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Bases for design of structures — Names and symbols of physical quantities and generic quantities

Bases du calcul des constructions — Noms et symboles des grandeurs physiques et grandeurs génériques

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3898 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 1, *Terminology and symbols*.

This fourth edition cancels and replaces the third edition (ISO 3898:1997), which has been technically revised.

The main reasons for this fourth edition of ISO 3898 are

— application of new techniques and methods in the analysis and design of structures, e.g. probabilistic and partial factor methods, introduction of codes for new design situations, and more advanced materials have increased the need for a more fundamental set of rules for the formation and presentation of symbols, and

— revisions of the ISO Guide 31 series for the International System of Units (S.I.).

The major technical changes from the previous edition are the following:

— the normative references have been updated; particularly with regard to the ISO 80000 series;

— the so-called 'kernel-index-method' for forming and writing names and new (compound) symbols is presented;

— the presentation of the (tables of) indices has been altered in accordance herewith;

— the concept of 'generic quantities' is introduced (Annex A).

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0 Introduction

0.1 The concept of a ‘physical quantity’

The concept of a ‘physical quantity’ is, according to ISO/IEC Guide 99, defined by the following descriptive statement: an attribute of a phenomenon, body or substance that can be distinguished qualitatively and determined quantitatively.

The concept ‘physical quantity’ is designated by a name [= a verbal designation of an individual concept (see 3.4.2 of ISO 1087-1:2000)] and a corresponding symbol.

A physical quantity is characterized by its unique dimension. The dimension of a physical quantity is expressed in units (of measurement).

NOTE 1 According to the ISO/IEC Directives, Part 2 for drafting International Standards, SI units are applied.

NOTE 2 Physical quantities can be dimensionless, e.g. often the case with factors. In that case their dimension is noted as 1.

The names and symbols of the most important physical quantities (according ISO/IEC Guide 99: physical quantities in a general sense) - and their characterizing units - within the field of physical sciences and technology are given in ISO 80000-1. However, this is a limited set of names and symbols.

0.2 General method for forming and writing names and symbols of physical quantities

The names and symbols of the most important physical quantities (and their units) within the field of the design of structures are given in this document: see the Tables 2 to 4 of this International Standard (but necessarily there will/must be some overlap with ISO 80000-1).

This set of names and symbols is also limited, but with the help of the method given in this International Standard (*kernel-index-method*) the user will be able to form/compose new and unique (compound) symbols for a wide variety of physical quantities (according ISO/IEC Guide 99: particular physical quantities).

Adapted ‘reading’ of the compound symbols moreover enables the user to designate and particularize the corresponding unique names of the physical quantities (see examples in 3.2.2.5 and 3.2.2.8).

The method itself is presented/worked-out in 3.1 of this International Standard, the kernel of a compound symbol is given in or has to be chosen from the above mentioned Tables 2 to 4 and the indices forming that unique (compound) symbol (mostly subscripts) are given in or have to be chosen from Tables 5 to 10.

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Bases for design of structures — Names and symbols of physical quantities and generic quantities

1 Scope

This International Standard covers physical quantities in a general sense. The kernel-index-method enables to form (compound) symbols of physical quantities related to a particular material and/or a particular technical field of design of structures.

It also gives the main names, symbols, and units for physical quantities within the field of design of structures.

Annex A in a general sense covers 'generic quantities' which are genuine to this field. The kernel-index-method can likewise be applied.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 80000-1, *Quantities and units — Part 1: General*

ISO 80000-2, *Quantities and units — Part 2: Mathematical signs and symbols to be used in the natural sciences and technology*

ISO 80000-3, *Quantities and units — Part 3: Space and time*

ISO 80000-4, *Quantities and units — Part 4: Mechanics*

3 Names and symbols for physical quantities and units

3.1 General rules and method for forming and writing names and symbols

The kernel of a (compound) symbol can be chosen from Tables 2, 3 and 4 and indices (mostly subscripts) forming that unique (compound) symbol can be chosen from Tables 5 to 10.

NOTE 1 The rules are mainly adopted from the ISO 80000 series. In 3.2 the 'kernel-index-method' (KIM) has been formulated for the first time in an ISO International Standard. The method stems from the mathematical disciplines: Riemannian geometry and Affinor/Tensor analysis (Second half of nineteenth century).

NOTE 2 ISO 10241 can be used as a basis for formulating the correct name and definition of terms and quantities.

3.2 Rules and method for forming and writing names and symbols of physical quantities

3.2.1 Names

The name (in general) of a general physical quantity is (mostly) one term, being a noun, written in Latin lower case letter symbols in Roman (upright) type.

For several systems of physical quantities the names (and the symbols) of some physical quantities in a general sense are given in the ISO 80000 series. For the design of structures the system of physical quantities in a general sense is given in the Tables 2, 3 and 4 of this International Standard.

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In case of the name of a new or a particular physical quantity a new name/term can be chosen/composed, for instance, by combining the name of an already existing physical quantity with all kinds of other terms.

For some terms like: coefficient, factor, parameter, number, ratio, level and constant, some guidance for applying them is given in ISO 80000-1.

EXAMPLE 1 One term of a physical quantity: area, thickness, force, strength, factor, etc.

EXAMPLE 2 A combination of (one of the above mentioned terms with other) terms:

— maximum area, nominal thickness of a flange, design value of a force,

— admissible (value of the) strength of timber in direction x, friction factor, etc.

3.2.2 Symbols

The following applies to the forming and notation of symbols:

3.2.2.1 The symbol of a physical quantity is a one-letter symbol, the kernel, written in italic type.

NOTE There is one exception: a characteristic number has two letter symbols, see ISO 80000-11.

3.2.2.2 A letter symbol for a kernel can be a lower case or an upper case letter symbol of the Latin or the Greek alphabet (see Tables 2, 3 and 4). In most cases the choice for a kernel of a physical quantity shall be based on considerations of dimension or the main usage, as given in Table 1 of this International Standard. A dimension or a main usage of a physical quantity not included in Table 1 shall comply the nearest appropriate category listed.

3.2.2.3 The kernel may be modified by applying one or more subscripts/indices (and sometimes superscripts), a so-called: compound symbol.

3.2.2.4 Subscripts/indices may be formed from letter symbols, digits and graphical symbols: they are written in Roman (upright) type. If the kernel of a physical quantity is used as a subscript/index it is written in italic type. Several kinds of subscripts/indices are given in the Tables 5 to 10.

3.2.2.5 A subscript/index is placed at the bottom right position of the kernel. By applying more than one subscript/index (sometimes superscript) the distinct indices should preferably be separated by a semi-colon (;). In the case of simple and clear, distinctive index symbols also a space or comma (,) is allowed. For simply two or three of these index symbols no separation at all may be appropriate.

NOTE Other positions, e.g. at the upper right, are possible too. However, in general these positions are reserved for other applications.

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EXAMPLES

F_{ext}	external force;
K_{nom}	nominal (value of) external couple;
N_x, V_y, V_z	normal and shear forces in a cross-section of a beam;
M_y, M_z, T_x	bending and torsional moments in a cross-section of a beam;
m_{xx}, m_{yy}, m_{xy}	internal bending and torsional moments per length in a plate or shell;
w_{ser}	serviceability limit (state) of deflection;
f_u	ultimate limit (state) of strength;
ε_x, $1/2\gamma_z$, ε_y	two-dimensional normal and shear strains in general;
γ_R	partial factor for the transfer of material properties, geometry of structure and actions into resistance of structure;
γ_S	partial factor for the transfer of actions, geometry of structure and material properties into response of structure;
v_{sat}	humidity per volume at saturation.

3.2.2.6 By applying more than one subscript/index, the order of the subscripts/indices is from right to left as follows (if necessary/relevant the same rules can be applied for superscripts):

General format (***K***: kernel of a physical quantity, **vi** to **i**: indices):

$K_{vi;v;iv;iii;ii;i}$

index i): subscripts/indices related to probabilistic and partial factor methods of analysis and design;

EXAMPLES rep(resentative), nom(inal), k (characteristic), d(esign), etc.;

index ii): subscripts/indices related to types of limit state;

EXAMPLES u(ltimate), ser(viceability), fat(igue), fi(re), etc.;

index iii): subscripts/indices related to various aspects;

EXAMPLES g(uaranteed), max(imum), obs(erved), *i*, *j* (ordinal numbers), etc.;

index iv): subscripts/indices related to the Basic variables and the Performance functionals. The preferred order is: first the indices ‘S’, ‘s’ and ‘R’, ‘r’, then the other indices iv).

EXAMPLES

Basic variables:

F:	f	(Action in general, Loadcase), a(ccidental), g (permanent), sn(ow),etc.;
GE:	ge	(Geometry of structure in general);
M:	m	(Material property in general), el(asticity), cr(eepiness), etc.;

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Performance functionals:

S: s (Response of structure, Sequel or Effect of action(s), Action-effect), dyn(amical), sli(ding), etc.;
NOTE Sometimes deviating from S, the symbol E is used, e.g. in a number of Eurocodes, and erroneously in ISO 22111:2007.

R: r (Resistance of structure, Capacity), frac(tional), fat(igue), etc.

index v): subscripts/indices related to (1) place, then to (2) direction;

EXAMPLES 1 (joint, knot, point, foundation) A, B, C, ..., a, b, c, ..., 1, 2, 3, ..., etc.;

EXAMPLES 2 x, y, z, //, etc.

index vi): subscripts/indices related to types of material;

EXAMPLES c(oncrete), ma(sonry), etc.

3.2.2.7 If, by applying the subscripts/indices i to vi (or superscripts), the dimension of the original physical quantity does not change, so $< K > = < K_{\text{index}} >$, such subscripts/indices are called descriptive subscripts/indices (or superscripts).

3.2.2.8 A (compound) symbol is written without a final full stop (except for normal punctuation).

EXAMPLES

physical quantities with names with one term	**symbol**
area	A
thickness	t
force	F
strength	f
factor	μ

physical quantities with names as a combination of terms	**symbol**
maximum area	A_{max}
nominal thickness of a flange	$t_{\text{fl;nom}}$
design (value of a) force	F_{d}
admissible (value of the) strength of wood in direction *x*	$f_{\text{ti};xx;\text{adm}}$
friction factor	μ_{fric}

NOTE For the equivalent rules in the case of generic quantities reference here is made to A.4.3.

