



General principles on reliability for structures



AS 5104:2017

This Australian Standard® was prepared by Committee BD-006, General Design Requirements and Loading on Structures. It was approved on behalf of the Council of Standards Australia on 4 July 2017.

This Standard was published on 7 September 2017.

The following are represented on Committee BD-006:

- Australasian Wind Engineering Society
- Australian Steel Institute
- Cement Concrete and Aggregates Australia - Cement
- Concrete Masonry Association of Australia
- Engineers Australia
- James Cook University
- Property Council of Australia
- Steel Reinforcement Institute of Australia
- Swinburne University of Technology
- Think Brick Australia
- University of Newcastle

This Standard was issued in draft form for comment as DR AS 5104:2017.

Keeping Standards up-to-date

Ensure you have the latest versions of our publications and keep up-to-date about Amendments, Rulings, Withdrawals, and new projects by visiting:

www.standards.org.au

www.saiglobal.com (sales and distribution)

ISBN 978 1 76035 880 8

Australian Standard®

General principles on reliability for structures

First published as AS 5104—2005.
This edition 2017.

COPYRIGHT

© ISO 2017 — All rights reserved
© Standards Australia Limited 2017

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher, unless otherwise permitted under the Copyright Act 1968 (Cth).

Published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001, Australia.

Preface

This Standard was prepared by the Standards Australia Committee BD-006, General Design Requirements and Loading on Structures, to supersede AS 5104—2005, *General principles on reliability for structures*.

The objective of this Standard is to provide a risk and reliability-informed foundation for decision making concerning design and assessment of structures in the context of specific projects. This Standard describes how the principles of risk and reliability can be utilized to support decisions related to the design and assessment of structures and systems involving structures over their service life. Three different but related levels of approach are facilitated, namely, a risk-informed, a reliability-based, and a semi-probabilistic approach.

This Standard addresses societal functionality and sustainable societal development which may exceed the current objectives of the National Construction Code (NCC) and the Australian Building Codes Board Intergovernmental Agreement (IGA) that establishes the ABCB. For buildings to which the NCC applies, the objective requirements of the IGA and NCC apply.

This Standard encompasses precautionary principles which may lead to outcomes which would not meet the ABCB and COAG best practice regulation principles. As appropriate, the designer may apply the concept of so far as is reasonably practicable (SFAIRP).

Australian Standards commonly use the load resistance factor design method (LRFD) in the determination of reliability when using the semi-probabilistic methods outlined in Clause 9.4 of this Standard.

This Standard is identical with, and has been reproduced from ISO 2394:2015, *General principles on reliability for structures*.

As this Standard is reproduced from an International Standard, the following applies:

- (a) In the source text ‘this International Standard’ should read ‘this Australian Standard’.
- (b) A full point substitutes for a comma when referring to a decimal marker.

None of the normative references in the source document have been adopted as Australian or Australian/New Zealand Standards.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the annex to which they apply. A ‘normative’ annex is an integral part of a Standard, whereas an ‘informative’ annex is only for information and guidance.

Contents

Preface	ii
Foreword	v
Introduction	vi
1 Scope	1
2 Terms and definitions	1
2.1 General terms	1
2.2 Terms related to design and assessment	5
2.3 Terms related to actions, action effects, and environmental influences	9
2.4 Terms related to structural response, resistance, material properties, and geometrical quantities	11
3 Symbols	12
3.1 General	12
3.2 Latin upper case letters	12
3.3 Latin lower case letters	13
3.4 Greek letters	13
3.5 Subscripts	14
4 Fundamentals	14
4.1 General	14
4.2 Aims and requirements to structures	15
4.2.1 Fundamental requirements to structures	15
4.2.2 Target performance level	15
4.3 Conceptual basis	16
4.3.1 Decisions concerning structures	16
4.3.2 Structural performance modelling	17
4.3.3 Uncertainty and treatment of knowledge	18
4.4 Approaches	18
4.4.1 General	18
4.4.2 Risk-informed and reliability-based approaches	18
4.4.3 Semi-probabilistic approaches	20
4.5 Documentation	20
5 Performance modelling	21
5.1 General	21
5.1.1 Structural performance and limit state concept	21
5.1.2 Performance and performance indicators	21
5.1.3 Basic performance requirement and design situations	21
5.1.4 Levels of verification	22
5.2 Performance model	22
5.2.1 General	22
5.2.2 Time-dependent aspects	22
5.2.3 System aspects	23
5.3 Limit states	23
5.3.1 Ultimate limit state	23
5.3.2 Serviceability limit states	23
5.3.3 Condition limit states	24
5.3.4 Limit state function	24
6 Uncertainty representation and modelling	25
6.1 General	25
6.1.1 Types of uncertainty	25
6.1.2 Treatment of uncertainty	26
6.1.3 Interpretation of probability	26
6.1.4 Probabilistic models	26
6.1.5 Population/outcome space	26

