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Bases for design of structures — General requirements

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 2, *Reliability of structures*.

This second edition cancels and replaces the first edition (ISO 22111:2007), which has been technically revised. The main change compared to the previous edition is as follows:

— the document has been made consistent with the latest edition of ISO 2394 (ISO 2394:2015).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document incorporates the general principles of structural design as set out in ISO 2394. The general requirements relevant to the design of structures given here are expressed according to the semi-probabilistic approach as presented in ISO 2394. The general requirements are based on the premise that sufficient information is available on all aspects that are needed to set target levels of reliability and for uncertainty representation to be categorized and standardized, to ensure realization of such reliability through a semi-probabilistic approach. Procedures for deriving semi-probabilistic requirements and design methods from risk and reliability approaches are provided in ISO 2394.

The general requirements for actions on structures and the material independent resistance of the structures provided in this document are expressed on the basis of related standards for all actions and structural materials relevant to the scope of application.

The main duties for standards organisations in adopting this document are:

— to set target levels of reliability;

— to provide a suitable format and a set of quantitative design parameters;

— to establish the relevant standards from which input values for actions and resistance are to be obtained.

International Standards on actions are referenced here in lieu of standards within the jurisdiction of the adopting group.

As this document is an International Standard, its scope represents general consensus for standardized procedures for the semi-probabilistic design verification requirements of structural reliability. Thus, this document is intended to promote harmonization of structural design practice. Additional requirements and procedures need to be added to provide for specific types of structures, conditions or design practice.

This document has the following aims:

— to facilitate international practice in structural design by expressing the general requirements for the basis for the design of structures;

— to obtain international standardization of the process for setting up rules for structural design, while allowing each economy to specify its own levels of structural performance, in accordance with its own needs;

— to provide a means of promoting commonality, interchangeability, consistency and comparability of structural standards developed by different economies, such that regulators, standards writers, designers and academics could then adopt such standards with confidence in their international acceptance;

— to encourage regulatory authorities in each country to describe their mandatory requirements in an internationally agreed format;

— to facilitate future coordination between the various specialist subcommittees and working groups for ISO structural standards;

— to create transparency in the process of comparison of national standards for structural design.

Annex A to Annex D provide additional guidance on the adoption of this document and its adaptation to suit the conditions and requirements of the relevant standardization organisation.

Bases for design of structures — General requirements

1 Scope

This document provides the requirements for structural design and procedures following a semi-probabilistic approach that conform to the general principles for structural reliability as stipulated by ISO 2394. The scope of requirements and procedures are accordingly limited to the design of structures for which sufficient knowledge and experience are commonly available on design and construction practice to ensure that target levels of reliability account for the nature and consequences of structural failure. Situations outside these limitations are covered by ISO 2394.

The methods that are included in this document are the semi-probabilistic limit states approaches that are proven to achieve sufficient and consistent levels of structural reliability.

This document relies on standardized procedures for the characterization of the load bearing performance of the structures within its scope. Sufficient information is needed on uncertainties of design variables and models to be able to derive semi-probabilistic design measures for verification of structural reliability within the scope of this and the related design standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13823, *General principles on the design of structures for durability*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 General terms

3.1.1
structure
organized combination of connected parts including geotechnical structures designed to provide *resistance* (3.3.14) and rigidity against various *actions* (3.3.1)

[SOURCE: ISO 2394:2015, 2.1.1]

3.1.2
structural performance
qualitative or quantitative representation of the behaviour of a *structure* (3.1.1) (e.g. load bearing capacity, stiffness, etc.) related to its safety and *serviceability* (3.1.6), durability and *robustness* (3.1.7)

3.1.3
reliability
ability of a *structure* (3.1.1) or structural member to fulfil the specified requirements, during the service life, for which it has been designed

Note 1 to entry: Reliability is often expressed in terms of probability.

Note 2 to entry: Reliability covers safety, serviceability, and durability of a structure.

[SOURCE: ISO 2394:2015, 2.1.8]

3.1.4
reliability index
β
substitute for the *failure* (3.2.7) probability p_f by $\beta = -\Phi^{-1}(p_f)$ where Φ^{-1} is the inverse standardized normal distribution

[SOURCE: ISO 2394:2015, 2.2.22]

3.1.5
structural safety
ability (of a *structure* (3.1.1) or structural member) to avoid exceedance of *ultimate limit states* (3.2.14), including the effects of specified accidental phenomena, with a specified level of *reliability* (3.1.3), during a specified period of time

[SOURCE: ISO 2394:2015, 2.1.9]

3.1.6
serviceability
ability of a *structure* (3.1.1) or structural member to perform adequately for normal use under all expected *actions* (3.3.1)

[SOURCE: ISO 2394:2015, 2.1.32]

3.1.7
robustness
damage insensitivity or ability of a *structure* (3.1.1) to withstand adverse and unforeseen events (like fire, explosion, impact) or consequences of human errors without being damaged to an extent disproportionate to the original cause

[SOURCE: ISO 2394:2015, 2.1.46, modified — "ability of a structure…" is modified to "damage insensitivity or ability of a structure …".]

3.2 Terms related to design and assessment

3.2.1
design situations
sets of physical conditions representing a certain time interval for which it shall be demonstrated that relevant *limit states* (3.2.12) are not exceeded

[SOURCE: ISO 2394:2015, 2.2.1]

3.2.2
persistent design situation
normal condition of use for the *structure* (3.1.1)

[SOURCE: ISO 2394:2015, 2.2.2]

3.2.3
transient design situation
provisional condition of use or exposure for the *structure* (3.1.1), for example, during its construction or repair, representing a time period much shorter than the *design service life* (3.2.10)

[SOURCE: ISO 2394:2015, 2.2.3, modified — "... design working life..." is modified to "... design service life ...".]

3.2.4
accidental design situation
design situation (3.2.1) involving possible exceptional conditions for the *structure* (3.1.1) in use or exposure, including flooding, fire, explosion, impact, mal-operation of systems, or local *failure* (3.2.7)

[SOURCE: ISO 2394:2015, 2.2.4]

3.2.5
seismic design situation
design situation (3.2.1) involving the exceptional conditions when the *structure* (3.1.1) is subject to seismic event

[SOURCE: ISO 2394:2015, 2.2.5]

3.2.6
basic variable
variable representing physical quantities which characterize *actions* (3.3.1) and environmental influences, material and soil properties, and geometrical quantities

[SOURCE: ISO 2394:2015, 2.2.15]

3.2.7
failure
loss of load-bearing capacity or inadequate *serviceability* (3.1.6) of a *structure* (3.1.1) or structural member, or rupture or excessive deformation of the ground, in which the strengths of soil or rock are significant in providing *resistance* (3.3.14)

[SOURCE: ISO 2394:2015, 2.2.6, modified — "insufficient load-bearing capacity..." is modified to "loss of load-bearing capacity...".]

3.2.8
consequence class
categorization of the consequences of structural *failure* (3.2.7) used to distinguish between *structures* (3.1.1), components, and *limit states* (3.2.12)

[SOURCE: ISO 2394:2015, 2.1.34, modified — the phrase "used to distinguish between structures, components, and limit states" is newly added.]

3.2.9
reliability class
specific *target reliability* (3.2.16) against *failure* (3.2.7), based upon *consequence classes* (3.2.8) for *structures* (3.1.1), structural members and *limit states* (3.2.12)

3.2.10
design service life
assumed period for which a *structure* (3.1.1) or a structural member is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

[SOURCE: ISO 2394:2015, 2.2.16]

3.2.11
reference period
period of time used as a basis for assessing the design value of variable and/or *accidental actions* (3.3.5)

[SOURCE: ISO 2394:2015, 2.2.31]

3.2.12
limit state
state beyond which a *structure* (3.1.1) no longer satisfies the design criteria

[SOURCE: ISO 2394:2015, 2.2.7]

3.2.13
serviceability limit state
limit state (3.2.12) concerning the criteria governing the functionalities related to normal use

[SOURCE: ISO 2394:2015, 2.2.10]

3.2.14
ultimate limit state
limit state (3.2.12) concerning the maximum load-bearing capacity

[SOURCE: ISO 2394:2015, 2.2.8]

3.2.15
irreversible limit states
limit states (3.2.12) which will remain permanently exceeded when the *actions* (3.3.1) which caused the exceedance are no longer present

Note 1 to entry: Conversely, reversible limit states are defined as limit states which will not be exceeded when the actions which caused the exceedance are no longer present.

[SOURCE: ISO 2394:2015, 2.2.11, modified — a note to entry has been added.]

3.2.16
target reliability
target reliability index
reliability (3.1.3) (index) corresponding to acceptable safety or *serviceability* (3.1.6) for a given *reference period* (3.2.11), which can coincide with the *design service life* (3.2.10)

[SOURCE: ISO 2394:2015, 2.2.23, modified — "for a given reference period, which can coincide with the design service life" is newly added.]

3.2.17
semi-probabilistic method
verification method in which allowances made for the uncertainties and variability are assigned to the *basic variables* (3.2.6) by means of representative values, partial factors and, if relevant, additive quantities

Note 1 to entry: Factors may be related to individual random variables or global variables and may be stated as unitary or partial factors; representative values may be related to service life, the nature of the limit state or action, or to the target reliability.

3.3 Terms related to actions and resistances

3.3.1
action
assembly of concentrated or distributed forces acting on a *structure* (3.1.1) (direct actions), displacements or thermal effects imposed to the structure, or constrained in it; or environmental influences that can cause changes with time in the material properties or in the dimensions of a structure

[SOURCE: ISO 2394:2015, 2.3.1, modified — "… that may cause change …" is modified to "… that can cause change …".]