3.3 Rules for forming and writing names and symbols of units

NOTE This International Standard adopts (the rules of) the International System of units (SI).

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3.3.1 Names

All names are given in ISO 80000-1. The names are written in Latin lower case letter.

EXAMPLES

(7) base units:	metre, kilogram, second, ampere, kelvin, mole and candela;
(18+3) derived units:	newton, pascal, radian, etc.;
(20 prefixes for) multiples of units:	(multiple:) megapascal, etc.; (sub-multiple:) millimetre, etc.;
compound units:	newton metre, metre per second, etc.

3.3.2 Symbols

The symbol of a unit is only (a kernel of) one or more successive separate (mostly) Latin lower and/or upper case letter symbols, written in Roman (upright) type (irrespective of the type used in the rest of the text).

EXAMPLES m, K, kg, s, N, Pa, rad, MPa, mm, etc.

No subscripts (and superscripts) are allowed.

The symbol of a compound unit: a multiplication is indicated by one space or a half-high dot and a division can be indicated by a solidus (/).

EXAMPLES N·m or N m, m/s or m s^{-1}, etc.

A (compound) symbol is written without a final full stop (except for normal punctuation) and shall be placed after the numerical value, leaving a space between that value and the unit symbol.

EXAMPLE F = 10,8 kN, etc.

3.4 Additional rules for forming of symbols

3.4.1 Symbols of physical quantities

3.4.1.1 Subscripts/indices

In most cases a subscript/index may be selected from the Tables 5 to 11. If other subscripts/indices (or superscripts) are used a clear definition of their meaning shall be given.

3.4.1.2 Precautions

In preventing confusion the following precautions shall be taken:

— where there is a possibility of confusing 1 (numeral) with *l* (letter symbol), the letter symbol *L* or *ℓ* shall be used in place of the letter symbol *l*;

— the Latin upper case letter symbol *O* shall not be used as a main letter symbol owing to the possibility of confusion with the numeral 0 (zero). The Latin lower case letter symbol *o* may, however, be used as a subscript/index with the same meaning as the numeral 0 (zero);

— the Greek lower case letter symbols iota (ι), omicron (o) and upsilon (υ) shall not be used owing to the possibility of confusing them with various Latin letter symbols. For the same reason, it is recommended to avoid, as far as possible, the use of the Greek lower case letter symbols kappa (κ) and chi (χ). If the Greek lower case letter symbols eta (η), mu (μ) and omega (ω) are used, care must be taken in writing these letter symbols to avoid confusion with the Latin lower case letter symbols *n*, *u* and *w*.

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3.4.2 Kernel-extending-subscripts/indices

In contrast with a descriptive subscript/index by applying a so-called ‘kernel-extending-subscript/index’ (k-e-index), the dimension of the (original) physical quantity will be changed (slightly). The order of both types of subscripts/indices is as follows (the graphical symbol ‘ | ‘ separates the descriptive indices from the kernel-extending-indices):

$K_{\text{k-e-index|descriptive indices}}$

or

$K_{\text{k-e-index|vi;v;iv;iii;ii;i}}$

A kernel-extending-subscript/index can be one of the types vi to i and if more than one k-e-index is necessary the order of these subscripts/indices shall conform to 3.2.2.6.

EXAMPLE By applying descriptive subscripts/indices the dimension of the original physical quantity X does not change, so $< X > = < X_{|\text{vi;... ;i}} >$. But in particular cases the dimension of $< X_{\text{index|}} >$ will be (slightly) altered, so $< X > \neq < X_{\text{vi; ... ;i|}} >$.

Compare the following physical quantities, viz. the original physical quantity X versus the particular physical quantity X_{index}:

‘force’ (X) versus ‘force per area’ (X_{index}) or ‘number’ (X) versus ‘number per year’ (X_{index}), etc.

In some cases, for the symbol of the particular physical quantity, this International Standard gives another, new kernel, e.g.:

symbol of the physical quantity ‘force’: F with $[F]$ = N versus the symbol of the physical quantity ‘force per area’:

p with $[p] = \text{N/m}^2$.

But in other cases the original kernel will only be changed/extended by a so-called ‘kernel-extending-subscript/index’, e.g.:

symbol of the physical quantity ‘number’: n with $[n] = 1$ versus the symbol of the physical quantity ‘number per year’: $n_{\text{a|}}$ with $[n_{\text{a|}}]$ = 1/year.

In this last example the subscript/index ‘a’ is mentioned a ‘kernel-extending-subscript/index’ or the compound symbol ‘n_{a}’ can be considered as a new kernel.

3.5 Tables

3.5.1 Format of the tables in this International Standard

3.5.1.1 Table 1 General use in the design of structures of types of alphabets

Table 1 in this International Standard is arranged so that it consists of three columns. The first column (from the left) gives the types of alphabets (in combination with upper case respectively lower case letter symbols), the second column gives dimensions and the third column gives common examples and recommendations of physical quantities having that dimension.

3.5.1.2 Tables 2 to 4 of physical quantities

The tables of physical quantities and units in this International Standard (Tables 2 to 4) are - in accordance with ISO 80000 arranged so that the physical quantities are presented in the first 5 columns

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and the units in columns 6 to 8. The quantities and corresponding symbols and units are in accordance with ISO 80000-3 and ISO 80000-4.

NOTE In the ISO 80000 series this layout is presented on two opposite pages.

All units between two full lines on the right-half belong to the physical quantities between the corresponding full lines on the left-half of the pages.

In each table the symbols of the physical quantities (so the rows of a table) are arranged in alphabetical order with respect tot the alphabet involved.

With respect to the numbering of the items, the first digit of the number corresponds with the number of the table.

3.5.1.3 Tables 5 to 10 of indices

The tables of indices in this International Standard (Tables 5 to 7, 9 and 10) are arranged so that every table consists of two columns: the left column gives the symbol (mostly one or more successive separate letter symbols) and the right column gives the meaning of the index involved.

Table 8 of this International Standard is arranged so that it consists of three columns: the first column (from the left) gives the upper case (of one or more successive) letter symbols, the second column gives the lower case letter symbols and the third column gives the meaning of the index involved.

The index symbols (so the rows of the table) in each of the five subdivisions of the columns (three Basic variables and two Performance functionals) of the table are arranged in alphabetical order.

3.5.1.4 Table 11 of mathematical signs and graphical symbols for use in the analysis and design of structures

The table of mathematical signs and graphical symbols in this International Standard (Table 11) is arranged so that the table consists of two columns: the left column gives the mathematical sign or graphical symbol and the right column gives a description of the sign/symbol with a short explanation.

3.5.2 Descriptive contents of the tables in this International Standard

3.5.2.1 Table 1 General use in the design of structures of types of alphabets

This table gives general guide-lines for the use of types of alphabets/scripts in combination with upper case and lower case letter symbols for forming symbols for physical quantities in general: common and new.

3.5.2.2 Tables 2 to 4 of physical quantities

The names (only in English) of the most important physical quantities in a general sense within the field of the design of structures are given together with their symbols and - in some cases - definitions. These names and symbols are recommendations. The definitions are given for identification of the physical quantities involved.

The scalar or vector character of the physical quantities is pointed out, especially, when this is needed for definitions.

In most cases one name but always one symbol for the physical quantity is given. If two or more names are given for one physical quantity and no special distinction is made, they are equivalent.

With respect to the system of units only the International System of Units (SI) is applied (see ISO 80000-1). (In some cases non-SI units are given, but this is explicitly mentioned in the column 'Remarks'.) Only the names (in English) and the international SI-symbols for the corresponding physical quantities are given and some remarks.

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3.5.2.3 Tables 5 to 10 of indices

The meanings (only in English) of the most important indices (mostly subscripts) are given together with their corresponding symbols. The meanings and symbols are recommendations. The meaning is the 'verbal designation of a general concept in a specific subject field' (see 3.4.3 in ISO 1087-1:2000), a definition of the concept is not given and is not necessary because (in most cases) it speaks for itself.

3.5.2.4 Table 11 of mathematical signs and graphical symbols for use in the analysis and design of structures

Most of the mathematical signs and symbols for use in the physical sciences and technology are given in ISO 80000-2. The mathematical signs and graphical symbols given in Table 11 are more or less specific for their use in the analysis and design of structures and they are a subset of or an additional set with respect to the set, given in ISO 80000-2.

3.5.3 Specific contents of the tables in this International Standard

Tables 1 to 11 inclusive.

Table 1 — General use in the design of structures of types of alphabets/scripts in combination with upper case and lower case letter symbols for forming symbols of physical quantities

Types of alphabets/scripts in combination with upper case and lower case letter symbols	Dimension	Main usages: examples of physical quantities (p.q.s)
Latin script upper case letter symbols	1 force	1 external and internal forces
	2 force times length	2 external and internal moments
	3 length to a power other than one	3 area, volume, section modulus, first and second (axial/polar) moments of area
	4 temperature	4 temperature
	'exceptions'	
	5 length	5 span
	6 force per area, force times area per length	6 p.q.s with respect to the elasticity of materials
	7 time	7 period, vibration time
Latin script lower case letter symbols	1 length	1 linear dimensions (length, distance, displacement, etc.)
	2 length per time to a power	2 velocity, acceleration
	3 force per length, force per area, force per volume	3 internal and external forces per length, per area or per volume, pressure, strength
	4 force times length per length	4 internal moments per length
	5 mass	5 mass
	6 force per mass	6 acceleration, e.g. due to gravity
	7 time	7 duration
	8 time to the power minus one	8 frequency
	9 certain dimensions	9 geometric parameters, coefficients (in general), other spring constants, statistical quantities
	'exceptions'	
	10 dimensionless	10 factor (in general), number
Greek script upper case letter symbols	-	reserved for mathematics and physics

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Table 1 *(continued)*

Types of alphabets/scripts in combination with upper case and lower case letter symbols	Dimension	Main usages: examples of physical quantities (p.q.s)
Greek script lower case letter symbols	1 dimensionless	1 (change of) angle, ratio, reliability index, (various) factors, strain, relative length coordinates, slenderness, relative (air) humidity
	‘exceptions’	
	2 certain dimensions	2 angular acceleration, linear expansion coefficient, weight and mass density; (change of) curvature, statistical quantities, stress, angular velocity, circular frequency

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Table 2 — Physical quantities - names - symbols, formed by one separate Latin upper case letter symbol in italic type [Roman type symbols represent specific collections of physical quantities (See Annex A)]

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
2.1.1	Accidental action	A			several dimensions		
2.1.2	Earthquake action	A_{eq},(Q_{eq})					
2.2	area	A	$A = \iint_A dx\, dy$ where x and y are cartesian coordinates	dA (= dx·dy): area of a surface element	square metre	m^2	
-	(vacant)	B					
2.3	(empirical) constant	C			name of [C]	[C]	
2.4	flexural rigidity per length	D			newton metre	N·m	
2.5	damage index/ratio of fatigue	D	$D = \Gamma\left(\frac{n_i}{N_i}\right)$ where n_i: number of applied load cycles with stress range level S_i N_i: number of load cycles at failure for stress range level S_i		one	1	
2.6	modulus of elasticity	E			pascal	Pa	1 Pa = 1 N/m^2
2.7	expectation	$E(X)$	$E(X) = \int x f(x)\, dx$	X: continuous stochastic variable	name of [E(X)]	[E(X)]	
2.8	(external) force in general	F			newton	N	
2.9.1	Action in general, Loadcase	F			several dimensions		
2.9.2	Permanent action	G					
2.9.3	Self-weight (action)	G_{sw}					
2.10	Geometry (of structure)	GE					
2.11	modulus of rigidity, shear modulus	G			pascal	Pa	
-	(vacant)	H					

[a] See note in 3.2.2.6, Performance functionals.

