Recommendations of the "Committee for Waterfront Structures Harbours and Waterways" EAU 2012

9th Edition

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9th Edition
Translation of the 11th German Edition

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Preface to 11th, revised edition (9th English edition) of the *Recommendations of the Committee for Waterfront Structures – Harbours and Waterways*

Eight years have passed since the 10th German (8th English) edition of the *Recommendations of the Committee for Waterfront Structures* was published. During that period the annual, in some cases six-monthly, technical reports of the years 2005 to 2011 have contained innovations and improvements. This 9th English edition (the translation of the 11th German edition), simply called the "EAU" by those in the know, represents a completely updated version of the recommendations of the Waterfront Structures Committee, a body organised jointly by the German Port Technology Association (HTG) and the German Geotechnical Society (DGGT). I feel sure that this edition, too, will become a standard work of reference for every engineer working on waterfront structures.
The main changes to the content are to be found in chapter 1 (production of geotechnical report and calculation of undrained shear strengths), chapter 2 (calculations with total and effective stresses), section 8.1 (installation of sheet pile walls and supervision of such installation work), section 8.2 (verification of vertical load-carrying capacity) and chapter 13 (using the *p*-*y* method to design dolphins). The previous chapter 14 has been incorporated in other parts of the EAU and the old chapter 15 renumbered accordingly, leaving this edition with just 14 chapters. Furthermore, the notation has been amended to match Eurocode 7 and Germany's National Application Document DIN 1054, which are now valid.
The principle for constituting committees laid down by the German Institute for Standarization (DIN), i.e. appropriate representation of all groups with an interest and availability of the necessary expertise, is followed by the EAU committee. Therefore, the committee is made up of members from all relevant disciplines and drawn from universities, the building departments of large seaports, inland ports and national waterways, the construction industry, the steel industry and consulting engineers.
The following members of the working committee were involved in preparing EAU 2012:

Univ.-Prof. Dr.-Ing. Jürgen Grabe, Hamburg (chair since 2009)
Ir. Tom van Autgaerden, Antwerp
Dipl.-Ing. Dirk Busjaeger, Hamburg
Dr. ir. Jakob Gerrit de Gijt, Rotterdam
Dr.-Ing. Michael Heibaum, Karlsruhe
Dr.-Ing. Stefan Heimann, Berlin
Prof. ir. Aad van der Horst, Delft
Dipl.-Ing. Hans-Uwe Kalle, Hagen

Prof. Dr.-Ing. Roland Krengel, Duisburg
Dipl.-Ing. Karl-Heinz Lambertz, Duisburg
Dr.-Ing. Christoph Miller, Hamburg
Dr.-Ing. Karl Morgen, Hamburg
Dipl.-Ing. Gabriele Peschken, Bonn
Dipl.-Ing. Torsten Retzlaff, Rostock
Dipl.-Ing. Emile Reuter, Luxembourg
Univ.-Prof. Dr.-Ing. Werner Richwien, Essen (chair until 2009)
Dr.-Ing. Peter Ruland, Hamburg
Dr.-Ing. Wolfgang Schwarz, Schrobenhausen
Dr.-Ing. Hartmut Tworuschka, Hamburg
Dr.-Ing. Hans-Werner Vollstedt, Bremerhaven

In a similar way to the work of the DIN when producing a standard, new recommendations are presented for public discussion in the form of provisional recommendations in the annual technical reports. After considering any objections, recommendations are published in their final form in the following annual technical report. Annex I contains a list of the annual technical reports relevant to this edition. The status of the *Recommendations of the Committee for Waterfront Structures – Harbours and Waterways* is therefore equivalent to that of a standard. Seen from the point of view of its relevance to practice and also the dissemination of experience, however, the information provided goes beyond that of a standard; this publication can be seen more as a "code of practice".
As the European standardisation concept is now fully incorporated in the EAU, this edition satisfies the requirements for notification by the European Commission. It is registered with the European Commission under notification No. 2012/426D.
The fundamental revisions in EAU 2012 made in-depth discussions with colleagues outside the committee necessary, even the setting-up of temporary study groups to deal with specific topics. The committee acknowledges the assistance of all colleagues who in this way made a significant contribution to the development of EAU 2012.
In addition, considerable input from experts plus recommendations from other committees and international engineering science bodies have found their way into these recommendations.
So, with such additions and the results of revision work, EAU 2012 corresponds to today's international standards. Experts working in this sector now have at their disposal an updated edition adapted to the European standards which will continue to supply valuable help for issues in design, tendering, award of contract, engineering tasks, economic and environmentally compatible construction, site supervision and contractual procedures. It will therefore be possible to design and build waterfront structures that are in line with the state of the art and have consistent specifications.