3.3.2
effect of action
action effect
result of *actions* (3.3.1) on a structural member (e.g. internal force, moment, stress, strain) or on the whole *structure* (3.1.1) (e.g. deflection, rotation)

[SOURCE: ISO 2394:2015, 2.3.12]

3.3.3
permanent action
action (3.3.1) which is likely to act continuously throughout the *design service life* (3.2.10) and for which variations in magnitude with time are small compared with the mean value

[SOURCE: ISO 2394:2015, 2.3.3, modified — "… design working life…" is modified to "… design service life …".]

3.3.4
variable action
action (3.3.1) which is likely to act during a given *design service life* (3.2.10) and for which the variation in magnitude with time is neither negligible nor monotonic

[SOURCE: ISO 2394:2015, 2.3.4, modified — "… design working life…" is modified to "… design service life …".]

3.3.5
accidental action
action (3.3.1) which is unlikely to occur with a significant value during the *design service life* (3.2.10) of the *structure* (3.1.1)

[SOURCE: ISO 2394:2015, 2.3.5, modified — "… design working life…" is modified to "… design service life …".]

3.3.6
individual action
single action
action (3.3.1) which can be assumed to be independent in time and space of any other actions on the *structure* (3.1.1)

[SOURCE: ISO 2394:2015, 2.3.2]

3.3.7
frequent value
value of *action* (3.3.1) determined in such a way that either the total time, within a chosen period, during which it is exceeded is only a given small part of the chosen period of time or the frequency of its exceedance is limited to a given value

Note 1 to entry: This "frequent value" may be expressed as the characteristic value reduced by a factor Ψ_1.

[SOURCE: ISO 2394:2015, 2.3.23, modified — "value determined in such a way..." is modified to "value of action determined in such a way ...".]

3.3.8
load case
compatible load arrangement, set of deformations, and imperfections considered for a particular verification of the specific *limit state* (3.2.12)

[SOURCE: ISO 2394:2015, 2.3.25]

3.3.9
characteristic value
value of a *basic variable* (3.2.6) specified preferably on statistical bases, so it can be considered to have a prescribed probability of not being exceeded

Note 1 to entry: For variable actions, the characteristic value corresponds to either of the following:

— an upper value with an intended probability of not being exceeded or a lower value with an intended probability of being achieved, during some specific reference period;

— a nominal value, which may be specified in cases where a statistical distribution is not known.

[SOURCE: ISO 2394:2015, 2.2.30]

3.3.10
representative value
characteristic value (3.3.9), nominal value, *combination value* (3.3.13), *frequent value* (3.3.7), or *quasi-permanent value* (3.3.11) of an *action* (3.3.1)

[SOURCE: ISO 2394:2015, 2.3.20, modified — the definition has been reworded so that it can replace the term in context.]

3.3.11
quasi-permanent value
value of *action* (3.3.1) determined in such a way that the total time, within a chosen period, during which it is exceeded is of the magnitude half the period

Note 1 to entry: This "quasi-permanent value" may be expressed as the characteristic value reduced by a factor Ψ_2.

[SOURCE: ISO 2394:2015, 2.3.24, modified — "value determined in such a way..." is modified to "value of action determined in such a way ...".]

3.3.12
load combination
design value of the different *actions* (3.3.1) considered simultaneously in the verification of the *reliability* (3.1.3) of a *structure* (3.1.1) for a specific *limit state* (3.2.12)

[SOURCE: ISO 2394:2015, 2.3.26]

3.3.13
combination value
value of *action* (3.3.1) determined in such a way that the probability of action effect caused by several combination values being exceeded is approximately the same as the probability of the design value being exceeded by a *single action* (3.3.6)

Note 1 to entry: The "combination value" may be expressed as the characteristic value reduced by a factor Ψ_0.

[SOURCE: ISO 2394:2015, 2.3.21, modified — "value determined in such a way..." is modified to "value of action determined in such a way ...".]

3.3.14
resistance
ability of *structure* (3.1.1) (or a part of it) to withstand *actions* (3.3.1) without *failure* (3.2.7)

[SOURCE: ISO 2394:2015, 2.1.27]

3.3.15
characteristic value of a material property
priori specified fractile of the statistical distribution of the material property in the relevant supply

4 Symbols and abbreviated terms

4.1 General

The following symbols are used in this document. All symbols are based on ISO 2394, whilst ISO 3898 defines standard notations for structural design.

4.2 Latin characters

A	accidental action
a	geometrical quantity
$\mathbf{a}_d$	vector containing the design values of the geometry
C_d	design value of the permissible serviceability constraint
E	function determining the effect of actions
E_d	design value of the effect of actions
$E_\mathrm{d,dst}$	design value of destabilizing actions
$E_\mathrm{d,stb}$	design value of stabilizing actions
f_k	characteristic value of material property
G	permanent action
$G_\mathrm{k,i}$	characteristic value of the i-th permanent action G_i,
$G_\mathrm{d,i}$	design value of i-th permanent action as factored characteristic value
$G_\mathrm{r,i}$	design value of the i-th permanent action corresponding to annual probability of exceedance of 1/r
Q	variable action
$Q_\mathrm{k,j}$	characteristic values of leading variable action Q_j
$Q_\mathrm{k,i}$ $(i{\neq}j)$	characteristic values of the i-th accompanying variable action, Q_i $(i{\neq}j)$
$Q_\mathrm{d,j}$	design value of variable actions as factored characteristic values
$Q_\mathrm{r,i}$	i-th variable action with $\mathrm{r_i}$-year return period value, which corresponds to the value with $1/\mathrm{r_i}$ annual probability of exceedance
R	resistance

R_d design value of the resistance

R_k characteristic value of the resistance

R_n specified resistance

X_k basic variable at characteristic value (action, material property, geometric dimension)

V coefficient of variability of basic variable

4.3 Greek characters

α_i standardized sensitivity factor for actions (E) or resistance (R)

β reliability index

β_n reliability index for reference period of n year

γ partial factor

γ_{ci} load factors for accompanying variable load

$\gamma_{G,i}$ partial (or load) factor for permanent action G_i,

γ_j load factors for leading variable load

$\gamma_{Q,j}$ partial factor for variable action Q_j; the value for $\gamma_{Q,j}$ is dependent on whether the variable action is leading or accompanying

γ_m partial factors for material properties [used in the partial factor (γ_m) method (for example, EN 1990)]

γ_M generalized partial factors for resistance properties taking account of material, model, and geometric uncertainties

γ_S partial factor for model uncertainties of action effects

γ_R partial factor for model uncertainties of resistance (partial factor for resistance)

μ mean value (of basic variable)

σ standard deviation (of basic variable)

σ_E, σ_R standard deviation of action effects and resistance, respectively

$\Phi(.)$ cumulative normal distribution function

ϕ resistance (capacity) factor (used for example, in the LRFD format)

Ψ_0 factor for determining combination values of actions

Ψ_1 factor for determining frequent values of actions

Ψ_2 factor for determining quasi-permanent values of actions

4.4 Subscripts

d design value

E action effect

i number denoting basic variable (accompanying action)

j number denoting basic variable (leading action)

k characteristic value

n reference period (y) for specifying target reliability

R resistance

5 Fundamental requirements for structural performance

5.1 General

A structure shall, with appropriate degree of risk and reliability, fulfil the following performance requirements:

— function adequately under all expected actions throughout its service life, providing service and functionality;

— provide reliable safety against extreme and/or frequently repeated and permanent actions, as well as environmental exposures occurring during its construction, anticipated use, and decommissioning;

— provide assurance that degradation of resistance over the service life does not reduce the reliability for safety or functionality below the acceptable targets;

— provide reliability with respect to damage and its consequences;

— provide sufficient robustness so as not to suffer severe damage or cascading failure by extraordinary and possibly unforeseen events like natural hazards, accidents, or human errors.

Target performance levels shall be based on the risk-based approach. The appropriate degree of reliability shall be judged with due regard to the possible consequences of failure, the associated expense, and the level of efforts and procedures necessary to reduce the risk of failure and damage. When the consequences of failure and damage are well understood and within normal ranges, reliability-based assessment can be applied to derive target reliabilities.

Design shall account for performance throughout the life cycle of the structure. The assessment of other phases in the life of the structure shall be based on directly related information, such as considering construction, operation, inspection, maintenance, decommissioning, life cycle management and the assessment of existing structures (see ISO 13822).

For the semi-probabilistic approach, uncertainties shall be categorized and standardized, to be represented through design values and characteristic values together with specified design equations, load cases, and action combination factors. The characteristic values shall, when relevant, account for available information relating, for example, to loads and material properties.

The validity of all assumptions underlying decisions concerning structures, e.g. the relevance of and the uncertainty associated with available knowledge and information, the intended use, the service life, as well as the environmental and operational loads, should be controlled, ensured and documented. Alternatively, it should be ensured that the performance of the structures is still adequate despite possible violations of or deviations from assumptions. Quality management plays a central role for the performance of structures and shall be completely integrated in the decision-making processes related to design and assessment of structures.

The expression of the principles of reliability for structures in standardized requirements is given below. Procedures based on the requirements are provided in subsequent clauses.

5.2 Design situations

The reliability requirement shall be verified for all relevant design situations related to the structural design. The design situations shall be sufficiently severe and varied so as to encompass all conditions that can reasonably be foreseen to occur during the construction and use of the structure. This typically refers to loading conditions subject to normal operation, extreme environmental loads, and accidental loads during the different phases of the life of the structure.