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Table 2 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
2.12	second or quadratic axial moment of area	I	$I = \iint_A r_Q^2 dA$	r_Q, see ISO 80000-4	metre to the power four	m^4	
-	(vacant)	J					
2.13	modulus of compression, bulk modulus	K			pascal	Pa	
2.14	(external) moment of a couple	K			newton metre	N·m	
2.15	length, span	L			metre	m	
2.16.1	(bending) moment in general	M,(M_m)			newton metre	N·m	
2.16.2	(internal) moment, due to actions	M_s					
2.16.3	(internal) moment, by resistance	M_r					
2.16.4	(internal) bending moment, due to actions	$M_{s;m}$					
2.16.5	(internal) bending moment, by resistance	$M_{r;m}$					
2.17	Material property in general	M			several dimensions		
2.18.1	normal force in general	N			newton	N	
2.18.2	normal force, due to actions	N_s					
2.18.3	normal force, by resistance	N_r					
-	(vacant)	O					
2.19	probability	P(A)	$0 \leq P(A) \leq 1$	A: event A	one	1	
2.20	prestressing force	P			newton	N	

[a] See note in 3.2.2.6, Performance functionals.

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Table 2 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
2.21.1	Variable action	Q			several dimensions		
2.21.2	Snow action	Q_{sn}					
2.21.3	Wind action	Q_w					
2.22	Resistance, Capacity	R					
2.23	Response [a], Sequel or Effect of action(s), Action-effect (or Sollicitation)	S					
2.24	linear (axial) moment of area (static moment)	S	$S = \iint_A r_Q \, dA$	r_Q, see ISO 80000-4	cubic metre	m^3	
2.25	period	T	duration of one cycle		second	s	
2.26	reference period	T_{ref}	chosen duration of a life-cycle of a structure		year	a	non-SI unit: a = $32 \cdot 10^6$ s
2.27	temperature	T			kelvin	K	
2.28.1	torsional/twisting moment in general	$T,(M_t)$			newton metre	N·m	
2.28.2	(internal) torsional or twisting moment, due to actions	$T,(M_{s;t})$					
2.28.3	(internal) torsional or twisting moment, by resistance	$T,(M_{r,t})$					
-	(vacant)	U					
2.29.1	shear force in general	V			newton	N	
2.29.2	shear force, due to actions	V_s					
2.29.3	shear force, by resistance	V_r					
2.30	volume	V	$V = \iiint_V dx \, dy \, dz$ where x, y and z are cartesian coordinates		cubic metre	m^3	
2.31	factor of variation	V			one	1	

[a] See note in 3.2.2.6, Performance functionals.

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Table 2 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
2.32	section modulus	W	$W = I / r$		cubic metre	m^3	
2.33	physical quantity in general	X	$X = \{X\} \cdot [X]$		name of $[X]$	$[X]$	
2.34	Basic variable or Performance functional in general	X			several dimensions		
-	(vacant)	Y					
-	(vacant)	Z					

[a] See note in 3.2.2.6, Performance functionals.

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Table 3 — Physical quantities - names - symbols, formed by one separate Latin lower case letter symbol in italic type

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
3.1	acceleration	a,($\boldsymbol{a}$)	$\boldsymbol{a} = \mathrm{d}v / \mathrm{d}t$		metre per square second	m/s^2	
3.2	distance	a			metre	m	
3.3	geometrical parameter	a			name of [a]	[a]	
3.4	breadth, width	b			metre	m	
-	(vacant)	c					
3.5.1	depth	d			metre	m	
3.5.2	diameter	d					
3.5.3	eccentricity	e					
3.6	force per volume	f	$f = \mathrm{d}F / \mathrm{d}V$		newton per cubic metre	N/m^3	
3.7	frequency	f	$f = 1 / T$		hertz	Hz	1 Hz = 1/s
3.8.1	strength	f			newton per square metre	N/m^2	
3.8.2	distributed permanent load	g		e.g. g_{sw} self-weight			
3.9	(local) acceleration of free fall [a]	g		standard acceleration of free fall: $g_n = 9{,}80665\ m/s^2$	metre per square second	m/s^2	
3.10	gravitational field strength	g_γ	$g_\gamma = G \cdot m / r^2$	G (gravitational constant) = 6,6742 (10)·10^{-11} $N \cdot m^2/kg^2$	newton per kilogram	N/kg	
3.11.1	height	h			metre	m	
3.11.2	thickness	h		see 3.26.2			
3.11.3	radius of gyration	i	$i = \sqrt{(l / A)}$				
3.12	number of days	j			one	1	
3.13	coefficient	k			name of [k]	[k] ≠ 1	
3.14	factor	k			one	1	
3.15	bedding spring coefficient	k			newton per cubic metre	N/m^3	

a Unfortunately in much literature the name of 'acceleration due to gravity' is used.

b Can be replaced by L or by ℓ to avoid confusion with the numeral 1.

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Table 3 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
3.16	length, span [b]	l		see text 3.4.1.2	metre	m	
3.17	mass	m			kilogram	kg	
3.18	internal moment per length (bending and torsional moment)	m		in plates and shells: m_{xx}, m_{xy}, m_{yy}	newton metre per metre	N·m/m	
3.19	(arithmetic) mean of a sample	m,(x)			name of [m]	[m]	
3.20	number	n			one	1	
3.21	internal force per length (normal and shear force)	n		in plates and shells: n_{xx}, n_{xy}, n_{yy}	newton per metre	N/m	
-	(vacant)	o					
3.22.1	force per area	p	$p = \mathrm{d}F / \mathrm{d}A$		newton per square metre = pascal	N/m^2	
3.22.2	pressure	p					
3.22.3	distributed variable load	q		e.g. q_w wind load			
3.23	force per length	q	$q = \mathrm{d}F / \mathrm{d}s$		newton per metre	N/m	
3.24	radius	r,($\boldsymbol{r}$)	$\boldsymbol{r} = (x,y,z)$		metre	m	
3.25	standard deviation of a sample	s			name of [s]	[s]	
3.26.1	spacing, length of path	s			metre	m	
3.26.2	thickness (of thin layers)	t		of plates and shells			
3.27	time	t			second	s	
3.28	duration	Δt			name of [t]	min, h, d, a (annum)	non-SI units: 1 min = 60 s 1 h = 3600 s 1 d = 86400 s
3.29.1	perimeter	u			metre	m	
3.29.2	(horizontal) displacement (of a point), sway	u,($\boldsymbol{u}$)	$\boldsymbol{u} = (u_x, u_y, u_z)$				
3.29.3	translation of a rigid body	u					
3.30	velocity	v,($\boldsymbol{v}$)	$\boldsymbol{v} = \mathrm{d}\boldsymbol{u} / \mathrm{d}t = \mathrm{d}\boldsymbol{w} / \mathrm{d}t$		metre per second	m/s	

[a] Unfortunately in much literature the name of ‘acceleration due to gravity’ is used.

[b] Can be replaced by L or by ℓ to avoid confusion with the numeral 1.

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Table 3 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Remarks**
3.31.1	(vertical) displacement (of a point), deflection	w,($\boldsymbol{w}$)	$\boldsymbol{w} = (w_x, w_y, w_z)$		metre	m	
3.31.2	length coordinates, cartesian coordinates	x, y, z					
3.31.3	lever arm	z,(y)					

a Unfortunately in much literature the name of 'acceleration due to gravity' is used.