The committee would like to thank all those who contributed to and made suggestions for this edition. It is hoped that EAU 2012 will attract the same resonance as earlier editions.
A special vote of thanks goes to my colleague Univ.-Prof. Dr.-Ing. Werner Richwien, who chaired this committee with dedication over many years. He created a working climate that had a positive influence on the motivation of every committee member and will shape the work of the committee in the coming years.
I would also like to thank my assistants Dr.-Ing. Hans Mathäus Hügel and Dipl.-Ing. Torben Pichler, who read through the chapters and organised the production process. Only through their efforts it became possible to meet the deadline for printing the 11th German edition in 2012.
I am also grateful to the publishers Ernst & Sohn for the good cooperation, the careful preparation of the many illustrations, tables and equations and the excellent quality of the printing and layout of EAU 2012.

Hamburg, October 2012 Univ.-Prof. Dr.-Ing. *Jürgen Grabe*

0 Structural calculations

0.1 General

The recommendations of the “Waterfront Structures” working committee have been repeatedly adjusted in line with the relevant standards. This applied and indeed continues to apply to the safety criteria defined in the standards. Up until the 8th German edition (EAU 1990), the earth pressure calculations were based on reduced soil parameter values, known as “calculation values” with the prefix “cal”. The results of calculations using these values then had to fulfil the global safety criteria in accordance with recommendation R 96, section 1.13.2a, of EAU 1990. The publication of EAU 1996 resulted in a changeover to the concept of partial safety factors. It was agreed within the European Union that this safety concept should be pursued in a uniform manner by all Member States.
The “Eurocodes” (EC) – harmonised directives specifying fundamental safety requirements for buildings and structures – were drawn up as part of the realisation of the European Single Market. Those 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 of structures for earthquake resistance
DIN EN 1999, EC 9: Design of aluminium structures

The Eurocodes “Basis of structural design” (DIN EN 1990) and “Actions on structures” (DIN EN 1991) with their various parts and annexes form the basis of European construction standards, the starting point for building designs throughout Europe. The other eight Eurocodes, along with their respective parts, relate to these two basic standards.

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Verification of safety must always be carried out according to European standards. However, in some instances such verification is not possible with these standards alone; a number of parameters, e.g. numerical values for partial safety factors, have to be specified on a national basis. Furthermore, the Eurocodes do not cover the entire range of German standards, meaning that a comprehensive set of national standards has been retained. However, this set of German standards along with its requirements must not contradict the regulations contained in the European standards, which in turn necessitated the revision of national standards.

For proof of stability according to the EAU, the standards DIN EN 1990 to DIN EN 1999, but especially DIN EN 1997 (Geotechnical design), are of particular importance. DIN EN 1997-1 defines a number of terms and describes and stipulates limit state verification procedures. The various earth pressure design models for stability calculations are also included in the annexes for information purposes. A particular feature here is that three methods of verification using the partial safety factor concept are available for use throughout Europe.

The publication of DIN 1054:2010 ensured that any duplication of DIN EN 1997-1 was avoided, but specific German experience has been retained. This standard was combined with DIN EN 1997-1:2010 and the National Annex (DIN EN 1997-1/NA:2010) to create the EC 7-1 manual [85].

DIN EN 1997-2 governs the planning, execution and evaluation of soil investigations. As for part 1, this standard has been published together with DIN 4020:2010 and the National Application Document in the EC 7-2 manual [86].