Safety shall be provided through adequate resistance to common actions and accidental events, and through robustness against unforeseeable events and/or events not considered. Design procedures are different for these three classes. Failure after an extended time due to degradation of resistance, or lack of durability, is a safety consideration.

Serviceability shall be provided by designing to limit response of the structure to common actions.

Specific design situations, or combinations of various actions that affect the structure, shall be considered as specified in subsequent clauses.

5.3 Limit states

Evaluation of the performance of a structure in design shall be accomplished by comparing the response of the structure to various combinations of actions to limit states where the response changes from acceptable to unacceptable.

Ultimate limit states account for structural safety. It shall account for modes of failure that involve a loss of resistance through fracture, crushing, buckling, or yielding of a member or connection within a structure, loss of equilibrium of the structure or part of it considered as a rigid body, instability of the structure or part of it, and sudden change of the assumed structural system to a new system. Some modes of failure for ultimate limit states are defined in terms of collapse of the entire structure, or a substantial part of it. The exceedance of an ultimate limit state shall be considered as irreversible and the first time that this occurs causes failure. The ultimate limit state resulting from a single extreme action event or from a deterioration process over time followed by a (less) extreme action event shall be considered.

Serviceability limit states account for loss of intended functionality related to normal use. The following undesirable serviceability limit states (non-exhaustive) shall be accounted for: unacceptable deformations which affect the efficient use or appearance of structural or non-structural elements or the functioning of equipment, excessive vibrations which cause discomfort to people or affect non-structural elements or the functioning of equipment, local damage affecting the appearance, the efficacy, or functional reliability of the structure, and local damage (including cracking) which can reduce the durability of the structure or make the structure unsafe for use. In the cases of permanent local damage or permanent unacceptable deformations, the exceedance of a serviceability limit state shall be considered as irreversible and the first time that this occurs causes failure. Reversible limit states shall be considered as failure at the first time of exceedance, when the duration of exceedance or number of occurrences is unacceptable, or combinations of these criteria.

NOTE In practice, many serviceability requirements are a matter of agreement between owner and designer. For example, a structure in which the use of an electron microscope is planned will have more stringent vibration limits than a structure not housing such sensitive equipment.

5.4 Considerations for actions, environmental influences and action combinations

All physical conditions likely to affect the performance of the structure shall be considered. Actions can be of natural or human origin. Models shall describe the temporal, spatial and directional properties of the action across the structure. Environmental influences that can cause changes with time in material properties or structural dimensions should be treated similarly.

Actions shall be classified in a manner that reflects the main characteristics related to structural reliability. Representative values of actions shall be specified at characteristic or equivalent levels as basis for design. Reliability design elements in the form of partial and combination factors shall be specified as basis for determining design values for actions.

5.5 Considerations for resistance

The probability characteristics of resistance shall take basis in all available knowledge, and the uncertainty representation shall include all relevant causal and stochastic dependencies, as well as temporal and spatial variability. Account shall be taken of whether resistance is related to individual failure modes or systems, whether the situation can be regarded as being time-invariant.

Properties of materials should be defined for some relevant volume of material and should be represented by their characteristic values X_k. For a produced material, the characteristic value should in principle be presented as an a priori specified quantile of the statistical distribution of the material property being supplied, produced within the scope of the relevant material standard. For soils, the values should be estimated according to the same principle and so that they are representative of the actual volume of soil or the actual part of the structure to be considered in the design.

For the purpose of providing the required durability of resistance, design may include the protection, specification of inspection, detection, and maintenance procedures to achieve the target reliability.

5.6 Considerations for design verification

Semi-probabilistic design shall comprise a safety format prescribing the design equations. The safety format shall cover the combinations of actions as well as the scheme for calculating design values for actions and action effects, material properties, resistance and other parameters associated with uncertainty of relevance for the design.

Structural analysis shall describe the behaviour of structural systems up to the limit state under consideration. Models should generally be regarded as simplifications which take into account decisive factors and neglect the less important ones. The geometry of a structure shall be adequately described. In general, use can be made of standard elements like one-dimensional elements (beams, columns, cables, arches, etc.), two-dimensional elements (slabs, walls, plates, etc.), and three-dimensional elements (e.g. shells, layered half spaces). The geometrical quantities which are included in the model generally refer to nominal values, i.e. the values given in drawings, and descriptions. Uncertainties in models for structural analysis shall be accounted for. When design is based on testing, the test shall be performed in such a way that the structure, as designed, has at least the same reliability with respect to all relevant limit states and load conditions as structures designed on the basis of calculation models only.

Accidental actions shall be quantified where there is sufficient knowledge and experience. Some accidental and unforeseeable actions cannot be quantified, yet it is an objective that the structural failure caused by a local failure not to be out of proportion to the initiating event. Therefore, it is required that structures possess a resistance to cascading failure. A suite of methods are used to achieve this objective, depending on the nature of the structure, and include:

— minimum force levels for gross lateral force resistance and internal load paths and connections between structural elements;

— specific local resistance to protect or strengthen vulnerable structural elements, such as the placement of protective devices around columns susceptible to vehicle impact;

— demonstration, usually through design analysis, that a structure will survive the removal of a structural element, such as a column;

— designs to resist specific threats, such as impact of a specific vessel, or explosion of a specific size at a specific distance.

NOTE Alternative formats for design verification that are consistent with the semi-probabilistic approach are the partial factor design format, load and resistance factor design (LRFD) format and direct specification of design values in terms of annual probability of exceedance. The equivalence of these formats is presented in Annex B.

6 Classification for establishing reliability

6.1 Safety consideration

Structures, components and limit states shall be assigned to classes based upon the consequence of failure of the structure to perform, considering the safety of people and the safety of the structure.

For safety of buildings (habitable structures), the consequence classification shall account for the number of people at risk of loss of life, directly or indirectly, from failure of the structure, as well as the likely resilience of the population affected by the building.

For safety of bridges, the consequence classification shall account for the functional capacity and the number of people at risk of loss of life, directly or indirectly, from failure of the structure, as well as the available redundancy in the transportation network concerning failure of the bridge.

For safety of other structures, the consequence classification shall account for the number of people at risk of loss of life, directly or indirectly, from failure of the structure, and for structures that are linked in some type of functional network, the available redundancy in the network.

Ultimate limit states shall be assigned to consequence classes based upon the nature of the particular failure.

The likelihood of death or injury for occupants given a failure varies depending on the nature of the structure and the limit state, and such variation should be considered in establishing consequence classifications.

NOTE 1 Indirect threats include, for instance, the loss of function of a hospital in a natural disaster, or loss containment of toxic materials.

NOTE 2 "Other structures" is a broad category that can include items that are not part of any lifeline, such as signs for advertising, and structures that are integral parts of a lifeline, such as power generation or distribution facilities, communication facilities, and so on. For some such structures, performance that can otherwise be considered a problem of functionality becomes a hazard to life, for example a vessel storing hazardous materials.

NOTE 3 Annex C contains examples of such classification.

NOTE 4 A common scheme for ultimate limit state classification accounts for a distinction between limit states that involve warning, such as yield of a ductile element, and those that do not, such as member buckling or fracture, and a distinction between limit states that are likely to cascade beyond the original failure, such as loss of a column or a transfer girder, and those that are not, such as flexural failure of a slab or a beam.

6.2 Serviceability consideration

Structures and serviceability limit states shall be classified for purposes of checking serviceability.

NOTE Common classes based upon the structure involve the economic loss upon failure of serviceability. Common classes based upon the limit state involve separating reversible from irreversible conditions. The classes for safety and serviceability are frequently not correlated.

6.3 Reliability classes

The performance objective of this document shall be established by assigning target reliabilities to classes defined by the safety and serviceability considerations established in this clause. The reliability classes shall be based upon the consequence classes established according to 6.1 and 6.2. The implementation of those target reliabilities in the semi-probabilistic method shall be accomplished by establishing appropriate factors on actions, combinations, and resistances for each limit state under each design situation.

NOTE For some actions, the target reliability can be incorporated in the definition of the characteristic value (see Annex C).

7 Principles of limit states design

7.1 General

For the semi-probabilistic format, structures shall be designed so that the probability that each member exceeds a limit state is lower than a pre-determined target value. Such a target reliability value is determined for a chosen reference period and determined considering the magnitude of the consequence (see Clause 6) of the limit state exceedance.

7.2 Verification of ultimate limit states

In the verification of ultimate limit states, resistance and static equilibrium are to be considered. The strength (load-bearing capacity for the ultimate) limit state shall be verified using Formula (1):

$$E_d \leq R_d \tag{1}$$

where

E_d is the design value of the effect of actions (for further information, see Clauses 8 and 9);

R_d is the design value of the corresponding resistance (for further information, see Clause 10).

NOTE Stability, for instance buckling, of members and portions of structures is considered as a strength limit state.

The ultimate limit state for static equilibrium shall be verified using Formula (2):

$$E_{d,dst} \leq E_{d,stb} \tag{2}$$

where

$E_{d,dst}$ is the design value of destabilizing actions;

$E_{d,stb}$ is the design value of stabilizing actions.

The expression may be supplemented by additional terms when appropriate (for example in case of stabilizing anchor and friction).

7.3 Verification of serviceability limit states

A limit state of serviceability shall be verified using Formula (3):

$$E_d \leq C_d \tag{3}$$

where

E_d is the design value of the effect of actions;

C_d is the design value of the corresponding permissible serviceability constraint.

NOTE The serviceability constraint includes static deflection, vibration, etc.