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Table 4 — Physical quantities - names - symbols, formed by one separate Greek lower case letter symbol in italic type [Roman type symbols represent specific collections of physical quantities (See Annex A)]

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Definition**
4.1	angle (plane)	α	$\alpha = s/r$ where s: length of the included arc of a circle between two radii of the circle r: radius of circle		one or radian	1 or rad	1 rad = m/m = 1
4.2	angular acceleration	$\boldsymbol{\alpha}$	$\boldsymbol{\alpha} = \mathrm{d}\boldsymbol{\omega} / \mathrm{d}t$		radian per square second	rad / s^2	
4.3	linear expansion coefficient	α,(α_ℓ)	$\alpha = (1 / \ell)(\mathrm{d}\ell / \mathrm{d}T)$		kelvin to the power minus one	1 / K	
4.4.1	ratio	α			one	1	
4.4.2	FORM sensitivity factor, or Separation factor	α		FORM: First Order Reliability Method			
4.5	angle (plane)	β		see 4.1	one or radian	1 or rad	
4.6.1	ratio	β			one	1	
4.6.2	reliability index	β		see ISO 2394			
4.7	(shear)angle (plane)	γ		see 4.1 and 4.10.2	one or radian	1 or rad	
4.8	factor in reliability analysis, partial factor	γ		see ISO 2394	one	1	
4.9	weight per volume, weight density	γ	$\gamma = \rho \cdot g$		newton per cubic metre	N / m^3	
-	(vacant)	δ		see Table 11			
4.10.1	(linear) strain (relative elongation)	ε,(e)	$\varepsilon = \Delta l / l_0$ where Δl: increase in length (elongation) l_0: original length		one	1	

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Table 4 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Definition**
4.10.2	strain (normal and shear)	$\varepsilon,(\gamma)$		2-dimensional: $\varepsilon_{xx}, \varepsilon_{xy}, \varepsilon_{yy}$ or ε_x, ½γ_z, ε_y	one	1	
4.10.3	relative coordinate	ζ	$\zeta = (z / l)$				
4.10.4	ratio in general	ζ		e.g. damping ratio			
4.10.5	volumetric strain	η	$\eta = \Delta V / V_0$ where ΔV: increase in volume V_0: original volume				
4.10.6	relative coordinate	η	$\eta = (\gamma / l)$				
4.10.7	conversion factor	η		see EN 1990			
4.11.1	angle (plane)	θ		see 4.1	one radian	1 or rad	
4.11.2	change (in size) of angle (due to a torsional moment)	$\Delta\theta$					
4.12	uncertainty of model(ling)	θ (and θ)		see ISO 2394	one	1	
-	(vacant)	ι					
4.13.1	curvature	κ	$\kappa = 1/r$		metre to the power minus one	m^{-1}	
4.13.2	change of curvature	$\Delta\kappa$					
4.14.1	slenderness	λ	l_{buc} / i		one	1	
4.14.2	(correction) factor	μ					
4.14.3	(static) factor of friction	μ	$\mu = F_{//} / F_{\perp}$				
4.15	(arithmetic) mean of a population as a whole	μ			name of [μ]	[μ]	
4.16	(arithmetic) Mean of a population as a whole	µ			several dimensions		
4.17	Poisson’s ratio	$\nu,(\mu)$			one	1	

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Table 4 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Definition**
4.18	humidity per volume	υ			kilogram per cubic metre	kg/m^3	
4.19	relative coordinate	ξ	$\xi = (x / l)$		one	1	
-	(vacant)	o					
-	(vacant)	π		see Table 11			
4.20	(mass)density, mass per volume	ρ	$\rho = m / V$		kilogram per cubic metre	kg/m^3	
4.21	standard deviation of a population as a whole	σ			name of $[\sigma]$	$[\sigma]$	
4.22	standard deviation of a population as a whole	σ			several dimensions		
4.23.1	(normal) stress	σ	$\sigma = dF_{\perp} / dA$	2-dimensional: σ_{xx}, σ_{xy}, σ_{yy} or σ_x, τ_z, σ_y	pascal	Pa	1 Pa = 1 N/m^2
4.23.2	(shear) stress	τ,(σ)					
-	(vacant)	υ					
4.24.1	angle (plane)	φ		see 4.1	one or radian	1 or rad	
4.24.2	change (in size) of angle (due to a bending moment (and shear force))	$\Delta\varphi$					
4.25	angle of (internal) friction	φ			numeral degrees	...°	non-SI unit
4.26	rotation of a rigid body	φ			radian	rad	1 rad = m/m = 1
-	(vacant)	χ					

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Table 4 *(continued)*

Physical quantities					Units		
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**	**Name**	**SI-symbol**	**Definition**
4.27.1	combination factor of a variable action	ψ_0		see ISO 2394	one	1	
4.27.2	frequent factor of a variable action	ψ_1					
4.27.3	quasi-permanent factor of a variable action	ψ_2					
4.27.4	relative humidity	ψ	$\psi = v / v_{sat}$	actual humidity per volume (v) divided by humidity per volume at saturation (v_{sat}) at the same temperature			
4.28.1	angular frequency	ω	$\omega = 2\pi f$		radian per second	rad/s	
4.28.2	angular velocity	ω	$\omega = d\varphi / dt$				
4.29	buckling factor	ω			one	1	

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Table 5 — Index i) - indices related to probabilistic and partial factor methods of analysis and design and formed by one or more successive separate Latin lower case letter symbols in Roman type

Symbol	Meaning
-	current (or true) value of
d	design value of
d-inf	inferior/lower bound design value of
d-sup	superior/upper bound design value of
k	characteristic value of
k-inf	inferior/lower bound characteristic value of
k-sup	superior/upper bound characteristic value of
m	mean or average value of
nom	nominal value of
rep	representative value of

Table 6 — Index ii) - indices related to types of limit state and formed by one or more successive separate Latin lower case letter symbols in Roman type

Symbol	Meaning [a]
dur	durability (DuLS)
fat	fatigue (FaLS)
fi	fire (FiLS)
ser	serviceability (SLS)
u	ultimate / structural failure (ULS)

[a] The abbreviations, mentioned within brackets, are or can be used - like acronyms - in descriptive text. The abbreviation ‘LS’ means: Limit State

Table 7 — Index iii) - (all other) indices related to various aspects and formed by one or more successive separate Latin lower case letter symbols in Roman (and twice in italic) type

Symbol [a]	Meaning
indices of Roman type	
abs	absolute
add	additional
adm [b]	admissible
act	active
cal	calculated
comp	comparative
con	constant, invariable
dir	direct
ef, (eff)	effective
eqv	equivalent
est	estimated
exc	exceptional

[a] It is recommended when determining abbreviations that are not included in this table to start from the English term.

[b] The expression ‘admissible’ in the meaning of an admissible value of ... was often indicated by placing ‘-’ above the symbol, but the index ‘adm’ is recommended, e.g. σ_{adm}.

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Table 7 *(continued)*

Symbol [a]	Meaning
indices of Roman type	
exe	executional
exp	experimental, exposure
fix	fixed
fla	flame
fl	flange (of a beam)
fund	fundamental
g,(gua)	guaranteed, safeguarded
i,(init)	initial
inc	incidental
ind	indirect
lg	long
lgt	long term
ls	limit state
max	maximum, peak
mea	measured
min	minimum
n,(net)	net(to)
obs	observed
ori	original
pas	passive
pro	provisional
red	reduced
ref	reference
rel	relative
req	required
rsi	residual
sh	short
sht	short term, brief
sit	situation, site
suc	suction
sur	survival
tar	target (value of)
th,(theo)	theoretical
tot	total
var	variable
w, (web)	web (of a beam)
indices of italic type	
I, *j*	ordinal number, number of...

[a] It is recommended when determining abbreviations that are not included in this table to start from the English term.

[b] The expression ‘admissible’ in the meaning of an admissible value of ... was often indicated by placing ‘-’ above the symbol, but the index ‘adm’ is recommended, e.g. σ_{adm}.

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Table 8 — Index iv) - indices [a] related to the Basic variables and the Performance functionals and formed by one or more successive separate Latin lower (and upper) case letter symbols in Roman type

Symbol		Meaning
upper case	lower case	
indices related to the Basic variable F		
F	f	Action in general, Loadcase
indices related to the three types of Action in general		
A	a	Accidental
G	g	Permanent
Q	q	Variable
indices indicating the origin of Action in general		
	av	avalanche, snowslide
	ea	earth, ground/soil, (mud-current)
	sw	self-weight
	eq	earthquake, seismic activity
	ex	explosion
	fi	fire, deflagration
	hur	hurricane, tornado
	ice	ice, ice-ing
	im	impact, shock, collision, crash
	liq	liquid/fluid
	p,(pr)	pressure, pressurizing, in/deflation
	p,(pre)	pretensioning, prestressing
	rai	(heavy) rain(fall), tropical rains
	sn	snow(fall)
	t,(tem)	temperature (fluctuation, gradient)
	t,(traf)	traffic, truck
	wav	(tidal) waves, swell, tsunami
	w	wind, storm, gale, cycloon/typhoon
	wa	groundwater, water(current), stormtide (flood/surge)
indices related to the Basic variable GE		
GE	ge	Geometry of structure in general
indices related to the Basic variable M		
M	m,(mat)	Material property in general
indices related to aspects and kind of Material property		
	a,(abs)	absorptiveness
	age	ageing [b]
	b,(bon)	adhesiveness (bond)
	brit	brittleness
	c,(com)	compression [b]
	cli	climatic(ally), (deteriorative, erosive)

[a] A number of indices have been repeated for the sake of consistency within the five column subdivisions correponding with the three Basic variables and the two Performance functionals.

[b] Susceptible to

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Table 8 *(continued)*

Symbol		**Meaning**
	coh	cohesiveness
	cond	conductivity
	cons	consolidation [b] (of soil)
	cor	corrosiveness
	cr	creepiness
	dam	damping capacity
	det	deteriorativeness
	duc	ductility
	dur	durability
	dyn	dynamic(ally)
	el	elasticity
	env	environmentally, (deteriorative, erosive)
	f,(fail)	failure
	fat	fatigue [b]
	frac	fracture
	fric	friction [b]
	gr,ag	grain, aggregate
	grad	(temperature-)gradient [b]
	iner	inertness
	pl	plasticity
	r,(rlax)	relaxation [b]
	rpl	rigid-plastic(ally)
	rup	rupture
	sat	saturation [b]
	shr	shrinkage [b]
	st,(stat)	static(ally)
	t,(temp)	temperature-dependant
	t,(ten)	(ex)tension(ing) [b]
	t,(tim)	time-dependant
	t,(tor)	torsion, twist [b]
	tou	toughness
	v	shear(ing) [b]
	y,(yie)	yieldingness
indices related to the Performance functional S		
S	s	Response of structure, Sequel or Effect of action(s), Action-effect
indices related to elementary Response of structure		
	buc	buckling
	c,(com)	compression
	m	bending
	t,(ten)	(ex)tension

[a] A number of indices have been repeated for the sake of consistency within the five column subdivisions correponding with the three Basic variables and the two Performance functionals.