6.1.6	Hierarchical modelling of uncertainty	27
6.2	Models for structural analysis	27
6.2.1	General	27
6.2.2	Actions and environmental influences	28
6.2.3	Geometrical properties	30
6.2.4	Material properties	30
6.2.5	Responses and resistances	31
6.3	Models for consequences	33
6.4	Model uncertainty	33
6.5	Experimental models	34
6.6	Updating of probabilistic models	35
7	Risk-informed decision making	35
7.1	General	35
7.2	System identification	35
7.3	System modelling	36
7.4	Risk quantification	36
7.5	Decision optimization and risk acceptance	36
8	Reliability-based decision making	37
8.1	General	37
8.2	Decisions based on updated probability measures	38
8.3	Systems reliability versus component reliability	38
8.4	Target failure probabilities	39
8.5	Calculation of the probability of failure	39
8.5.1	General	39
8.5.2	Time-invariant reliability problems	40
8.5.3	Transformation of time-variant into time-invariant problems	40
8.5.4	Out-crossing approach	41
8.6	Implementation of probability-based design	41
9	Semi-probabilistic method	41
9.1	General	41
9.2	Basic principles	42
9.3	Representative and characteristic values	43
9.3.1	Actions	43
9.3.2	Resistances	43
9.4	Safety formats	44
9.4.1	General	44
9.4.2	Partial factor method	44
9.4.3	The design value method	46
9.5	Verification in case of cumulative damage	47
Annex A	(informative) Quality management	48
Annex B	(informative) Lifetime management of structural integrity	56
Annex C	(informative) Design based on observations and experimental models	64
Annex D	(informative) Reliability of geotechnical structures	72
Annex E	(informative) Code calibration	80
Annex F	(informative) Structural robustness	89
Annex G	(informative) Optimization and criterion on life safety	101
Bibliography		111

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: [Foreword — Supplementary information](#).

The committee responsible for this document is ISO/TC 98, *Bases for design of structures*, SC 2, *Reliability of structures*.

This fourth edition cancels and replaces the third edition (ISO 2394:1998), which has been technically revised.

Introduction

The present fourth edition of this International Standard is intended to reflect advances in the common basis for decision making related to load-bearing structures relevant to the construction industry. Advances range from the development of systematic and rational treatment of risk to implementation of reliability-based design through codes and standards.

Compliance with this International Standard should therefore promote harmonization of design practice internationally and unification between the respective codes and standards such as for actions and resistances for the respective structural materials.

The principles and appropriate instruments to ensure adequate levels of reliability provide for special classes of structures or projects where the common experience base need to be extended in a rational manner.

In particular, a risk framework has been introduced which is scenario based, facilitates unified modelling approaches over different applications, accounts for consequences of both a direct and indirect nature, and has emphasis on robustness.

Whereas requirements to safety and reliability in the previous edition of this International Standard took their basis in efficiency requirements of a heuristic character, these are now based on risk considerations and socio-economics. This, in turn, facilitates a more relevant use of the International Standard in the context of sustainable societal developments and adaptation for application of the International Standard in different nation states in accordance with economic capacity and preferences.

The present International Standard, thus, enables the possibility to regulate, verify, and document the adequate safe performance of structures and also to consider them in a broader sense as part of societal systems. The International Standard provides for approaches at three levels, namely the following:

- risk informed;
- reliability based;
- semi-probabilistic.

The methodical basis for this edition of ISO 2394 is described in the Probabilistic Model Code^[8] and Risk Assessment in Engineering — Principles, System Representation and Risk Criteria^[9] by the Joint Committee on Structural Safety (JCSS), and EN 1990 (2007), where the reader will find additional information of relevance for its use.

Informative Annexes are included to this International Standard as a support to its users in the interpretations and use of the principles contained in its clauses.

Australian Standard®

General principles on reliability for structures

1 Scope

This International Standard constitutes a risk- and reliability-informed foundation for decision making concerning design and assessment of structures both for the purpose of code making and in the context of specific projects.

The principles presented in this International Standard cover the majority of buildings, infrastructure, and civil engineering works, whatever the nature of their application and use or combination of the materials used¹⁾. The application of this International Standard will require specific adaptation and detailing in special cases where there are potentially extreme consequences of failure²⁾.

This International Standard is intended to serve as a basis for those committees responsible for the task of preparing international standards, national standards, or codes of practice in accordance with given objectives and context in a particular country.

The present International Standard describes how the principles of risk and reliability can be utilized to support decisions related to the design and assessment of structures and systems involving structures over their service life. Three different but related levels of approach are facilitated, namely, a risk-informed, a reliability-based, and a semi-probabilistic approach.