8 Actions

8.1 General

Actions are generally classified into permanent actions, variable actions, and accidental actions; static and dynamic actions; fixed or free, direct and indirect actions. Actions caused by water may be considered as permanent and/or variable, depending on the variation of their magnitude with time. Classification of seismic actions as variable or accidental should be based on the frequency of occurrence of seismic events.

8.2 Permanent actions

Actions shall be classified as permanent actions (G) if the variations in time around the mean are small and slow or monotonically change to a limiting value. The consideration of permanent actions is mandatory in the design. Permanent actions include, but are not limited to, the following:

a) self-weight of the structure;

b) supported constructions;

c) earth pressure, ballast, fluids with well-defined pressure; actions from movement due to differential settlement;

d) prestressing, imposed deformation from construction processes.

NOTE Examples of the stipulation of permanent actions can be obtained from existing standards (see C.1).

8.3 Variable actions

Actions shall be classified as variable actions (Q) if the variations in time are frequent and large (e.g. all actions caused by the use of the structure and by most of the external actions such as wind and snow). The consideration of variable actions is mandatory in the design. They include, but are not limited to, the following:

a) action imposed due to use and occupancy;

b) wind action;

c) snow action;

d) seismic action (see 12.2.4);

e) action due to ponding of water and/or hail;

f) action due to fluids, where variable, including ground water and floods;

g) atmospheric and floating ice action;

h) action due to currents and waves;

i) action due to moving loads and their effects;

j) action due to forces and effects arising from contraction or expansion resulting from climatic changes or technological temperature changes such as heating and cooling, moisture changes;

k) environmental influences.

NOTE Information on variable actions is given in the relevant International Standards; see Annex A.

8.4 Accidental actions

Actions shall be classified as accidental actions (A) if the magnitude is considerable but the probability of occurrence for a given structure is small relative to the anticipated time of use. Frequently, the duration is short (e.g. impact loads, explosions, earthquakes, and snow avalanches). The consideration of accidental actions is dependent on the design situations. They include, but are not limited to, the following:

a) action due to explosion;

b) action due to collision;

c) seismic action (see 12.2.4);

d) action due to erosion;

e) actions due to fire.

Provision for accidental actions that are not foreseen (see 5.2) shall be made through design verification for robustness (see 5.6 and 12.4).

NOTE Information on seismic actions and for fire actions is given in the relevant International Standards. See Annex A.

8.5 Evaluation of actions and their effects

Actions shall be evaluated in terms of the probabilistic nature of their occurrences. Action effects shall be evaluated with the understanding of the underlying physical mechanisms that translate actions into action effects on structural elements (see Clause 11). The action effects are expressed as the multiplications of action with factors that represent the underlying physical mechanisms. Additional factors shall be introduced to take into account the modelling uncertainty of the action effects, where relevant; see Annex B.

Where response up to the limit state is essentially linear, superposition may be used and the factors may be applied at any convenient point in the evaluation. Where response is nonlinear, this can lead to substantial errors in the reliability achieved. Common examples of nonlinear response include the geometric nonlinearity of tensile membrane structures and the material nonlinearity of response to strong ground shaking.

8.6 Design values of actions

The reliability class as well as design situations shall be considered when establishing the design action.

The design value can be determined as the product of a factor and a characteristic value or on the basis of achieving reliability target directly.

NOTE The value corresponding to annual exceedance probability or return period can be estimated as a product of the characteristic value and a conversion factor.

8.7 Characteristic values of actions

When design values of actions are determined as the product of a factor and a characteristic value, characteristic values shall be determined appropriately in terms of the probability of annual exceedance or expected return period of the basic physical quantity (treated as a random variable) describing the magnitude of each action. In order to determine the characteristic values of permanent actions, variable actions, and some type of accidental actions, their statistical characteristics shall be obtained through relevant investigations.

A value for accidental actions may be assumed non-probabilistically in order to ensure that structural integrity and other functions of the structure are maintained under those accidental actions.

NOTE 1 A 50 %, 98 % or 99 % upper fractile value for permanent actions and some types of variable actions such as imposed action, and a 50-year or 100-year return value for variable actions are often adopted. Characteristic values only represent the statistical nature of actions, and thus are independent of the design service life.

NOTE 2 For durability related actions, resistance models can require more detailed input.

9 Combinations of actions

9.1 General

Combinations of actions in semi-probabilistic formats shall be determined considering possibilities of simultaneous occurrence of actions.

NOTE Semi-probabilistic methods usually reduce random variables to a set of design values with a specific use: extreme favourable or unfavourable values, action combination values, serviceability level values, etc.

9.2 Design scenarios

Combinations of actions to be considered for verification of reliability against design limit states (ultimate and serviceability) shall include:

a) permanent action only;

b) permanent action together with one variable or accidental action;

c) permanent action together with one leading variable action such as imposed, wind, snow, or accidental action, and one or more accompanying variable actions.

Scenarios that include multiple accompanying actions shall be selected on a probabilistic basis, for having a significant influence on the reliability achieved by the specific action combination.

9.3 Additional considerations for serviceability limit state

In verification of serviceability limit states, the combination of actions depends on the nature of the limit state:

a) expected maximum effect of a combination during the service life for irreversible limit states, for example cracking;

b) expected maximum effect of a combination during shorter periods of time for reversible limit states, for example human discomfort due to oscillation in wind;

c) permanent and near permanent action effects for long term effects, for example creep or settlement.

9.4 Design values of combinations of action effects

The maximum value of the combined action effect during the reference period shall be considered when determining design values. The maximum value can be approximately estimated as the sum of the maximum effect of the leading action during the reference period and a suitable intensity of the other (accompanying) action effects. Each variable action should be considered as a leading action.

Considering persistent or transient design situations, the effects of actions E_d for ultimate and serviceability limit states shall be determined using Formula (4):

$$E_d = E\left[G_{d,i}; Q_{d,j}; \boldsymbol{a}_d\right] \tag{4}$$

where

E is a function determining the effect of actions;

$\mathbf{a}_d$ is a vector containing the design values of the geometry.

Design values $G_{d,i}$ and $Q_{d,j}$ of permanent and variable actions are given as factored by their characteristic values:

$$G_{d,i} = \gamma_{G,i} G_{k,i} \tag{5}$$

$$Q_{d,j} = \gamma_{Q,j} Q_{k,j} \tag{6}$$

where

$\gamma_{G,i}$ and $\gamma_{Q,j}$ are partial factors for permanent and variable actions G_i, and Q_j respectively, taking account of uncertainties in the actions, the action models and the action effect models, and

$G_{k,i}$ and $Q_{k,j}$ are the characteristic values of permanent and variable actions G_i, and Q_j, respectively.

The values for $\gamma_{G,i}$ and γ_{Qji} are dependent on whether the action is leading or accompanying. Alternatively, the adjustment for variable actions is made by introducing a combination factor Ψ_0.

NOTE In some cases, the effects of actions can depend on material properties.

In some cases, the factor for the model effect uncertainty should be applied after the calculation of the action effect.

10 Resistance

10.1 General

The resistance shall be determined as specified in established standards for design of the structures and elements of specific construction materials and shall consider the reliability class. Resistance factors shall be established based upon the reliability targets for the appropriate design situations and limit states.

10.2 Material properties

Material properties shall be defined by their characteristic values f_k.

Material properties to be used in non-linear analyses may either be based on design values, characteristic values or mean values provided that a consistent safety concept resulting in a design with the required target reliability is used; see also 11.1.

10.3 Geometrical data

Geometrical data (a) include external and internal dimensions of structural members, imperfections, tolerances for connected parts, and similar information related to the geometry of the structure.

Geometrical data are represented by their characteristic values or directly by their design values. The dimensions specified in the design documentation may be taken as characteristic values. When their statistical distribution is sufficiently known, values of geometrical quantities that correspond to a prescribed fractile of the statistical distribution may be used.

NOTE 1 Geometrical parameters can, in the course of time, be affected by environmental processes like corrosion.

NOTE 2 Imperfections are normally specified directly as the design values.

10.4 Characteristic values of resistance parameters

When a limit state verification is sensitive to the variability of a material property and/or the geometrical properties, upper and lower characteristic values of the material property should be taken into account.

As an example, the characteristic value may be defined as the 5 % fractile value where a low value of material or product property is unfavourable. Where a high value of material or product property is unfavourable, the characteristic value may be defined as the 95 % fractile value. When insufficient statistical data are available to establish the characteristic values of a material or product property, nominal values may be taken as the characteristic values, or design values of the property may be established directly.

The structural stiffness parameters (e.g. moduli of elasticity, creep coefficients) and thermal expansion coefficients may be represented by the mean values. Different values may be used to take into account the duration of the load. Adjustment factors may be applied where structural stability limit states depend on the stiffness.

The nominal values of dimensions specified by the designer are usually used as characteristic values of geometrical quantities.

Material parameters like strength and stiffness may in the course of time be affected by environmental processes like changes in moisture and temperature, corrosion, fatigue, UV-light and chemical and biological agencies; these processes should be taken into account, including their uncertainties, in such a way that the potential effect on the reliability level is compensated.

10.5 Design value of resistance

The design value of resistance, R_d, shall be determined by models provided in relevant standards; see e.g. ISO 2394. The design value shall be determined taking into account:

— variability in material and geometric properties;

— resistance model uncertainty including its dispersion and possible bias;

— change in resistance over the design life.

In principle, all sources of aleatory and epistemic uncertainties should be considered.

Guidance for resistance specification in the case with cumulative damage is provided in ISO 2394.