[b] Susceptible to

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Table 8 *(continued)*

Symbol		**Meaning**
	t,(tor)	torsion
	v	shear
	war	distortion (warping)
indices related to aspects of and intricate Response of structure		
	cons	consolidation
	cyc	cyclical
	dyn	dynamical
	ext	external
	extr	extreme
	flu	flutter
	geo	geotechnical
	int	internal
	r,(rlax)	relaxation
	sat	saturation
	sli	sliding
	st,(stat)	statical
	sup	support
	vib	vibration
indices related to the Performance functional R		
R	r	Resistance, Capacity of structure
indices related to Performance conditions (limit states→ index ii)		
	dur	durability
	fat	fatigue
	fi	fire
	ser	serviceability
	u	ultimate
indices related to aspects and kind of Resistance of structure		
	a,(abs)	absorptive
	b,(bon)	adhesive (bond)
	buc	buckling
	c,(col)	collapse
	c,(com)	compressive
	cr,(crit)	critical
	det	deteriorative
	dis	dissipative
	dst	destabilizing
	dyn	dynamical
	extr	extreme
	f,(fail)	failure
	frac	fractural

[a] A number of indices have been repeated for the sake of consistency within the five column subdivisions correponding with the three Basic variables and the two Performance functionals.

[b] Susceptible to

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Table 8 *(continued)*

Symbol		Meaning
	fric	frictional
	geo	geotechnical
	irr	irreversible
	m	bending
	pro	progressive
	res	resonance
	rev	reversible
	rup	rupture
	st,(stat)	statical
	stb	stabilizing
	t,(ten)	(ex)tensional
	t,(tor)	(dis)torsional, twisting
	v	shearing
	vib	vibrational
	y,(yie)	yielding

[a] A number of indices have been repeated for the sake of consistency within the five column subdivisions correponding with the three Basic variables and the two Performance functionals.

[b] Susceptible to

Table 9 — Index v) - indices related to place and (then) direction and formed by one or more successive or separate Latin upper and/or lower case letter symbols in Roman and in italic type, by one separate Greek lower case letter symbol in italic type, by mathematical signs and/or by Arabic numerals/digits

Symbol	Meaning
indices related to place	
one separate Latin lower case letter symbol in Roman type	
o	in the origin
one or more successive Latin upper and/or lower case letter symbols in Roman type in combination with coordinates, labels, digits, etc.	
B,(bea)	beam nr...........
C,(cou)	column nr.........
crs	cross-section nr.........
elt	element nr ....
flo	floor nr ....
fou	foundation: labels ....
J,(joi)	joint: coordinates, labels ....
K,(kno)	knot: coordinates, labels ....
mee	membrane nr ....
mer	member nr ....
pla	plate nr ....
P,(poi)	point: coordinates, labels ....
W,(wal)	wall nr ....
indices related to direction	
one Latin lower case letter symbol in Roman type	

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Table 9 *(continued)*

Symbol	**Meaning**
indices related to place	
one separate Latin lower case letter symbol in Roman type	
h	horizontal, level
l	longitudinal direction, lengthways, -wise
r,(rad)	radial direction
t	tangential direction(see also the index ‘tra’ below)
v	vertical direction
one separate Latin lower case letter symbol in italic type	
x, y, z	direction of a coordinate axis
successive Latin lower case letter symbols in Roman type	
lat	lateral
par	parallel (to)
per	perpendicular, normal, upright
tra	transverse direction
one separate Greek lower case letter symbol in italic type	
α, β, γ, θ, φ	angle
mathematical signs	
|| or //	parallel (to)
$\perp$	perpendicular, normal, upright
Arabic numerals or digits in combination with mathematical signs	
0, 1, 2, 3, … …°, …’, …”	Arabic numerals, digits 7°, 42’, 3” or: 7 degrees, 42 minutes, 3 seconds

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Table 10 — Index vi) - indices related to types of material and formed by one or more successive separate Latin lower case letter symbols in Roman type

Symbol [a]	Meaning
a	steel, structural (Acier constructive)
al	ALuminium
c	Concrete
ca	Concrete, Aerated / gas concrete
cl	Concrete, Lightweight
cla	CLAy
gl	GLass, structural
gr	(under)GRound, (sub)soil
ma	MAsonry
ps	Prestressing Steel
py	PolYmer
ro	ROck
s	Steel, reinforcing
sa	SAnd
te	TExtile, cloth, fabric
ti	TImber
wa	(ground)WAter

[a] The letter symbols are derived from the capital letter symbols of the terms in the column ‘Meaning’.

Table 11 — Mathematical signs and graphical symbols for use in the analysis and design of structures

Symbol, sign	Meaning
e	mathematical constant, base of natural logarithms (e = 2,718 281 8...)
Δx	operator, (finite) increment of x
Σ	operator, $\Sigma a_i = a_1 + a_2 + \ldots + a_n$, combination of
δf	operator, (infinitesimal) variation of the function f
π	mathematical constant, ratio of the circumference to the diameter of a circle, π = 3,141 592 6...
ϕ	graphical symbol, indication of diameter (for example of rivets, reinforcing bars, etc.)
⎅	graphical symbol, indication of dimension (of square tubes/ hollow sections)
‘ (prime)	mathematical sign, compression [a]
|| or //	mathematical sign, parallel (to)
⊥	mathematical sign, perpendicular, normal, upright
∧ (circumflex)	mathematical sign, $\hat{S}$: limit or ultimate value of S
∞	mathematical sign, infinity
0, 1, 2, 3, ...	Arabic numerals or digits
$\dot{f}$ (point above a symbol)	$\dot{f}$(= df /dx) derivative of the function f of one variable
; (semicolon)	punctuation mark (between subscripts)

[a] The use of a subscript such as c, t (ten) makes it possible to avoid the use of ‘ (prime).

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Annex A
(normative)

Definition and scope of generic quantities

A.1 Introduction

Besides physical quantities typical groups/collections of physical quantities have gained importance in theory and practice within the field of the design of structures. These groups/collections of physical quantities functionally represent the structure, its exposures/actions, its behaviour/materials, its responses and capabilities.

They qualitatively characterize, systematise and comprise what is simply meant by: the process, content and result of the analysis and design of structures.

They embrace the notions:

— a (technical) structure (geometry, materials) with its constraints/supports;

— under external and internal actions, loadcases and other exposures;

— its response in terms of external displacements, rotations and deflections and internal strains and stresses; and

— the requirements to be fulfilled (a.o. sufficient resistance/capacity).

The quintessence of this representation of the design of structures is pictured in Figure A.1.

The collections of physical quantities involved read from the scheme:

Three Fundamental or Basic variables:	F: Action, Loadcase
	GE:Geometry or GEometry of structure
	M: Material property
and two Performance functionals:	S: Response of structure
	R: Resistance of structure

Collections as designated by the symbols F, GE, M, S and R are called 'generic quantities'.

A.2 The concept of a 'generic quantity'

The concept of a 'generic quantity' is introduced and defined in this annex to distinguish between 'physical quantities' (as described/defined in this International Standard) and quantities/variables in a more generic (read: generative/representative) sense. With respect to the field of the design of structures generic quantities show up, among others, as 'Basic variables'

NOTE See ISO 2394 and EN 1990.

The concept of a 'generic quantity' is defined and represented by a set of specific physical quantities, such as actions, resistances, etc. Each set, i.e. generic quantity has a specific name and corresponding symbol. Physical quantities have a unique dimension expressed in units (of measurement). Generic quantities do

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not. However, the constituents of the latter (i.e. the specific physical quantities of the constituent set) each do have a dimension, in general not alike.

NOTE In both ISO 2394 and EN 1990 relations between generic quantities have been expressed in the form of functional ’expressions’/’equations’ (for instance: the generic quantity ‘Resistance’ (symbol: R) is expressed as fU_{RMGEF}(M,GE,F)). An other example are the so-called combination ’rules’ of Actions, like: *F* = A ‘+’ Q, etc.).

More examples of functional ’expressions’ and ’rules’ of generic quantities are given in A.5.

A.3 Further exemplification of the concept of a generic quantity

In Table A.1 the sets of specific physical quantities F, GE, M, S and R, which represent generic quantities, are delineated with respect to their scope and content and in view of their practical usage in verification ’equations’ of Response versus Resistance of structure and in combination ’rules’ of Actions for the determination of the critical Loadcases. See also A.5.

Table A.1 — Elaboration of sets of physical quantities representing generic quantities: Basic variables and Performance functionals

Name	Symbol	‘Content’ and scope
Basic variables		
(Force,) Action in General, Loadcase	F	F-set comprising a.o. • distributed, static and dynamic loads over the volume and/or (part of) the bounding surface • external, static and dynamic loads, forces and moments (e.g. shock, impact, concentrated actions) • constraints; viz. imposed: - strains - displacements - rotations (due to e.g. thermal expansion, temperature gradients, creep/relaxation, shrinkage and from (local or strong gradient) settlements of (pile)foundations, subsoil, supports) • exposure to fire (fire scenarios) (e.g. heat flux and pressures, temperature gradients, fire storms)
three types of Action in general:		
1. Accidental action	A	
2. Permanent action	G	
3. Variable action	Q	
Geometry of structure in general	GE	GE-set comprising a.o. • dimensions of - structures: schematisations and models (line-, plane/surface-shaped and volumetric/solid members) - structural members (e.g. length, width, height, thickness, angle, slope, skewness, radius, (cross-sectional) shape and area, volume, linear and quadratic axial moments of area) • dimensional imperfections (e.g. tolerances, eccentricities, damages)

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Table A.1 *(continued)*

Name	Symbol	'Content' and scope
Basic variables		
Material property in general	M	M-set comprising, a.o • linear behaviour (e.g. static and dynamic, elastic moduli) • non-linear/irreversible behaviour (e.g. rigid-plastic moduli, yield/flow rules, moment-curvature law, flow, and failure surfaces: strengthening and softening) • ductile versus brittle failure behaviour (e.g. toughness, sudden rupture) • time-dependant behaviour (e.g. vibrational damping, creep and relaxation, shrinkage, saturation, consolidation of soil, soil-pile adhesion, fatigue: accumulated periodical microstructural damage) • temperature-dependant behaviour (e.g. thermal expansion and conductivity, high-temperature deterioration) • durability and chemical inertness (e.g. corrosion, ageing, environmental and climate agents sensitivity)
Performance functionals		
Response of structure, Sequel or Effect of action(s), Action-effect (or Sollicitation)	S	S-set comprising a.o. • external Response of structure: displacements and rotations of overall structure, parts thereof and its supports and foundation (footings, piles) deformations and deflections of structural members and subsoil (e.g. tension/compression, bending, shear, torsion and buckling; sliding of soil layers, subsoil settlement) dynamic and cyclic movements(/vibrations) of members and overall structure, c.q. parts thereof (e.g. velocities, accelerations, frequencies, number of cycles, resonance, flutter) • internal Response of structure: deformations and strains, normal and shear forces, bending and torsional moments and stresses in members and parts thereof and in subsoil/underground
Resistance or Capacity of structure	R	R-set comprising a.o. • strength: structural (e.g. tensile/compressive, bending, shear, torsional; adhesion(bond), frictional) fatigue high temperature • rigidity: static (e.g. deflections, sway, displacements, rotations, strain) dynamic (e.g. movements, velocities, accelerations, critical damping) geotechnic (e.g. of foundation (piles, footings) and subsoil) • stability: static, first and second order dynamic (e.g. natural frequencies, eigen modes) geotechnic (e.g. of slopes and taluds) • absorption capacity of energy, elastic and/or non-elastic/dissipative (e.g. shock, impact, earthquake/seismism, explosion, fatigue, plastic hinges) heat (fire exposure) • structural and non-structural capabilities: structural integrity: redundancy, robustness (preventing the progress of local damage and/or failure → progressive collapse) non-structural provisions (e.g.temperature barriers (insulation), fire walls, damping devices)

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A.4 Names and symbols for generic quantities

A.4.1 General method (KIM) for forming and writing of names and symbols

The same remarks for the forming and writing of new and unique (names and) symbols for physical quantities (see 3.2.) are valid for generic quantities: the kernel of a (compound) symbol can be chosen from Table A.2 and indices (mostly subscripts) forming that unique (compound) symbol can be chosen from Tables 5 to 10.