The existing German execution standards have been replaced by new European standards under the general designation “Execution of special geotechnical works”. However, this process is still ongoing.

Likewise, the German calculation standards, containing individual safety stipulations in some instances, have been revised so that all safety criteria are now defined in DIN 1054.

Where standards are cited in the recommendations, then the current version applies, unless stated otherwise. All standards cited are listed in annex I.3.

0.2 Safety concept

0.2.1 General

A structure can fail as a result of exceeding the ultimate limit state of bearing capacity (“ultimate limit state – ULS”, failure of the soil or the structure, loss of static equilibrium) or the limit state of serviceability (“serviceability limit state – SLS”, excessive deformations).

In order to verify the ultimate limit state of bearing capacity, three cases were distinguished in the past (five from now on):

DIN 1054:2005-01		EC 7-1 manual	
Loss of static equilibrium	LS 1A	Loss of equilibrium of structure or ground	EQU
		Loss of equilibrium of structure or ground due to uplift by water pressure (buoyancy)	UPL
		Hydraulic heave, internal erosion or piping in the ground due to hydraulic gradients	HYD
Failure of structures or components due to failure in the structure or supporting subsoil	LS 1B	Internal failure or very large deformation of the structure or its components	STR
		Failure or very large deformation of the ground	GEO-2
Loss of overall stability	LS 1C	Loss of overall stability	GEO-3

DIN EN 1997-1 permits three options for verifying safety, designated “design approaches 1 to 3”. For approach 1, two groups of factors are taken into account and used in two separate analyses. For approaches 2 and 3, a single analysis with one group of factors suffices.
In approaches 1 and 2, the factors are applied, in principle, to either actions or action effects and to resistances. However, DIN 1054 stipulates that the characteristic, or representative, effects $E_{Gk,i}$ or $E_{Qrep,i}$ (e.g. shear forces, reactions, bending moments, stresses in the relevant sections of the structure and at interfaces between structure and subsoil) are determined first and then the factors are applied. This is also referred to as design approach 2^*.
In approach 3, the factors are applied to the soil parameters and to actions or action effects not related to the subsoil. Actions or action effects induced by the subsoil are calculated from the factored soil parameters.

According to DIN 1054, design approach 2 (2*) should be used for the geotechnical analysis of limit states STR and GEO-2, and design approach 3 for analysing limit state GEO-3.
In the Eurocodes, the determination of design situations (DS) has superseded the differentiation between loading cases customary up until now:

- Loading case 1 becomes permanent design situation DS-P
- Loading case 2 becomes transient design situation DS-T
- Loading case 3 becomes accidental design situation DS-A

These design situations are assigned different partial safety factors and combination factors.
Additionally, design situation DS-E has been introduced for earthquakes. According to DIN EN 1990, no partial safety factors are applied in design situation DS-E.
The partial safety factors specified in DIN 1054 are reproduced in Tables R 0-1 to R 0-3.

Table R 0-1. Partial safety factors for actions and action effects (to DIN 1054:2010, Table A 2.1, with additions)

Action or action effect	Symbol	Design situation		
		DS-P	DS-T	DS-A
HYD and UPL: Limit state of failure due to hydraulic heave and buoyancy				
Destabilising permanent actions[a)]	$\gamma_{G,dst}$	1.05	1.05	1.00
Stabilising permanent actions	$\gamma_{G,stb}$	0.95	0.95	0.95
Destabilising variable actions	$\gamma_{Q,dst}$	1.50	1.30	1.00
Stabilising variable actions	$\gamma_{Q,stb}$	0	0	0
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
EQU: Limit state of loss of equilibrium				
Unfavourable permanent actions	$\gamma_{G,dst}$	1.10	1.05	1.00
Favourable permanent actions	$\gamma_{G,stb}$	0.90	0.90	0,95
Unfavourable variable actions	γ_Q	1.50	1.25	1.00
STR and GEO-2: Limit state of failure of structures, components and subsoil				
Action effects from permanent actions generally[a)]	γ_G	1.35	1.20	1.00

Table R 0-1. (*Continued*)