For exposure to fire, the structure shall be designed in a manner that the load-bearing capacity is adequate and the structural integrity is maintained for a sufficient time to permit evacuation of the occupants, provide appropriate protection for fire-fighting services, and protect the building and adjoining property from the spread of the fire.

The design value of resistance for the ultimate limit state R_d is expressed by Formula (7):

$$R_d = R\left[\frac{f_k}{\gamma_M}; \boldsymbol{a}_d\right] \tag{7}$$

where

R is a function determining the resistance,

f_k is the characteristic value of material property,

γ_M is the partial factor for resistance, taking account of material properties, model and geometric uncertainties,

$\mathbf{a}_d$ is a vector containing the design values of the geometry.

NOTE 1 Resistance parameters include properties of materials including soil and rock and geometrical quantities that are defined for a relevant part of the structure.

The value of the resistance factor shall also account for the model uncertainty of the resistance (bias b and uncertainties θ). The partial factor for resistance γ_M can accordingly consist of a combination of the partial factors for material properties γ_m and model uncertainty γ_R respectively. A single resistance factor ϕ (= $1/\gamma_M$) can also be used.

For implementation of a complete design, reference to established standards for the computation of resistance is required. This document defines the computation of resistance factors to achieve reliability targets, but the computation of resistance itself is beyond its scope.

NOTE 2 For guidance on standards for resistance, see for example ISO 19338, including information on national and regional standards that are deemed to satisfy the requirements of this document.

11 Analysis and testing

11.1 Analysis

Analysis shall be based on a calculation model of a structure (including the foundation) that can predict the structural behaviour, with an acceptable level of accuracy appropriate to the requirements under consideration. Specified material properties and structural dimensions shall be used to determine the action effects for all or part of a structure. For checking any ultimate limit state, plastic, non-linear, or linear elastic theory may be used, depending on the response of the structural material and of the structure as a whole to the applied loads and imposed deformations. Linear elastic methods are appropriate for checking the serviceability limit states using appropriate constitutive relationships. It may also be used in ultimate limit state verification, but that can be conservative.

For static analysis, structural models shall be based on an adequate choice of the force-deformation relationship of the elements and their connections, and between the elements and the ground. In some cases, the history of load application shall be taken into account. Effects of deformations and displacements on equilibrium shall be taken into account, if they result in a significant increase of the effect of the action or reduction in capacity.

When dynamic actions are specified as equivalent static actions, the dynamic aspects of actions shall be considered either by including them in the static values or by applying equivalent dynamic amplification factors to the static actions.

For dynamic analysis, structural models shall be based on relevant properties, such as masses, stiffnesses and damping characteristics of structural and relevant non-structural components. The structural response may be determined using modal analysis, time histories or any other appropriate method.

The geometrical quantities used in the computation generally refer to nominal values (i.e. the values given in the drawings, etc.). Where the structural behaviour is sensitive to imperfections (e.g. deviations from intended geometry such as geometrical tolerances), the allowable deviations for the execution of works shall be considered.

In semi-probabilistic nonlinear FEM, in principle, design values should be used for all random variables, loads as well as material properties and model uncertainties. Material properties should include deformation capacities. Unfavourable or favourable effects of action and resistance parameters need to be considered; appropriate upper or lower fractiles should then be applied in reliability assessment. Measures to account for model uncertainty of FEM analysis should be considered. As FE models are complex, they shall be validated against material and structural tests to check approximations and assumptions concerning constitutive models, numerical discretization and boundary conditions adopted in structural analysis.

For the analysis of the structure under fire conditions, all parameters that can affect the occurrence and development of the fire as well as the resulting changes in structural properties shall be taken into account.

A number of special conditions sometimes need to be considered in structural analysis: The load history sometimes needs to be considered in non-linear analysis. Frequency response ratios between structure and action should be considered when static equivalent treatment is applied. Design loads should be applied to determine equilibrium in the deformed geometry for highly non-linear structures. Design values for ductile failure can lead to underestimation of possibly dangerous brittle mechanisms of adjacent elements (see Annex A).

11.2 Testing

When design is based on a combination of tests and calculations, the experimental setup and evaluation of the tests shall be performed in such a way that the resulting design achieves the level of reliability required for the relevant design condition. Conditions which are not met during the test (e.g. long-term behaviour) shall be taken into account separately.

Testing may be used in the following circumstances:

a) adequate calculation models are not available;

b) for prototype testing (if a large number of similar components are to be used);

c) to confirm assumptions made in the design.

Statistical uncertainty due to a limited number of tests shall be taken into account.

NOTE 1 Standard checks on material properties or other control tests are not considered as design based on testing.

NOTE 2 Requirements for considering the relationship between calculation models and quantities evaluated from the tests are provided in ISO 2394:2015, with additional guidance on planning test arrangements and evaluating the test results in its Annex C.

12 Demonstrating conformance with requirements

12.1 General

Conformance with the basic requirements of this document shall be demonstrated. It shall be verified that no relevant limit state is exceeded for all relevant design situations, when design values for all combinations of actions and action effects and resistances are used in the design models. Verification of the non-exceedance of all limit states can be deemed to demonstrate conformance with the basic requirements for structural performance as based on the principles of limit states design.

A comprehensive and systematic design procedure shall be followed and recorded to ensure that all the provisions of this document are complied with, including the utilization of information on actions and resistance obtained from related standards (see Annex D).

12.2 Ultimate limit state

12.2.1 Resistance

When considering collapse, rupture or excessive deformation of a structure, element or connection, it shall be demonstrated that, during construction and throughout the design service life of the structure, the ultimate limit state is satisfied.

The design resistance shall be determined with appropriate allowance for the following:

a) the uncertainties resulting from construction activities;

b) variation in material properties;

c) the characteristics of the site;

d) the degree of accuracy inherent in the methods used to assess structural behaviour.

12.2.2 Static equilibrium

When considering instability due to overturning, uplift and sliding, it shall be demonstrated that, during construction and throughout the design service life of the structure, the expression for the limit state of static equilibrium is satisfied.

12.2.3 Accidental design situation

Provision for accidental design situations shall be based on:

a) the action combination scheme as provided for in Clause 9;

b) structural resistance as stipulated by the relevant materials-based standard.

12.2.4 Seismic design situation

Seismic actions may be classified either as variable actions or, in low seismic hazard regions, as accidental actions.

12.3 Serviceability

Appropriate serviceability criteria representing structural responses shall be chosen for demonstrating conformance with serviceability requirements.

The serviceability criterion shall take into account whether the serviceability limit state is reversible or irreversible.

12.4 Robustness

12.4.1 General

The capability of the structure to withstand local damage without being damaged to an extent disproportionate to the original cause shall be demonstrated to comply with requirements for robustness of the structures.

NOTE Local damage can be caused by accidental actions as provided for by 12.2.3 or from causes that are not considered in design such as fire, explosions, vehicular impact, the consequences of human error, or terrorist activities (refer to ISO 10252[1)]).

Conformance with the robustness requirement shall be demonstrated by an appropriate choice of one or more of the following:

a) avoiding, eliminating or reducing the hazards to which the structure can be subjected;

b) selecting a structural form which has low sensitivity to the hazards considered;

c) selecting a structural form and design that can survive adequately the accidental removal of an individual element or a limited part of the structure, or the occurrence of acceptable localised damage;

d) avoiding, as far as possible, structural systems that can collapse without warning;

e) tying the structural elements together;

f) providing additional strength.

12.4.2 Design strategies

Strategies for robustness design verification shall be based on the classification of structures by considering the consequences of structural failure (see Clause 6). The structural class shall determine the degree to which indirect measures are taken, such as event control that influences the probability of the occurrence of a hazard, or consequence reducing measures aiming at reducing the direct and indirect consequences of failure and thus the total risk. Similarly, direct design methods for preventing disproportionate collapse shall be applied, consisting of providing specific load resistance to resist failure from accidental loads and providing alternative load paths to provide robustness against local failure.

Design verification methods for robustness that are based on the classification of structures shall be used to determine the degree to which the following progressive steps are complied with:

a) prescriptive design and detailing rules that are based on simplified analysis of idealized load and structural performance models;

b) specific identified scenarios for structural collapse to be used as basis for applying prescriptive design and detailing rules;

c) systematic identification of scenarios leading to structural collapse serving as basis for specific collapse scenarios, with simplifications and idealizations based on reliability and risk analysis;

d) identified accidental design situations that are hazard specific or reasonable scenarios of initial damage in the case of non-hazard specific design;

e) extensive investigation and analysis of scenarios leading to structural collapse that include risk screening and involvement of experts on all relevant matters;

f) detailed assessment based on dynamic and non-linear structural analysis;

g) involvement of external expert review for quality control.

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1) Under preparation. Stage at the time of publication: ISO/DIS 10252:2018.

NOTE A methodical framework for the identification of appropriate assessment and provisions for robustness dependent on the exposures acting on the structure as well as the structural system and the consequences of system failure is provided in ISO 2394:2015 Annex F.

12.4.3 Prescriptive verification measures

Verification shall be given of providing of a continuous load path for the structure such as

— a complete lateral force-resisting system,

— all members of the structural system connected to their supporting members, including structural walls to be anchored to diaphragms and supports.

The effects and resistances shall be assessed due to forces resulting from notional loads that are suitably combined with the effect of related loads.

NOTE Further guidance on notional loads and their combinations with related loads can be obtained from ASCE SEI-7. Further guidance on provision of effective horizontal and vertical ties or effective anchorage of suspended floors to walls can be obtained from EN 1991-1-7.

12.4.4 Collapse scenarios

The notional removal of each supporting column, each beam supporting a column and any nominal section of a load bearing wall, one at a time in each storey, shall be used as basis for verifying sufficient robustness for higher consequence class structures.