Table A.2 — Generic quantities, to be used in verification equations and combination rules - names - symbols, formed by one or two Latin upper case letter symbols in Roman type

Generic quantities			
Item. No.	**Name**	**Symbol**	**Remarks**
Basic variables			
A.2.1	(Force,) Action in general, Loadcase three types of Action in general:	F	
	A 2.1.1 Accidental action	A	
	A.2.1.2 Permanent action	G	
	A.2.1.3 Variable action	Q	
A.2.2	Geometry of structure in general	GE	
A.2.3	Material property in general	M	
Performance functionals			
A.2.4	Response of structure, Sequel or Effect of action(s), Action-effect (or Sollicitation)	S	
A.2.5	Resistance or Capacity of structure	R	

A.4.2 Method and Rules for forming and writing names and symbols of generic quantities

A.4.2.1 Names

In general the name of a generic quantity is one term or a combination of several terms (often the term ‘action’ is used);

The terms are written in Latin lower case letter symbols in Roman (upright) type, with exception of the first (or the first two) letter symbol(s), written as an upper case letter symbol;

For the design of structures the names (and symbols) of the most commonly used generic quantities are given in Table A.1 and Table 8.

EXAMPLES 1 One termAction, Resistance, etc.

EXAMPLES 2 Combination of terms Snow action, Material property in general, etc.

A.4.2.2 Symbols

The kernel of a symbol of a generic quantity is a one-(or two-)letter symbol in upper case of the Latin alphabet, written in Roman (upright) (see Table A.1).

NOTE in probalistic analysis of structures Greek lower case lettersymbols in Roman type are also used (see Table 4).

The kernel can be modified by applying one or more subscripts/indices.

Subscripts/indices are formed from letter symbols, digits and graphical symbols: they are written in Roman (upright) type. If the kernel of a physical quantity, is used as a subscript/index it is written in italic type. Several kinds of subscripts/indices are given in the Tables 5 to 10.

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A subscript/index is placed at the bottom right position of the kernel. By applying more than one subscript/index they should preferably be separated by a semi-colon (;). In the case of simple and clear, distinctive index symbols also a space or comma (,) is allowed. For simply two or three of these index symbols no separation at all is appropriate.

By applying more than one subscript/index the order of the subscripts/indices is given in 3.2.2.6.

EXAMPLES

F	Action in general
F_k	Characteristic (values of) F
Q	Variable action
Q_{hur}	Variable action(s) due to hurricane(s)
S	Response of structure
S_d	Design (values of) S
A_{ex}	Accidental action due to explosion
G_{ea}	Permanent action due to earth, ground/soil (movement)
$Q_{sn,d}$	Design (values of) variable action(s) due to snow(fall)
GE_{nom}	Nominal (values of) geometry (configuration and measurement properties) of structure
$R_{ser,k}$	Characteristic (values of) serviceability resistance or capacity of structure

A.4.3 Kernel-extending-subscripts/indices for generic quantities

The commonly used (kernels of) generic quantities are given in Table A.1. Kernels can also be chosen/formed in correspondence with the ‘ indices related to the Basic variable F ‘, given in Table 8 (some examples of that type of generic quantities are already contained in A.4.2.2. Most often they are used in combination rules of Actions).

A.5 Functional formulation of combination rules of Actions and of verification equations of Response versus Resistance of the structure with the help of generic quantities

A.5.1 Combination rules of Actions

A.5.1.1 Combination rules

The Design (values of) actions F_d acting on a structure generally comprise:

G_d: Design (value of) permanent actions,

Q_d: Design (value of) variable actions,

A_d: Design (value of) accidental actions.

Concepts/rules for forming representative combinations of these Actions, acting on a structure, generally may be expressed in the form of functionals (symbol: fU) of G_d, Q_d and A_d:

$F_{jd} = fU_{FGQA}\,|_j(G_d, Q_d, A_d),\ j \geq 1,$

or by first order approximation (FOAM[1]):

1) First Order Actions Modelling

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$F_{jd} = (G_d + Q_d + A_d)_j$, with $j \geq 1$.

The index j refers to a series of combinations of Permanent (G_d), Variable (Q_d) and Accidental (A_d) actions. The Actions of each combination j (j equals 1, or 2, or …) simultaneously act on the structure as a whole and/or on parts thereof.

For the three Actions generally distinguished: G_d, Q_d and A_d, the rules further read:

G_d: G_{id}, summed over $i \geq 1$,

where, for example, $G_{4d} = G_{pre,d}$, the Design (values of) pretensioning/prestressing forces acting on the structure,

Q_d: $Q_{1d} + \psi_{0|i}\, Q_{id}$, or

$\psi_{0|1}Q_{1d} + \psi_{0|i}\, Q_{id}$, summed over $i > 1$,

or in combination with A_d (or A_{eq}):

$(\psi_{1|1} + \psi_{2|1})Q_{1d} + \psi_{2|i}\, Q_{id}$, summed over $i > 1$, or

$\psi_{2|i}\, Q_{id}$, summed over $i \geq 1$,

A_d: A_{id}, or in case of earthquake actions:

$A_{eq,id}$, summed over $i \geq 1$.

The functional expression $F_d = G_d + Q_d + A_d$, for each j, represents as many genuine arithmetic equations as the number of separate dimensions (of physical quantities) comprised in the right-hand side of the expression, i.e. $G_d + Q_d + A_d$.

Within an analysis and design with the help of partial factors, G_{id}, Q_{id} and A_{id} generally are composed of (See ISO 2394 and EN 1990):

$G_{id} = \gamma_{G,i}\, G_{i,rep}$,

$Q_{id} = \gamma_{Q,i}\, Q_{i,rep}$,

$A_{id} = \gamma_{A,i}\, A_{i,rep}$, no summation over i,

where γ_i are the respective partial factors for G_i , Q_i and A_i .The principal representatives of $G_{i,rep}$, $Q_{i,rep}$ and $A_{i,rep}$ generally are G_{ik} , Q_{ik} and A_{ik} .

The model(ling) uncertaincies inherent with G_i , Q_i and A_i are taken into account in γ_i , or in the Actions G_i , Q_i and A_i themselves

Herewith the representations of G_d, Q_d and A_d read

$G_d = \gamma_{G,i}\, G_{ik}$, summed over $i \geq 1$,

$Q_d = \psi_{0|i}\, \gamma_{Q,i}\, Q_{ik}$, or

$= (\psi_{1|i} + \psi_{2|i})\, \gamma_{Q,i}\, Q_{ik}$, summed over $i \geq 1$,

$A_d = \gamma_{A,i}\, A_{ik}$, summed over $i \geq 1$.

Within a probability-based analysis and design G_{id}, Q_{id} and A_{id} are composed of:

$G_{id} = \mu_{G,i} + \alpha_{G,i}\, \beta_G\, \sigma_{G,i}$,

$Q_{id} = \mu_{Q,i} + \alpha_{Q,i}\, \beta_Q\, \sigma_{Q,i}$,

$A_{id} = \mu_{A,i} + \alpha_{A,i}\, \beta_A\, \sigma_{A,i}$, no summation over i.

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Where in the Actions G_j, Q_j and A_j the model(ling) uncertaincies of these Actions, i.e. θ_G, θ_Q and θ_A are to be taken into account. Again substituting these expressions in the representations of G_d, Q_d and A_d results in:

$G_d = \mu_{G,i} + \alpha_{G,i}\,\beta_G\,\sigma_{G,i}$, summed over $i \geq 1$,

$Q_d = \psi_{0|i}\,(\mu_{Q,i} + \alpha_{Q,i}\beta_{\,Q}\,\sigma_{Q,i})$, or

$= (\psi_{1|i}.+ \psi_{2|i})(\mu_{Q,i} + \alpha_{Q,i}\,\beta_Q\,\sigma_{Q,i})$, summed over $i \geq 1$,

$A_d = \mu_{A,i} + \alpha_{A,i}\,\beta_A\,\sigma_{A,i}$, summed over $i \geq 1$.

For further information consult with the formulae in Figure A.2 and those following.