Action or action effect	Symbol	Design situation		
		DS-P	DS-T	DS-A
Action effects from permanent actions for calculating anchorage[b)]	γ_G	1.35	1.20	1.10
Action effects from favourable permanent actions[c)]	$\gamma_{G,inf}$	1.00	1.00	1.00
Action effects from permanent actions due to earth pressure at rest	$\gamma_{G,EO}$	1.20	1.10	1.00
Water pressure in certain boundary conditions[d)]	$\gamma_{G,red}$	1.20	1.10	1.00
Water pressure in certain boundary conditions for calculating anchorage[b)]	$\gamma_{G,red}$	1.20	1.10	1.10
Action effects from unfavourable variable actions[e)]	γ_Q	1.50	1.30	1.00
Action effects from unfavourable variable actions for calculating anchorage[b)]	γ_Q	1.50	1.30	1.10
Action effects from favourable variable actions	γ_Q	0	0	0
GEO-3: Limit state of failure due to 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
SLS: 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) The permanent actions are understood to include permanent and variable water pressure. Differing from DIN 1054:2010, $\gamma_G = 1.00$ applies in DS-A except when verifying anchorage.

b) The design of anchorages (grouted anchors, micropiles, tension piles) also includes verifying stability at the lower failure plane according to R 10 (section 8.5) when dealing with retaining structures.

c) If during the determination of the design values of the tensile action effect a characteristic compressive action effect from favourable permanent actions is assumed to act simultaneously, then this should be considered with the partial safety factor $\gamma_{G,inf}$ (DIN 1054, 7.6.3.1, A(2)).

d) For waterfront structures in which larger displacements can be accommodated without damage, the partial safety factors $\gamma_{G,red}$ for water pressure may be used if the conditions according to section 8.2.1.3 are complied with (DIN 1054, A 2.4.7.6.1, A(3)).

e) Differing from DIN 1054:2010, $\gamma_Q = 1.00$ applies in DS-A except when verifying anchorage.

f) The permanent actions are understood to include permanent and variable water pressures.

Table R 0-2. Partial safety factors for geotechnical parameters (DIN 1054:2010, Table A 2.2)

Soil parameter	Symbol	Design situation		
		DS-P	DS-T	DS-A
HYD and UPL: Limit state of failure due to hydraulic heave and buoyancy				
Friction coefficient tan φ′ of drained soil and friction coefficient tan φ_u of undrained soil	$\gamma_{\varphi'}$, $\gamma_{\varphi u}$	1.00	1.00	1.00
Cohesion c' of drained soil and shear strength c_u of undrained soil	$\gamma_{c'}$, γ_{cu}	1.00	1.00	1.00
GEO-2: Limit state of failure of structures, components and subsoil				
Friction coefficient tan φ′ of drained soil and friction coefficient tan φ_u of undrained soil	$\gamma_{\varphi'}$, $\gamma_{\varphi u}$	1.00	1.00	1.00
Cohesion c' of drained soil and shear strength c_u of undrained soil	$\gamma_{c'}$, γ_{cu}	1.00	1.00	1.00
GEO-3: Limit state of failure due to loss of overall stability				
Friction coefficient tan φ′ of drained soil and friction coefficient tan φ_u of undrained soil	$\gamma_{\varphi'}$, $\gamma_{\varphi u}$	1.25	1.15	1.10
Cohesion c' of drained soil and shear strength c_u of undrained soil	$\gamma_{c'}$, γ_{cu}	1.25	1.15	1.10

Table R 0-3. Partial safety factors for resistances (to DIN 1054:2010, Table A 2.3, with additions)

Resistance	Symbol	Design situation		
		DS-P	DS-T	DS-A
STR and GEO-2: Limit state of failure of structures, components and subsoil				
Soil resistances				
- Passive earth pressure and ground failure resistance	$\gamma_{R,e}$, $\gamma_{R,v}$	1.40	1.30	1.20
- Passive earth pressure when determining bending moment[a)]	$\gamma_{R,e,red}$	1.20	1.15	1.10
- Sliding resistance	$\gamma_{R,h}$	1.10	1.10	1.10
Pile resistances from static and dynamic pile loading tests				
- Base resistance	γ_b	1.10	1.10	1.10
- Skin resistance (compression)	γ_s	1.10	1.10	1.10
- Total resistance (compression)	γ_t	1.10	1.10	1.10
- Skin resistance (tension)	$\gamma_{s,t}$	1.15	1.15	1.15