It shall be demonstrated that the building remains stable and that any local damage does not exceed a certain limit.

Where the notional removal of such columns and sections of walls would result in an extent of damage in excess of the stated limit, then such element shall be designed as a key element.

NOTE Further guidance on the application of notional collapse scenarios, limits on local damage and design verification for key elements can be found in EN 1991-1-7.

12.5 Durability

The durability of the structure and structural elements in their environment shall be such that they remain fit for use during their design service lives, given appropriate maintenance. Growth of cracks by fatigue to a critical size for fracture shall also be considered in the design (see D.4). Verification of sufficient durability shall be based on the requirements and procedures stipulated in ISO 13823.

Annex A
(informative)

Guidance for the adoption of this document

A.1 General

This annex gives further information on issues to be considered by a national group for the adoption of this document. It is intended that this document be adopted with addition of a national annex or annexes (provided by the adopting group) setting out the additional information and values necessary for use in design.

The adopting group should use this document as a template. This annex is provided as guidance to the adopting group and may not be used, like the other informative annexes, if users do not need them.

The adoption should take into account the national conditions and the loading and design documents to be used with it. These national documents will be referred to in the adopted standard.

The semi-probabilistic approach is represented by alternative formats for design verification to allow for different levels of approximation of the performance function. The partial factor design format utilises representative values and partial factors for a set of design variables. The load and resistance factor design (LRFD) format applies factors directly to specified loads and resistances to obtain design values to be used for design verification. Design values can be expressed directly in terms of an annual probability of exceedance (with a partial factor = 1,0), so as to account for the differing non-linearity of the action for different structural responses. See Annex B for a more detailed description of alternative design formats.

The adopted standard should provide for alternative paths to conformance through the use of basic principles, research or testing to prove reliability (see ISO 2394). Such alternatives would need to be supported by documentation to the satisfaction of the authority approving the structure.

A.2 Process for adoption

A.2.1 Guidance/explanations on Clause 1

The scope of structures is limited by the requirement for the use of the semi-probabilistic design approach as set out by ISO 2394. Standards and specifications serve to ensure the quality of analysis, design materials, production, construction, operation, maintenance, and documentation to such an extent that uncertainties which influence the performance of the structures can be quantified. The scope of application of this document is accordingly limited to structures for which sufficient knowledge, competence and experience are available to comply with these requirements. This may generally be taken to apply to common structures for buildings, bridges, industrial and civil engineering infrastructure.

Adoption committees should carefully consider and adjust the requirements and procedures to the scope of application of the adopted standard. Additional measures based on special investigations are required for structures using new construction systems or new materials, for those of extremely large size, with long spans or heights, or those of special use.

The requirements and design verification procedures presented in this document are based on and derived from the knowledge and experience captured by leading structural standards internationally.

A.2.2 Guidance/explanations on Clause 2

In addition to the standards that are normatively cited in this document, the implementation of the requirements and design verification procedures is based on the input typically of representative values of design variables such as actions on the structures and resistance for the failure modes of standard structural materials. All design standards that are related to the adopted standard should consequently be listed as normative references that are indispensable for its application.

A selection of International Standards on the basis of design for actions on structures provides an illustration of actions that may be considered as relevant to this document, as given in References [26] to [41].

A.2.3 Guidance/explanations on Clause 3

Key concepts of the semi-probabilistic design verification process are listed, providing definitions to ensure the standardized use of terminology and to assign the intended meaning of the terms. The list of terms is consistent with the extended list on the principles of reliability presented by ISO 2394. The listed concepts, terms and definitions should enhance the harmonized sharing of knowledge on structural performance and reliability. Where there is a need to deviate locally from the terms, a list of equivalent terms may be provided to ensure consistency with general practice.

The intention for the definition is to provide a clear formulation of the meaning of a term. The normative function of the term should be stated separately in the standard. For example, the definitions of "action", "individual action" and "permanent action" describe the nature of these actions, whilst the way in which provisions for how they need to be taken into account needs to be stipulated in the standard. Inclusion of common terms of language may restrain their general use, and should therefore be avoided.

A.2.4 Guidance/explanations on Clause 4

The use of standardized symbols enhances the international harmonization of structural design practice and ensures unification with the normative standards within the scope of application. The symbols used in this document are closely related to the set of symbols used in ISO 2394, whilst ISO 3898[1] provides a broader basis for the standard usage of symbols.

A.2.5 Guidance/explanations on Clause 5

A.2.5.1 General

The fundamental requirements for structural performance are provided as basis for a scheme of situations and cases for which procedures for demonstration of conformance are to be used. The classification of cases for which target levels of reliability can be set include provisions for design situations, limit states, reliability and consequence differentiation, failure modes and further subdivisions. The semi-probabilistic approach utilises design procedures which are deemed to achieve the intended levels of reliability for each case.

A.2.5.2 Design situations

Design situations complement the classification of structural performance into limit states by accounting mainly for time related processes for actions and the function of the structure.

A.2.5.3 Limit states

A structure, or part of a structure, is considered unfit for use or to have failed when it exceeds a particular state, called a limit state, beyond which its performance or use is impaired. All relevant limit states should be considered in the design.

A.2.5.4 Actions

Procedures for the implementation of the general requirements for the identification of all actions and environmental influences relevant to the scope of structures and conditions, their classification, specification and combination given here are provided in Clauses 8 and 9. All the actions that need to be considered to ensure reliability conformance should be included in the process.

A.2.5.5 Resistance

The materials independent requirements for structural resistance are intended to ensure that a unified approach is applied to the diverse common structural materials within the scope of the standard.

The durability requirements of a structure are normally taken into account by attention to design details, the specification and control of materials and workmanship, the control of cracking, and where necessary, protection and maintenance provisions.

A.2.5.6 Design verification

Requirements for design verification are intended to provide for a systematic process for demonstrating conformance to all the relevant design situations.

A.2.5.7 Quality assurance

Quality assurance concerns the activities carried out during planning, design, construction, and use, including design checks, quality control of materials and components, and field review during construction, maintenance and replacement. Quality assurance is intended to ensure that the final structure is as free from human error and material defects as practicable; it is achieved by proper communication between those involved. The level of quality assurance therefore significantly impacts the degree of safety, serviceability and durability achieved.

Design checks should be performed by persons other than those responsible for carrying out the original design, though they may belong to the same organization. The design review should be conducted by an independent organization when the structure is unusual or when the consequences of failure are high.

Material quality control is often assigned to the material provider or builder, but should be verified by an independent qualified organization working under the technical direction of the original designer. The original designer should review all material quality reports for conformance with the project specifications.

The designer should conduct periodic field reviews of construction for conformance with the design intent and specifications. The periodic reviews should be supplemented by the contractor's own quality assurance review of construction. When the structure is unusual or when the consequences of failure are high, additional field reviews of construction by a third party should be considered.

A.2.6 Guidance/explanations on Clause 6

The adopting group should elaborate further on the kinds of structure applicable to each class.

Indicative classification on the basis of the consequences of failure is provided by ISO 2394 to allow for determining the need for risk-based assessment of robustness and the level of design efforts. Consequence classes that can require risk treatment may be regarded to fall outside the scope of this document.

Examples of alternative classification schemes and categories are provided in Annex C.

A.2.7 Guidance/explanations on Clause 7

A distinction is made between limit states for safety of the structure as provided for by the ultimate limit state, and functionality provided for by the serviceability limit state. A condition limit state may be used when the real limit state is either not well defined or difficult to calculate. The reliability requirements for the condition limit state should be consistent with the original limit state. Although the requirement of achieving a limit state for a certain period of time implies sufficient durability, for practical reasons it can be helpful to add a specific durability limit state.

Structures shall satisfy ultimate limit states in which members and components are proportioned to carry the design actions to resist yielding, fracture, buckling and any other unacceptable performance. Although strength is a primary concern, it cannot be considered independent of the stiffness of the structure.

Structures shall also satisfy serviceability limit states that define functional performance and behaviour under load and include such items as deflections and vibration. Exceeding a serviceability limit state in a building or other structure usually means that its function is disrupted or impaired because of local minor damage or deterioration or because of occupant discomfort or annoyance.

When sufficient information is available to prove that a limit state is satisfied by the controlling limit state, a conformance check or omitting of the redundant limit state is acceptable.

In situations where the information is insufficient for proper calibration of design parameters, design procedures may be based on acceptable practice. Refer to Annex C for guidance on standard practice.

A.2.8 Guidance/explanations on Clause 8

The types and means of specifying of actions need to be stated, in order for the user to be clear about what actions must be considered in the design. While most adopting groups will be able to reference national documents for most major actions, there may be little or no information that can be specifically stated for some actions. Therefore, the list of actions and the referenced documents may be modified as needed by the adopting group.

The variables used as the means of specifying each action should be the same as that given in the corresponding International Standard, if available (see the Bibliography for a list of relevant International Standards).

In the context of this document, accidental actions can be considered as rare events. In some environments, particular actions may be considered to be accidental rather than variable.

In some situations, wind actions may include the effect of wind-borne debris on building envelopes and thus on internal pressure.

A.2.9 Guidance/explanations on Clause 9

It is expected that the adopting group will insert a set of combinations that are appropriate, given the construction conditions and the other design information to be used (e.g. load data and materials design methods). Alternative action combination formats are derivatives of the Turkstra rule[25] where one of the actions is taken at its extreme value whilst the accompanying actions are taken at mean or "arbitrary point in time" values. This implies that multiple load cases need to be considered in design verification.

