Q = 1.00$ for variable actions or action effects				

a) According to DIN 1054, section 6.4.1(7), the partial safety factors γ_G for hydrostatic pressure may be reduced as specified for waterfront structures in which larger displacements can be accommodated without damage if the conditions according to section 8.2.0.3 are complied with.

0.2.2.4.2 Partial safety factors for resistances

Table 0-2. Partial safety factors for resistances for the ultimate limit state of bearing capacity for permanent and temporary situations

Resistance	Symbol	Loading case		
		LC 1	LC 2	LC 3
LS 1B: limit state of the failure of structures and components				
Soil resistances				
Earth resistance	γ_{Ep}	1.40	1.30	1.20
Earth resistance for determining bending moment[a]	$\gamma_{Ep,red}$	1.20	1.15	1.10
Ground failure resistance	γ_{Gr}	1.40	1.30	1.20
Sliding resistance	γ_{Gl}	1.10	1.10	1.10
Pile resistances				
Pile compression resistance for test load	γ_{Pc}	1.20	1.20	1.20
Pile tension resistance for test load	γ_{Pt}	1.30	1.30	1.30
Pile resistance in tension and compression based on empirical values	γ_P	1.40	1.40	1.40
Grouted anchor resistances				
Resistance of steel tension member	γ_M	1.15	1.15	1.15
Pull-out resistance of grout	γ_A	1.10	1.10	1.10
Resistances of flexible reinforcing elements				
Material resistance of reinforcement	γ_B	1.40	1.30	1.20
LS 1C: limit state of loss of overall stability				
Shear strength				
Friction angle tan φ' of drained soil	γ_φ	1.25	1.15	1.10
Cohesion c' of drained soil				
Shear strength cu of undrained soil	γ_c, γ_{cu}	1.25	1.15	1.10
Pull-out resistances				
Ground or rock anchors, tension piles	γ_N, γ_Z	1.40	1.30	1.20
Grout of grouted anchors	γ_A	1.10	1.10	1.10
Flexible reinforcing elements	γ_B	1.40	1.30	1.20

[a] Reduction for calculating the bending moment only. According to DIN 1054, section 6.4.2(6), the partial safety factors γ_{Ep} for earth resistance may be reduced as specified for waterfront structures in which larger displacements can be accommodated without damage if the conditions according to section 8.2.0.2 are complied with.

0.2.3 Ultimate limit state LS 1: bearing capacity

The calculated verification of adequate stability is always carried out for the ultimate limit state of bearing capacity 1 (LS 1) with the help of design values (index *d*) for actions or action effects and resistances. The design values are derived from the characteristic values (index *k*) of the actions or action effects and resistances as follows:

- the characteristic actions or action effects are multiplied by partial safety factors,
  e.g. $E_{a,d} = E_{a,k} \cdot \gamma_G$ (earth pressure component from permanent loads).
- the characteristic resistances are divided by the partial safety factors, e.g. $E_{p,d} = E_{p,k} / \gamma_{Ep}$ (earth resistance) in LS 1B or $c'_d = c'_k / \gamma_c$ (effective cohesion) in LS 1C.

The characteristic value of a parameter is the value of a, normally scattered, physical variable, e.g. the friction angle φ' or the cohesion c' or c_u of a component resistance (e.g. the pull-out force of an anchor pile of the earth resistance force in front of the base of sheet piling), that is to be used in calculations. It is the cautious anticipated mean value lying on the safe side and is defined in DIN 1054.

The verification of safety is assessed according to the following fundamental equation:

$$E_d \leq R_d$$

E_d is the design value of the actions or action effects derived from the characteristic values of the actions or action effects, multiplied by the respective safety factors (e.g. foundation load).

R_d is the design value of the resistances derived as a function of the characteristic soil resistances, or from structural elements, divided by the associated partial safety factors according to the corresponding method of calculation (e.g. ground failure to DIN 4017).

The partial safety factors to be used are to be taken from tables R 0-1 and R 0-2 and from the corresponding building materials and components standards, provided no other partial safety factors are specified in the corresponding recommendations of EAU 2004.

0.2.3.1 Limit state LS 1A

Proceed as follows for analyses of stability for limit state LS 1A:

a) Firstly, calculate the design values of the actions from the characteristic actions. In doing so, distinguish between favourable and unfavourable actions. Resistances do not play a role determining the support safety (LS 1A).

b) Secondly, compare the design values of the favourable and unfavourable actions and verify that the respective limit state condition is complied with. For further information see DIN 1054.

0.2.3.2 Limit state LS 1B

The following procedure is useful for analysing stability for limit state LS 1B:

a) Firstly, apply the characteristic actions to the chosen structural system and hence determine the characteristic action effects (e.g. internal forces).
b) Secondly, convert the characteristic action effects with the partial safety factors for actions into design values for action effects, the characteristic resistances to design values for resistances.
c) Finally, compare the design values of the action effects with the design resistances and show that the limit state equation is complied with for the failure mechanism under investigation.

This method assumes that a linear–elastic calculation is generally possible. Refer to DIN 1054, section 4.3.2 (3) when calculating the stability of non-linear problems for LS 1B. According to this standard the action effects calculated from the most unfavourable combination of permanent and variable actions may be broken down into a component comprising permanent actions and a component comprising variable actions in each case owing to a sufficiently accurate criterion.

0.2.3.3 Limit state LS 1C

Proceed as follows for analyses of stability for limit state LS 1C:

a) Firstly, calculate the design values of the actions from the characteristic actions for the failure mechanism under investigation.
b) Secondly, convert the characteristic shear strengths and, if necessary, component resistances with the partial safety factors for resistances into design resistances.
c) Finally, show that the limit state equation is complied with using the design values for actions and resistances for the failure mechanism under investigation.

0.2.4 Limit state LS 2: serviceability

Deformation verification is to be provided for all structures whose function can be impaired or rendered useless through deformations. The deformations are calculated with the characteristic values of actions and soil reactions and must be less than the deformations permissible for perfect functioning of a component or the whole structure. Where applicable, the calculations should include the upper and lower limit values of the characteristic values.