Table R 0-3. (*Continued*)

Resistance	Symbol	Design situation		
		DS-P	DS-T	DS-A
Pile resistances based on empirical values				
- Compression piles - Tension piles (in exceptional cases only)	γ_b, γ_s, γ_t $\gamma_{s,t}$	1.40 1.50	1.40 1.50	1.40 1.50
Pull-out resistances				
- Ground or rock anchors - Grout body of grouted anchors - Flexible reinforcing elements	γ_a γ_a γ_a	1.40 1.10 1.40	1.30 1.10 1.30	1.20 1.10 1.20

[a] Reduction for calculating the bending moment only. For waterfront structures in which larger displacements can be accommodated without damage, the partial safety factors $\gamma_{R,e,red}$ for passive earth pressure may be used if the conditions according to section 8.2.1.2 are complied with (DIN 1054, A 2.4.7.6.1, A(3)).

Remarks:

– For limit state of failure due to loss of overall stability GEO-3, the partial safety factors for shear strength are to be taken from Table R 0-2, and pull-out resistances are multiplied by partial safety factors according to STR and GEO-2.
– The partial safety factor for the material resistance of steel tension members made from reinforced and prestressed steel for limit states GEO-2 and GEO-3 is given in DIN EN 1992-1-1 as $\gamma_M = 1.15$.
– The partial safety factor for the material resistance of flexible reinforcing elements for limit states GEO-2 and GEO-3 is given in *Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements* [62].

Provided that greater displacements and deformations of the structure do not impair the stability and serviceability of the structure, as can be the case for waterfronts, ports, harbours and waterways, the partial safety factor γ_G can be reduced for earth and water pressures in justified cases (DIN 1054, A 2.4.7.6.1, A(3)). This is exploited in EAU by using the factors in the form of $\gamma_{G,red}$ (Table R 0-1) and $\gamma_{R,e,red}$ (Table R 0-3). Furthermore, a partial safety factor $\gamma_G = \gamma_Q = 1.00$ is used for action effects due to permanent and unfavourable variable actions in design situation DS-A.

0.2.2 Combination factors

When calculating a design value for actions F_d according to EN 1990, this value must either be stipulated directly or derived from representative values:

$$F_d = \gamma_F \cdot F_{rep}$$

where

$$F_{rep} = \psi \cdot F_k$$

γ_F partial safety factor
ψ combination factor

For permanent actions and the leading action of variable actions, then $F_{rep} = F_k$ applies.
In the case of several independent variable characteristic actions $Q_{k,i}$, DIN EN 1990 requires combinations with corresponding coefficients ψ to be investigated for buildings and bridges. In such investigations, one of the independent actions should be taken as the leading action $Q_{k,1}$ on a case-by-case basis.
A combination factor $\psi = 1.00$ is usually used for waterfront structures. Exceptions are discussed in section 5.4.4.
For verifying safety against buoyancy (UPL) and safety against hydraulic heave (HYD), the design values F_d are always calculated without considering combination factors.

0.2.3 Analysis of ultimate limit state

Numerical proof of adequate stability is carried out for limit states STR and GEO-2 with the help of design values (index *d*) for actions or action effects and resistances, and for limit state GEO-3 with the help of design values for actions or action effects and soil properties.
Verification of safety is assessed according to the following fundamental equation:

$$E_d \leq R_d$$

where

E_d design value of sum of actions or action effects
R_d design value of resistances derived from sum of resistances of soil or structural elements

When analysing the limit state of loss of equilibrium (EQU) or failure due to hydraulic heave (HYD) or buoyancy (UPL), it is necessary compare the design values for favourable and unfavourable or stabilising or destabilising actions and verify that the respective limit state condition is complied with. Resistances do not play a role in these analyses.