If Format A is used for presenting load combinations (see B.2), further guidance can be found in EN 1990[10]. If Format B is used for presenting load combinations (see B.3), load specifications from the USA (ASCE SEI 7[6]), Australia/New Zealand (AS/NZS 1170[7]), Canada (CSA S408[9]), Japan (AIJ Recommendations[3]), etc. may be used as examples. The use of Format C (see B.4) is demonstrated by load specification practice presented in EN 1991/German NA[11], EN 1998[18], ASCE SEI 7[6], AS/NZS 1170[7].

A.2.10 Guidance/explanations on Clause 10

A clause on structural resistance is introduced to provide for the material independent reliability requirements. The related materials based structural design standards from which design values for structural resistance are obtained shall be unified with the requirements of this document.

Three alternative partial factor formats for the design values of structural resistance as used in the semi-probabilistic approach are provided in ISO 2394:2015, 9.4.2.2.

It is common that structural resistance is defined in standards for the design of one or a few structural materials. The characteristic and design values in such standards need to be consistent with the fundamental requirements in this document. Examples of coordinated sets of such standards exist and can be consulted for guidance. For example, EN 1990 through EN 1999[10]–[19], known collectively as the Eurocodes, are one such set. ASCE SEI 7[6] paired with ACI 318[2], AISC 360[4], AISI S100[5], TMS 402[21], and AWC-NDS[8] provide a collective set used for buildings and similar structures in the United States. There are similar collections in many other nations.

A.2.11 Guidance/explanations on Clause 11

It can be necessary to specify accepted methods for analysis, particularly for dynamic actions such as earthquakes and wind.

It can also be necessary to specify the conditions for the acceptance of testing as a supplement to calculations. Various methods are available for treating the uncertainty due to a limited number of tests and to ensure the reliability level of design using test data, e.g. ISO 2394. These sometimes also need to be specified by the adopting group.

It can be difficult to judge in advance whether a low or a high design value is unfavourable. For loads, this is a well understood problem and load cases with favourable and unfavourable action effects are distinguished in codes. The same holds for resistance parameters and in principle combinations of various lower and higher design values should be considered. In particular, it is important to note that low design values in ductile elements sometimes reduce action effects in adjacent brittle (or strongly softening) members and the development of possible dangerous brittle mechanisms is sometimes not identified by the analysis. This issue can be resolved by checking whether the lower design values of brittle elements are higher than the upper design values of the ductile elements (capacity design). If this is satisfied, lower design values for material properties and model uncertainties may be considered for the ductile elements. Geometrical nonlinearities may lead to the same softening behaviour as is the case with material properties.

Another practical problem is that FEM programs cannot handle model uncertainties as explicit input parameters. The most convenient solution is to include the model factor for the global load effect model in the design value of the loading (with an exception for geometrically under proportional load effects) and the model factor for the local resistance model in the design values of the material parameters. In some cases, this can, however, lead to incorrect results. This issue can be overcome by developing FEM programs with explicit input options for model uncertainties.

As an alternative, non-linear analysis is thus often based on mean values to provide unbiased estimate of structural response to considered loads. The global resistance factor shall then be adjusted, in general increased, to provide for sufficient reliability that is normally ensured by material factors and characteristic values of materials derived as lower fractiles of probabilistic distributions. The global resistance factor shall account for the uncertainty due to randomness of material properties and other parameters affecting the resistance and for model uncertainty. Special attention should be paid to the situations when structural reliability is affected by two or more failure modes of similar importance. If one analysis is not sufficient to verify all the failure mechanisms, separate additional analyses should be carried out (EN 1992-2[12]). Simplified safety formats for non-linear analysis are devised in Reference [20].

As an example of the need for validating FEM analysis against tests, mesh refinement has an opposite effect for crack formations (increased stiffness) and maximum load capacity (reduced strength)[22]. Generally a mean values based model should be used in the validation process. Resistance model uncertainty factor can be differentiated with respect to the level of validation of the model[20].

A.2.12 Guidance/explanations on Clause 12

A.2.12.1 Resistance

There are alternative methods for specifying the resistance of a structure. The two most common methods are

a) the partial factor (γ_M) method (for example, EN 1990), and

b) the resistance (capacity) factor (ϕ) method (for example, the US and AIJ LRFD format; load and resistance factor format).

Structural resistance is normally defined in terms of the maximum load-carrying capacity of a structure or structural element. For slender structures with a large deformation capacity, the resistance may be defined by the load-carrying capacity that corresponds to the maximum acceptable strain or deformation.

A.2.12.2 Static equilibrium

When considering sliding, overturning and uplift, the following applies.

a) Permanent actions contributing to stabilising effects should be limited to permanent actions that cannot be removed from the structure and they should have load factors less than or equal to 1,0, while all permanent actions contributing to destabilising effects should be included and they should have load factors greater than 1,0.

b) Variable actions contributing to stabilising effects should be excluded, while all variable actions contributing to destabilising effects should be included in combinations, as given in Clause 9.

A.2.12.3 Serviceability

The adopting group needs to be clear on its specification of serviceability criteria (actions and associated response limits) and can determine this criterion to be normative. Lists of acceptable serviceability criteria that are material-independent should be established in the national standard as either normative or informative guidance. Serviceability criteria that are material-dependent should be provided in the appropriate design document for the specific material.

A.2.12.4 Robustness

Additional measures for robustness may be introduced by the adopting group, such as minimum lateral resistance for elements and connections, minimum sizes or other quantifiable measures such as limiting the area of damage, etc. Tying the structure together can include consideration of the transmission of forces in both the horizontal and vertical directions.

A.2.12.5 Durability

The performance of the structure should ensure reliability throughout its design service life. Durability criteria can be considered as normative and the adopting group needs to be clear on this in its specification. Since the method of design for durability is normally material-dependent, details for conformance should be established in the appropriate design document for the specific material.

Annex B
(informative)

Formats for presentation of design values for combinations of actions

B.1 Design format

Design formats are generally classified into:

— A) partial factor design format,

— B) load and resistance factor design format, and

— C) annual probability of exceedance based design format.

In the following, the representations of the safety and serviceability check formula, $E_d \leq R_d$, in these formats are provided considering combinations of actions including permanent actions, leading variable actions, accompanying variable actions and/or an accidental action. Combinations of different formats are also sometimes used, particularly combining formats B and C. A procedure for deriving action values point by point over a diverse region at risk based optimal values is provided in Clause B.5.

NOTE 1 For correlated actions (e.g. storm surge and wind), there can be more than one leading action.

NOTE 2 Design situation of ultimate limit states can be categorized into either strength or static equilibrium (see 7.2). Limit states for strength can further be categorized into either normal (persistent and transient) or accidental.

NOTE 3 When the combination includes an accidental action, the design combination values for permanent actions and accompanying variable actions can be adjusted.

For favourable permanent actions, consideration should be given to omitting components of permanent actions that can be removed from the structure.

NOTE 4 Design situation of serviceability limit states can be categorized into either characteristic, frequent, or quasi-permanent. Characteristic values are usually applied in the case of irreversible situations. Frequent values are usually applied in the case of reversible situations.

NOTE 5 Combinations of actions for serviceability depend on the specific serviceability limit state (e.g. deflection causing damage to non-structural components, vibration affecting people or equipment or causing fatigue, loss of appearance) and the mechanisms leading to failure (e.g. elastic response, creep, shrinkage, fatigue crack growth, material deterioration) which are material dependent. Simplified serviceability criteria are contained in codes for buildings and structures and in material design standards.

B.2 Format A: Partial factor design format

The design formats, Formulae (1) and (3), may be expressed as a combination of actions as follows:

$$E\left(\sum_{i}\left(\gamma_{G,i}G_{k,i}\right)+\gamma_{Q,j}Q_{k,j}+\sum_{i\neq j}\left(\gamma_{Q,i}\Psi_{0,i}Q_{k,i}\right)\right)\leq\frac{1}{\gamma_R}R\left(\frac{f_k}{\gamma_m}\right) \quad \text{(B.1)}$$

where

E is a function determining the effect of actions;

R is a function for resistance;

$G_{k,i}$ are the characteristic values of the i-th permanent action;

$Q_{k,j}$ is the leading variable action;

$Q_{k,i}$ $(i{\neq}j)$ is the i-th accompanying variable action;

f_k is the characteristic value of material property;

γ_X are partial factors for basic variable X;

$\Psi_{0,i}$ is the combination factor of accompanying variable actions.

NOTE Examples of partial factors and combination factors can be found in Tables B.1 and B.2 for ultimate limit states and serviceability limit states, respectively.

Table B.1 — Examples of partial factors and combination factors for ultimate limit states

1	2	3	4	5	6	7
Design situation		**Permanent** Σ		**Leading variable action**	**Accompanying variable action**	
		Unfavourable	**Favourable**		**Main**	**Other, Σ**
Strength	Normal	$\gamma_{G,i,\mathrm{sup}}G_{k,i,\mathrm{sup}}$ [1,35]	$\gamma_{G,i,\mathrm{inf}}G_{k,i,\mathrm{inf}}$ [1,0]	$\gamma_{Q,1}Q_{k,1}$ [1,5]		$\gamma_{Q,i}\Psi_{0,i}\, Q_{k,i}$ [1,5 × 0,7]
	Accidental	$G_{k,i,\mathrm{sup}}$	$G_{k,i,\mathrm{inf}}$	A_d	$\Psi_{1,1}Q_{k,1}$ [0,5]	$\Psi_{2,i}\, Q_{k,i}$ [0,3]
Static equilibrium		$\gamma_{G,i,\mathrm{sup}}G_{k,i,\mathrm{sup}}$ [1,1]	$\gamma_{G,i,\mathrm{inf}}G_{k,i,\mathrm{inf}}$ [0,9]	$\gamma_{Q,1}Q_{k,1}$ [1,5]		$\gamma_{Qi}\, \Psi_{0,\mathrm{i}}\, Q_{k,i}$ [1,5 × 0,7]
NOTE The γ and Ψ values in brackets are typical values for illustrative purposes only. The combination values Ψ_0, Ψ_1, and Ψ_2 vary depending on the type of structures and the type of loading.						