The general principles are applicable to the design of complete structures (buildings, bridges, industrial structures, etc.), the structural elements and joints making up the structures and the foundations. The principles of this International Standard are also applicable to the successive stages in construction, the handling of structural elements, their erection, and all work on-site, as well as the use of structures during their design working life, including maintenance and rehabilitation, and decommissioning.

Risk and reliability are concepts accounting for and describing actions, structural response, durability, life-cycle performance, consequences, design rules, workmanship, quality control procedures, and national requirements, all of which are mutually dependent.

The application of this International Standard necessitates knowledge beyond what is contained in the Clauses and the Annexes. It is the responsibility of the user to ensure that this knowledge is available and applied.

2 Terms and definitions

2.1 General terms

2.1.1

structure

organized combination of connected parts including geotechnical structures designed to provide resistance and rigidity against various actions

2.1.2

structural member

physically distinguishable part of a structure, e.g. column, beam, plate, foundation

1) The present International Standard is completely general from the perspective of basic principles and can be applied for any structure below, on, and over the surface of the Earth.

2) This concerns, for example, structures of nuclear power plants and offshore oil and gas facilities in highly sensitive environments.

2.1.3**system**

bounded group of interrelated, interdependent, or interacting members forming an entity that achieves a defined objective in its environment through interaction of its parts and interactions of its parts with the environment

2.1.4**structural system**

load-bearing members of a building or civil engineering structure and the way in which these members function together and interact with the environment

2.1.5**requirement**

demand with respect to structural aspects like safety for people and environment, functionality, usage, and commitment of resources and cost efficiency

2.1.6**compliance**

fulfilment of specified requirements

2.1.7**life cycle**

life cycle incorporates initiation, project definition, design, construction, commissioning, operation, maintenance, refurbishment, replacement, deconstruction, and ultimate disposal, recycling, or re-use of the structure (or parts thereof), including its components, systems, and building services

2.1.8**reliability**

ability of a structure or structural member to fulfil the specified requirements, during the working 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.

2.1.9**structural safety**

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

2.1.10**durability**

capability of a structure or any structural member to satisfy with planned maintenance the design performance requirements over a specified period of time under the influence of the environmental actions

2.1.11**exposure events**

events which may cause damage or otherwise affect the performance indicators for the structure

2.1.12**assessment**

total set of activities performed in order to verify the reliability of an existing structure

2.1.13**upgrading**

modifications of an existing structure, construction works, and procedures to improve its structural performance or facilitate its use for new purposes

2.1.14**repair (of a structure)**

restoring the condition of a structure that has been damaged or deteriorated

2.1.15**rehabilitation**

repairing or upgrading of an existing structure

2.1.16**monitoring**

frequent or continuous, normally long-term, observation or measurement of structural conditions or actions or structural response

2.1.17**inspection**

on-site examination within the scope of quality control and condition assessment aiming to assess the present condition of a structure

2.1.18**constituent events**

events associated with damage or failure of structural members or parts of these, such as individual cross sections and joints

2.1.19**reliability-based design**

design procedure that is subjected to prescribed reliability level of the structure

2.1.20**member reliability**

reliability of a single structural member which has one single dominating failure mode

2.1.21**system reliability**

reliability of a system of more than one relevant structural member or a structural member which has more than one relevant failure mode

2.1.22**population**

set of entities for which the same probabilistic descriptions (mean values, etc.) are valid

2.1.23**outcome space**

set of all possible outcomes of a random phenomenon

2.1.24**constituent**

component or ingredient contributing to a certain performance

2.1.25**performance indicator**

parameter describing a certain property of the structure or a certain characteristic of the structural behaviour

2.1.26**structural performance**

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

2.1.27**resistance**

ability of a structure (or a part of it) to withstand actions without failure

2.1.28**quality control**

activities to control quality of design, execution, use, and decommissioning of a structure

2.1.29**damage**

unfavourable change in the condition of a structure that can affect the structural performance unfavourably

2.1.30**collapse**

development of failure mechanisms in a structure to a degree involving disintegration and falling (parts of) structural members

2.1.31**deterioration**

process that adversely affects the structural performance including reliability over time

Note 1 to entry: Deterioration may be caused by naturally occurring chemical, physical, or biological actions, normal or severe environmental actions, repeated actions such as those causing fatigue, wear due to use, and improper operation and maintenance of the structure.