A.5.1.2 Probability of complete sum of Actions

In general, for more than two Q,s (viz. Q_1 and Q_2 in Figure A.2) and including G and A, the Sum of Actions comprised in $G_d + Q_d + A_d$ reads:

$$\text{Sum} = \sum_{i=1}^{n_G} G_i + \sum_{i=1}^{n_Q} \left\{\psi_{0|i} \text{ or } \left(\psi_{1|i} + \psi_{2|i}\right)\right\} \cdot Q_i + \sum_{i=1}^{n_A} A_i \quad \text{with } n_G + n_Q + n_A = n,$$

$$= \sum_{i=1}^{n_G} \sigma_{G,i}\left(G_i / \sigma_{G,i}\right) + \sum_{i=1}^{n_Q} \left\{\psi_{0|i} \text{ or } \left(\psi_{1|i} + \psi_{2|i}\right)\right\} \cdot \sigma_{Q,i}\left(Q_i / \sigma_{Q,i}\right) + \sum_{i=1}^{n_A} \sigma_{A,i}\left(A_i / \sigma_{A,i}\right)$$

This functional Sum represents as many arithmetic Sums as the number of separate dimensions (of physical quantities) comprised in the functional. The G_i, Q_i and A_i of each of these separate arithmetic Sums all have the same dimension. Each such a separate, true arithmetic equation: Sum = constant, i.e. a linear equation in the n dimensionless 'coordinates':

$G_i/\sigma_{G,i}$ ($i = 1$ to n_G), $Q_i/\sigma_{Q,i}$ ($i = 1$ to n_Q) and $A_i/\sigma_{A,i}$ ($i = 1$ to n_A),

depicts parallel planes (for $n > 2$) in the n-dimensional (Euclidean) space described on the n 'coordinates'. The normal vector to these planes is the gradient vector, the components of which are derived by partial differentiation with respect to the 'coordinates' of the equation:

Sum = constant, viz.

$\sigma_{G,i}$ ($i = 1$ to n_G), $\psi_{0|i}\,\sigma_{Q,i}$ or $(\psi_{1|i} + \psi_{2|i})\sigma_{Q,i}$ ($i = 1$ to n_Q) and $\sigma_{A,i}$ ($i = 1$ to n_A)

The magnitude or 'length' of the gradient vector is equal to:

$$\ell_{\text{grad}} = \left[\sum_{i=1}^{n_G}\left(\tilde{A}_{G,i}\right)^2 + \sum_{i=1}^{n_Q}\left[\left\{\psi_{0|i} \text{ or } \left(\psi_{1|i} + \psi_{2|i}\right)\right\} \cdot \tilde{A}_{Q,i}\right]^2 + \sum_{i=1}^{n_A}\left(\tilde{A}_{A,i}\right)^2\right]^{\frac{1}{2}}$$

The components of the unit normal vector to the parallel planes, i.e. the components of the gradient vector divided by ℓ_{grad}, are called the direction-cosines of the normal.

Within the probability-based analysis and design of structures these direction-cosines define the (FORM) sensitivity factors α. Hence,

$\alpha_{G,i} = (\ell_{\text{grad}})^{-1}\,\sigma_{G,i}$, $i = 1$ to n_G,

$\alpha_{Q,i} = (\ell_{\text{grad}})^{-1}\{\psi_{0|i}\,\sigma_{Q,i}$ or $(\psi_{1|I} + \psi_{2|i})\sigma_{Q,i}\}$, $i = 1$ to n_Q, and

$\alpha_{A,i} = (\ell_{\text{grad}})^{-1}\,\sigma_{A,i}$, $i = 1$ to n_A.

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Consequently,

$$\sum_{i=1}^{n_G}(\alpha_{G,i})^2+\sum_{i=1}^{n_Q}(\alpha_{Q,i})^2+\sum_{i=1}^{n_A}(\alpha_{A,i})^2=1$$

A.5.2 Verification equations of Response versus Resistance of the structure

A.5.2.1 General rule

The reliability conditions of structures for limit states, a.o.

ULS: Ultimate Limite State, and

SLS: Serviceability Limit State,

in terms of functional (symbol: *fU*) conditions generally read:

$fU_{SR}(S_{j,d}, R_{j,d}) = fU_{SRFGEM\,|j}(F_d, GE_d, M_d) \le 0, j \ge 1$,

or by first order approximation (FORM[2]):

$S_{j,d} - R_{j,d} \le 0$, with $j \ge 1$, and

$S_{j,d} = fU_{SFGEM\,|j}(F_d, GE_d, M_d)$,

$R_{j,d} = fU_{RMGEF\,|j}(M_d, GE_d, F_d)$.

The index *j* refers to several reliability verifications of S versus R, a.o. verification of a number of limit states, verification of the criteria: strength, rigidity, etc., for the structure as a whole and parts thereof, e.g. members, substructures, supports, etc.

The functional relations $S_{j,d} - R_{j,d} \le 0$ represent, for each *j*, as many genuine arithmetic equations as the number of separate dimensions (of physical quantities) comprised in the left-hand side of the relations, i.e. $S_{j,d} - R_{j,d}$. Moreover, the separate dimensions comprised in S_{jd}, respectively, in R_{jd} should be one-to-one identical, again for each *j*.

In case of $S_{j,d} - R_{j,d} \le 0$ and with respect to a partial factor-based analysis and design the $S_{j,d}$ and $R_{j,d}$ generally are composed of:

$S_{j,d} = \gamma_{S,j}\, S_{j,k}$,

$R_{j,d} = (\gamma_{R,j})^{-1}\, R_{j,k}$, no summation over *j*.

The $S_{j,k}$ and $R_{j,k}$ are the functionals $fU_{SFGEM\,|j}$ and $fU_{RMGEF\,|j}$ of, respectively, F_d(i.e. G_d, Q_d, A_d and θ_F), GE_d(i.e. GE_d, θ_{GE}) and M_d(i.e. M_d, θ_M). These functionals represent the calculated and/or measured Response(s), respectively, Resistence(s) of structure as a result of the Actions, Geometry of structure and Material properties, including their model(ling) uncertainties. The latter θ_F, θ_{GE} and θ_M sometimes may be or are incorporated in the partial factors $\gamma_{S,j}$ and $\gamma_{R,j}$ themselves too.

Within a probability-based approach $S_{j,d}$ and $R_{j,d}$ are composed of (See Figure A.3):

$S_{j,d} = \mu_{S,j} + \alpha_{S,j}\, \beta_j\, \sigma_{S,j}$, and

$R_{j,d} = \mu_{R,j} + \alpha_{R,j}\, \beta_j\, \sigma_{R,j}$, no summation over *j*, with:

$\alpha_{S,j} = (\ell_{grad\,|j})^{-1}\, \sigma_{S,j}$, and

$\alpha_{R,j} = -\,(\ell_{grad\,|j})^{-1}\, \sigma_{R,j}$., with

$\ell_{grad\,|j} = \{(\sigma_{S,j})^2 + (\sigma_{R,j})^2\}^{1/2}$

2) First Order Reliability Modelling

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In the Response(s) S_j and Resistance(s) R_j the model(ling) uncertainties of Response(s) and Resistance(s), i.e. θ_S and θ_R, are to be taken into account.

For further information consult with the formulae in Figure A.3 and those following.

A.5.2.2 Reliability index β

In general the reliability of structures in terms of the probability of underlying, respectively, the probability of exceeding a certain limit state ranges in the order of magnitude of one hundredth to one 10 millionth, i.e. 10^{-2} to 10^{-7}. Adopting the cumulative standardized normal probability distribution ϕ, the probability P_{ls} is:

$$P_{ls} = \Phi(-\beta) = \int_{-\infty}^{-\beta} \left(2\pi \cdot e^{x^2}\right)^{-1/2} dx = 1 - \int_{-\infty}^{+\beta} \left(2\pi \cdot e^{x^2}\right)^{-1/2} dx = 1 - \Phi(\beta)$$

The reliability index β equals for $P_{ls} = 10^{-2}$ to 10^{-7}:

P_{ls}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	2,32	3,09	3,72	4,27	4,75	5,20

With the help of the formulae in Figure A.3 the sensitivity factors α_S and α_R can be calculated:

$\alpha_S = \cos(\arctan \sigma_R(\sigma_S)^{-1})$

$\alpha_R = -\sin(\arctan \sigma_R(\sigma_S)^{-1})$, hence $(\alpha_S)^2 + (\alpha_R)^2 = 1$.

For a few values of σ_R/σ_S, the angle φ_2 and the sensitivity factors α_S and α_R are equal to:

σ_R/σ_S	φ_2	α_S	$-\alpha_R$
0,5	26,6°	0,894	0,447
0,8	38,7°	0,781	0,625
1,0	45,0°	0,707	0,707
1,25	51,3°	0,625	0,781
2,0	63,4°	0,447	0,894

A.5.2.3 Series of verifications ($J > 1$)

A.5.2.3.1 Verification

With the expressions for $S_{j,d}$ and $R_{j,d}$ resulting from a partial factor- or a probability-based analysis and design, the required verifications of the reliability of the structure, viz. as a whole and parts/members thereof, can be carried out.

For instance:

$j = 1$:	SLS, i.e.	$S_{ser,d} \leq R_{ser,d}$
$j = 2$:	FaLS, i.e.	$S_{fat,d} \leq R_{fat,d}$
$j = 3$:	ULS, i.e.	$S_{ud} \leq R_{ud}$
etc.		
$j = 7$:	Foundation 5, i.e.	$S_{cla,fou5,z,ser,d} \leq R_{cla,fou5,z,ser,d}$
etc.		$S_{cla,fou5,z,ud} \leq R_{cla,fou5,z,ud}$

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A.5.2.3.2 Symbol < = > name of a generic (or physical) quantity vice versa

EXAMPLE

Given the symbol, the names of these generic quantities may be phrased easily, e.g.

Symbol: $S_{cla,fou5,z,ud}$, or $S_{cla;fou5;z;u;d}$,

Name: Design (values of) ultimate Response(s) of ‘Clay foundation 5’ in direction z.

And vice versa, with the proper names of these generic (or physical) quantities, their symbols may be reproduced immediately.