Table B.2 — Examples of partial factors and combination factors for serviceability limit states

1	2	3	4
Design situation	**Permanent** Σ	**Leading variable action**	**Accompanying variable action**
Characteristic	Σ G_i	Q_k	Σ $\Psi_{0,i}\, Q_{k,i}$ [0,7]
Frequent	Σ G_i	$\Psi_{1,1}\, Q_{k.1}$ [0,5]	Σ $\Psi_{2,i}\, Q_{k,i}$ [0,3]
Quasi-permanent	Σ G_i	$\Psi_{1,1}\, Q_{k,1}$ [0,5]	Σ $\Psi_{2,i}\, Q_{k,i}$ [0,3]
NOTE The γ and Ψ values in brackets are for illustrative purposes only. These values vary with types of actions, types of combinations and the target reliability level.			

B.3 Format B: Load and resistance factor design format

The design formats, Formulae (1) and (3), may be expressed as a combination of actions as follows:

$$E\left(\sum_{i}\left(\gamma_{Gi}G_{k,i}\right)+\gamma_{j}Q_{k,j}+\sum_{i\neq j}\left(\gamma_{ci}Q_{k,i}\right)\right)\leq\phi R_{n} \tag{B.2}$$

where

R_n is the specified resistance;

γ_{ci} is the factor for accompanying variable actions; and

ϕ is a resistance factor.

NOTE Examples of load and resistance factors can be found in Tables B.3 and B.4 for ultimate limit states and serviceability limit states, respectively.

Table B.3 — Examples of load and resistance factors for ultimate limit states

1	2	3	4	5	6
Design situation		**Permanent actions**		**Leading variable or accidental action**	**Accompanying variable actions**
		Unfavourable	**Favourable**		
Strength or static equilibrium	Normal	$\Sigma\ \gamma_{Gi,\text{sup}}\ G_{k,i}$ [1,2]	$\Sigma\ \gamma_{i,\text{inf}}\ G_{k,l}$ [0,9]	$\gamma_{Q,1}\ Q_{k,1}$ [1,6 typical] [range 1,4–2,0]	$\Sigma\ \gamma_{a,i}\ Q_{k,i}$ [0,5 typical] [range 0,2–1,0]
	Accidental	$\Sigma\ \gamma_{Gi,\text{sup}}\ G_{k,i}$ [1,2]	$\Sigma\ \gamma_{i,\text{inf}}\ G_{k,l}$ [0,9]	A_d	$\Sigma\ \gamma_{a,i}\ Q_{k,i}$ [0,2–0,5]
NOTE The γ values in brackets are for illustrative purposes only. These values vary with types of actions, types of combinations and the target reliability level.					

Table B.4 — Examples of load and resistance factors for serviceability limit states

1	2	3	4
Design situation	**Permanent Σ**	**Leading variable action**	**Accompanying variable action**
Characteristic	$\Sigma\ \gamma_{G,\text{i}}\ G_i$ [1,0]	$\gamma_{Q,1}\ Q_k$ [1,0]	$\Sigma\ \gamma_{Q,\text{i}}\ Q_k$ [0,7]
Frequent	$\Sigma\ \gamma_{G,\text{i}}\ G_i$ [1,0]	$\gamma_{Q,1}\ Q_k$ [0,5]	$\Sigma\ \gamma_{Q,\text{i}}\ Q_k$ [0,3]
Quasi-permanent	$\Sigma\ \gamma_{G,\text{i}}\ G_i$ [1,0]	$\gamma_{Q,1}\ Q_k$ [0,5]	$\Sigma\ \gamma_{Q,\text{i}}\ Q_k$ [0,3]
NOTE 1 The γ values in brackets are for illustrative purposes only. These values vary with types of actions, types of combinations and the target reliability level. NOTE 2 The Q_k values are not necessarily the same as those for strength checking.			

B.4 Format C: Annual probability of exceedance based design format

The design formats, Formulae (1) and (3), may be expressed as a combination of actions as follows:

$$E\left(\sum_{i}\left(G_{r,i}\right)+Q_{r,j}+\sum_{i\neq j}\left(Q_{r,i}\right)\right)\leq\frac{1}{\gamma_{R}}R_{n} \tag{B.3}$$

where

$G_{r,i}$ is the design value of the i-th permanent action;

$Q_{r,j}$ is the r_j-year return value (corresponding to annual probability of exceedance of $1/r_j$) of the leading variable action;

$Q_{r,i}$ is the r_i-year return value of the i-th accompanying variable action;

γ_R is a partial factor for resistance; and

R_n is the specified resistance.

NOTE 1 The design value of variable action in Formats A and B is determined as a product of a partial factor/load factor, which is adjusted according to the target performance level, and a characteristic value, which is specified as a prescribed return value. On the contrary, the design value in Format C is determined directly by a return value by adjusting the return period. Different return period values are determined for different action effect combinations. These return period values are seen to correspond to the factored design action effects in Formats A and B.

NOTE 2 Format C can lead to better reliability consistency for systems with non-linear characteristics. However, the reliability level cannot always be controlled directly using target reliability index.

NOTE 3 Examples for demonstrating equivalence of annual probability of exceedance of the leading actions for ultimate limit states can be found in Table B.5.

NOTE 4 A return period conversion factor can be introduced as a load factor, in order to modify the characteristic value to the value corresponding to the return period considered in the design. Examples can be found in AIJ Recommendations.

Table B.5 — Examples of annual probabilities of exceedance for leading variable actions at the ultimate limit state

1	2	3	4	5
Consequence class	**Annual probability of exceedance**			
	Wind		**Earthquake**	**Snow**
	Cyclonic	**Non-cyclonic**		
I	1:500	1:250	1:500	1:250
II	1:1 000	1:1 000	1:1 000	1:500
III	1:2 500	1:2 500	1:1 500	1:750
IV	Determine for actual case	Determine for actual case	Determine for actual case	Determine for actual case
NOTE 1 The values are given for illustrative purposes only. The values vary with geographic conditions and target reliability.				
NOTE 2 The return intervals used for wind in ASCE 7 are 300, 700, 1 700, and 3 000 years for their Risk Categories I through IV (see Table C.1).				

B.5 Reliability targeted action format

There are circumstances where a single probability model cannot represent the characteristics of an action over the region of interest for the standard. Widely different coefficients of variation or very different shapes of histograms are indicators of such circumstances. Examples include seismic ground motion over large areas with diverse geologic mechanisms or climatic actions (e.g. wind or snow) over large areas with varying topography and climate. Where the data exists to characterize the occurrence of the action at points and the nature of the structural design problem is such that a generic description of the variability in the resistance will suffice, the amplitude of the action to achieve a specific target reliability can be computed numerically point by point. Seismic ground motions in ASCE/SEI 7 are computed using this technique. The pertinent formula is as follows:

$$f = p[F \mid a] \frac{d\kappa}{da} da \qquad \text{(B.4)}$$

where

f is the target annual rate of failure;

$p[F|a]$ is the conditional probability of failure given the occurrence of ground motion with amplitude a; and

κ is the annual rate at which intensities of ground motion a are exceeded.

Other techniques, including Monte Carlo simulation, have been used[8]. Actions computed in this fashion have been used in combination with other loads using Format B, but in concept can be used in any format. This technique results in action design values that do not have a consistent mean recurrence interval.

B.6 Examples of design format

The above three design formats are based on the same concept of structural reliability, and can be interchangeable as demonstrated in the following using examples.

Assume the probability models of actions and resistance as shown in Table B.6. Then using Turkstra's rule (see A.2.9) for the simple modelling of the combinations of actions, the design values are determined based on the results of FORM so that the target reliability β_T = 3,3 for a 50-year reference period is satisfied. The design values can be expressed in any of the above three formats. The values using partial factors and combination factors for Format A, load and resistance factors for Format B, and the annual probability of exceedance for Format C are presented in Table B.7 for the combinations of actions of $G_1 + Q_i$ and in Tables B.8 and B.9 for $G_1 + Q_1 + Q_2$ and $G_1 + Q_1 + Q_2 + Q_3$, respectively, assuming that Q_1 is the leading action.

It is assumed here that the characteristic values of the actions and the resistance are determined as follows:

— resistance: 5 % fractile value,

— permanent action (dead load): mean value (50 % fractile value),

— variable action (live load): 98 % fractile value at an arbitrary point in time,

— variable actions: 50-year return value.

The same level of reliability, which is β_T = 3,3 for a 50-year reference period, can be obtained using any of these formats. Parametric variations of model parameters across a wide range of values provide similar results of the equivalence of the alternative design formats.

Table B.6 — Probability models of actions and resistance

1	2	3	4
	Probability distribution	**Mean**	**Coefficient of variation**
Resistance (R)	Lognormal	Value to obtain β_T = 3,3	0,15
Permanent (G_1)	Normal	5	0,1
Variable action 1 (Q_1)	Gumbel	5	0,3
NOTE The statistics of variable actions are of their annual maximum values.			