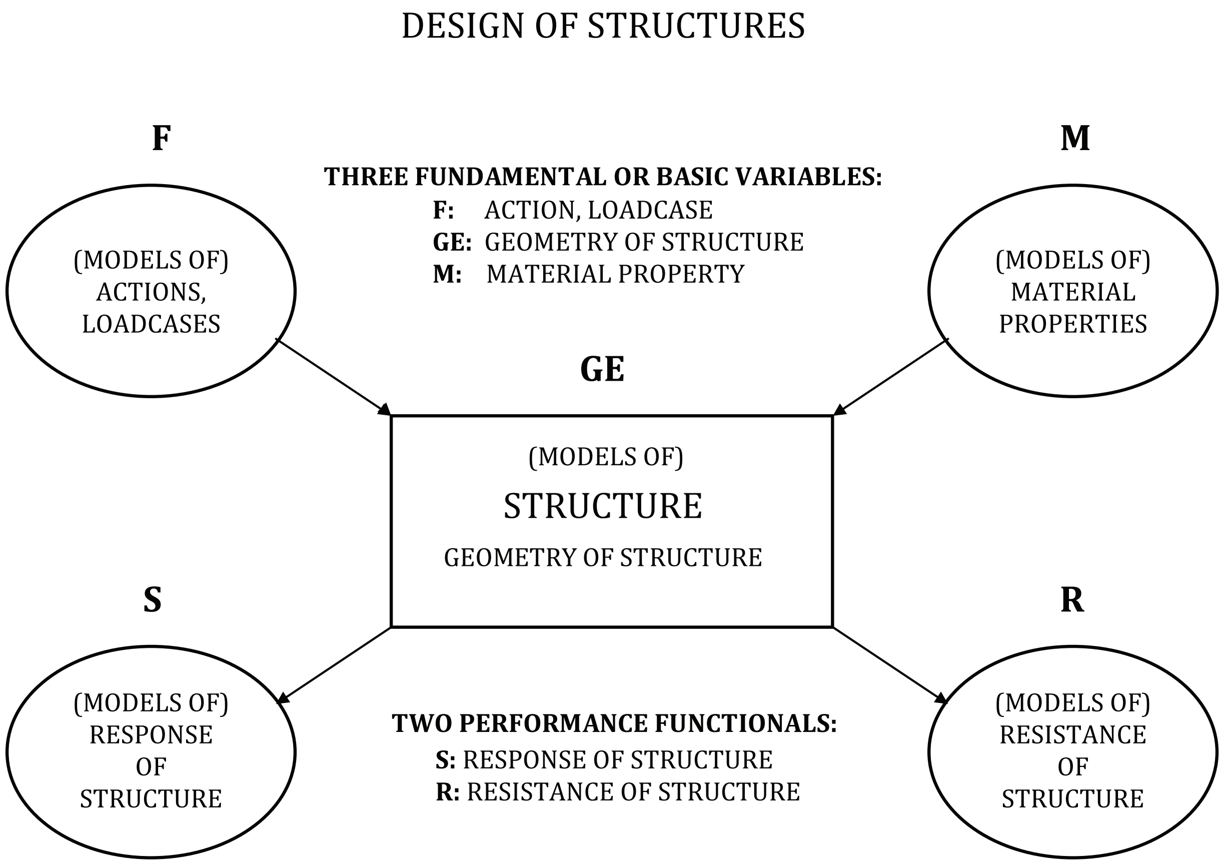

Figure A.1 — Design of structures in a nutshell

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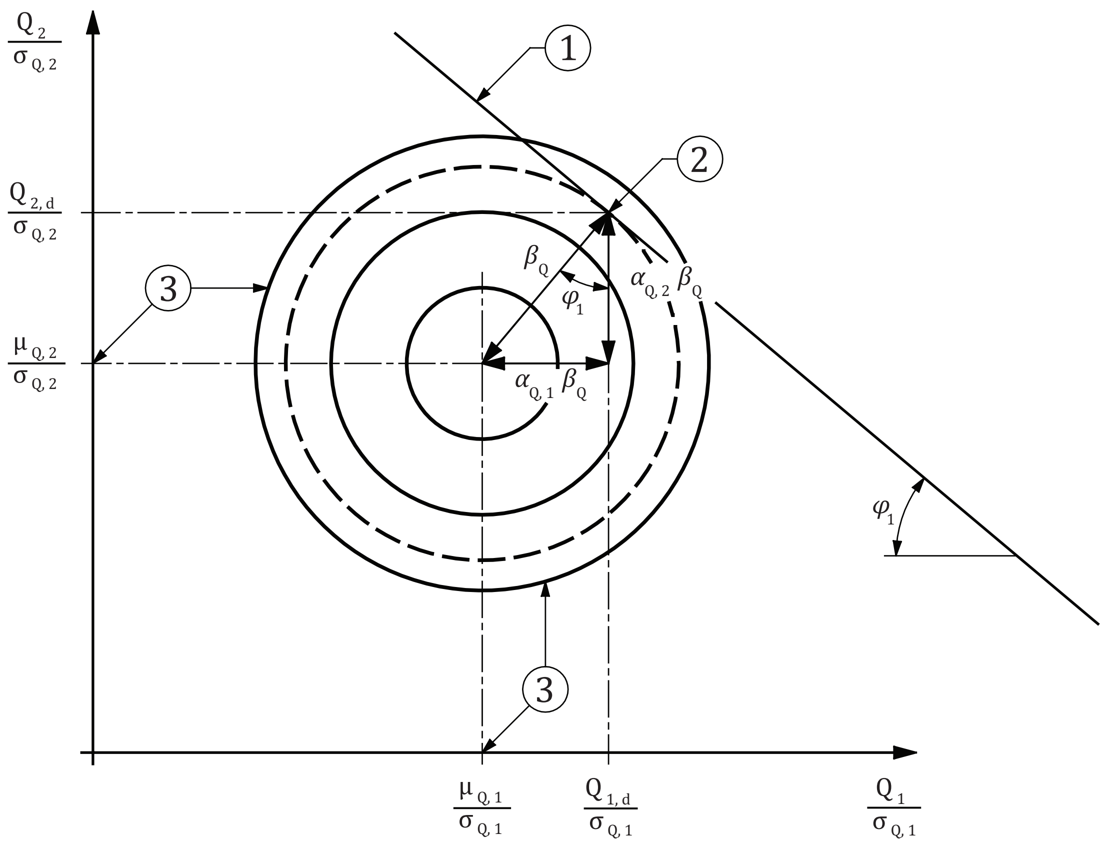

Key

1 graphical representation of Sum

2 design point

3 standardized normal probability distributions

Figure A.2 — Combination rules of actions

With respect to the Figure above the following holds:

Sum = $\psi_{0|1}\, Q_1 + \psi_{0|2}\, Q_2$, or

= $(\psi_{1|1}+\psi_{2|1})\, Q_1 + (\psi_{1|2}+\psi_{2|2})\, Q_2$

$\tan \varphi_1 = \psi_{0|1}\sigma_{Q,1}\, (\psi_{0|2}\sigma_{Q,2})^{-1}$, or

= $(\psi_{1|1}+\psi_{2|1})\, \sigma_{Q,1}\, \{(\psi_{1|2}+\psi_{2|2})\, \sigma_{Q,2}\}^{-1}$, and

$\tan \varphi_1 = \alpha_{Q,1}\, (\alpha_{Q,2})^{-1}$, with $(\alpha_{Q,1})^2 + (\alpha_{Q,2})^2 = 1$.

In addition: $\beta_Q > 0$ and $0 < \varphi_1 < 90$ °.

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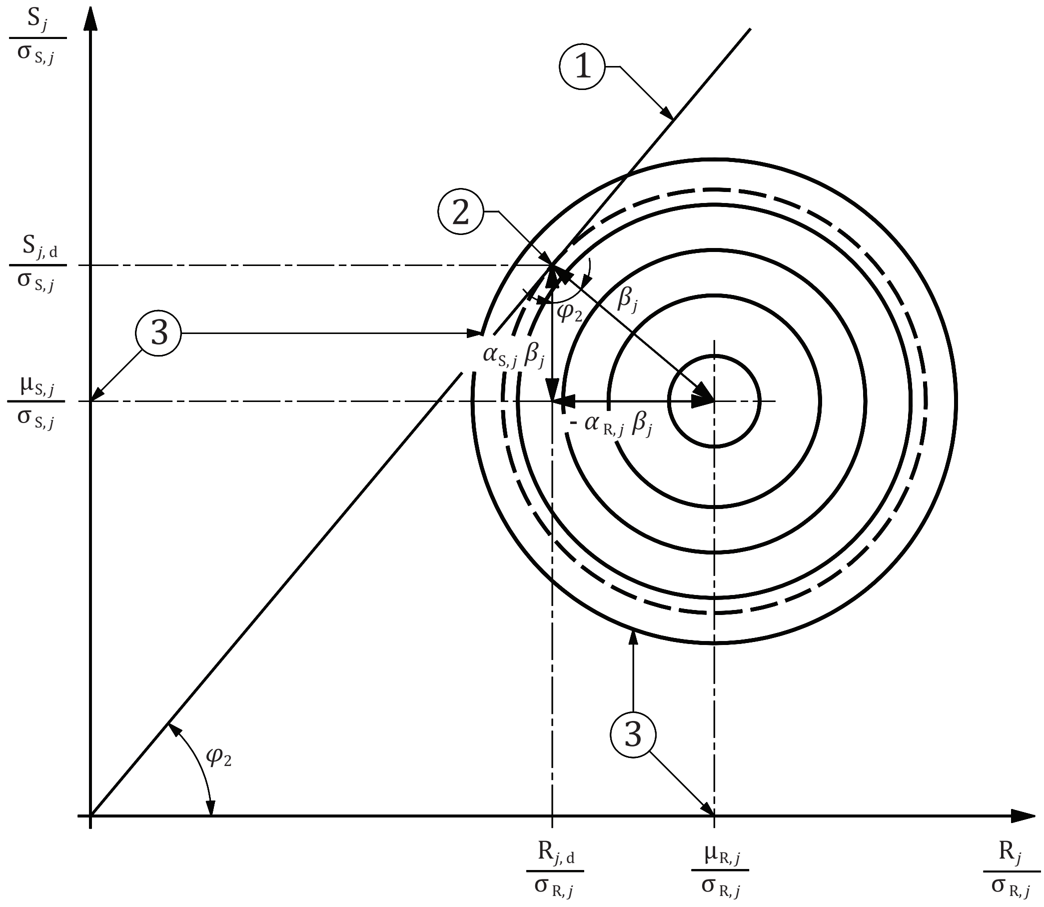

Key

1 graphical representation of Sum

2 design point

3 standardized normal probability distributions

Figure A.3 — Verification equations S_j versus R_j

With respect to the Figure above the following holds:

Sum = $S_j - R_j = 0$, with $j \geq 1$,

$\tan \varphi_2 = \sigma_{R,j} (\sigma_{S,j})^{-1}$, and

$\tan \varphi_2 = -\alpha_{R,j} (\alpha_{S,j})^{-1}$, with $(\alpha_{R,j})^2 + (\alpha_{S,j})^2 = 1$.

In addition: $\beta_j > 0$ and $0 < \varphi_2 < 90$ °.

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