2.1.32**serviceability**

ability of a structure or structural member to perform adequately for a normal use under all expected actions

2.1.33**scenario description**

determination of different sequences of events which affect the performance indicators, taking into account the likelihood of occurrence

2.1.34**consequence class**

categorization of the consequences of structural failure

2.1.35**reliability class**

class of structures or structural members for which a particular specified degree of reliability is required

2.1.36**reliability differentiation**

socio-economic optimization of the resources to be used to build construction works, taking into account all the expected consequences of failures and the cost of the construction

2.1.37**hazard scenario**

set of situations, transient in time, that a system might happen to undergo and which may endanger the system itself, the people, and the environment

2.1.38**risk-informed design**

design optimized with due consideration of the total risks, including loss of lives and injuries, damages to the qualities of the environment, and monetary losses

Note 1 to entry: Risk-based design is presently not generally accepted by all national standards and codes.

2.1.39**safety plan**

plan specifying the performance objectives, the hazard scenarios to be considered for the structure, and all present and future measures (design, construction, or operation, e.g. monitoring) to ensure the safety of the structure

2.1.40**risk**

effect of uncertainty on the objectives

Note 1 to entry: From the view point of the decision theory, risk is the expected value of all undesirable consequences, i.e. the sum of all the products of the possible consequences of an event and the corresponding probabilities.

2.1.41**marginal lifesaving cost**

increment of cost associated with saving one additional life through additional safety measures

2.1.42**risk screening**

investigation into and classification of risks identified for all the hazard situations

2.1.43**Life Quality Index****LQI**

indicator of the societal preference and capacity for investments into life safety expressed as a function of GDP, life expectancy at birth, and ratio between leisure to working time

2.1.44**utilisation plan**

plan containing the intended use (or uses) of the structure and listing the operational conditions of the structure including maintenance requirements and the corresponding performance requirements

2.1.45**reliability target**

specified average acceptable failure probability that is to be reached as close as possible

Note 1 to entry: Reliability targets are generally model dependent and need to be set for each case considered based on the models used.

2.1.46**robustness****damage insensitivity**

ability of a structure 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

2.1.47**hazard**

unusual and severe threat, e.g. a possible abnormal action or environmental influence, insufficient strength or stiffness, or excessive detrimental deviation from intended dimensions

2.2 Terms related to design and assessment**2.2.1****design/assessment situations**

set of physical conditions representing a certain time interval for which it shall be demonstrated that relevant limit states are not exceeded

2.2.2**persistent design situation**

normal condition of use for the structure

2.2.3**transient design situations**

provisional condition of use or exposure for the structure, for example, during its construction or repair, representing a time period much shorter than the design working life

2.2.4**accidental design situations**

design situation involving possible exceptional conditions for the structure in use or exposure, including flooding, fire, explosion, impact, mal-operation of systems, or local failure

2.2.5**seismic design situation**

design situation involving the exceptional conditions when the structure is subjected to a seismic event

2.2.6**failure**

insufficient load-bearing capacity or inadequate serviceability of a structure or structural member, or rupture or excessive deformation of the ground, in which the strengths of soil or rock are significant in providing resistance

2.2.7**limit states**

state beyond which a structure no longer satisfies the design criteria

2.2.8**ultimate limit states**

limit states concerning the maximum load-bearing capacity

2.2.9**design criteria**

quantitative formulations describing the conditions to be fulfilled for each limit state

2.2.10**serviceability limit states**

limit state concerning the criteria governing the functionalities related to normal use

2.2.11**irreversible limit states**

limit states which will remain permanently exceeded when the actions which caused the exceedance are no longer present

2.2.12**reversible limit states**

limit states which will not be exceeded when the actions which caused the exceedance are no longer present

2.2.13**condition limit state**

well-defined and controllable limit state without direct negative consequences, which is often an approximation to a real limit state that cannot be well defined or is difficult to calculate

Note 1 to entry: In applications relating to durability aspects, the condition limit state is often referred to as the durability limit state.

2.2.14

limit state function

function $g(X_1, X_2, \dots, X_n)$ of the basic variables, which characterizes a limit state when $g(X_1, X_2, \dots, X_n) = 0$

2.2.15**basic variables**

variables representing physical quantities which characterize actions and environmental influences, material and soil properties, and geometrical quantities

2.2.16**design service life**

assumed period for which a structure or a structural member is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

2.2.17**model uncertainty**

basic variable related to the accuracy of physical or statistical models

2.2.18**aleatory uncertainty**

inherent variability typically associated with the loading environment, the geometry of the structure, and the material properties

2.2.19**epistemic uncertainty**

lack of knowledge that, in principle, can be reduced by measurements or improved theories

Note 1 to entry: The exact borderline between aleatory and epistemic is not always unambiguous.

2.2.20**hierarchical modelling of uncertainty**

random variable is a function of other random variables

2.2.21**probabilistic methods**

verification methods in which the relevant basic variables are treated as random variables, random processes, and random fields, discrete or continuous

2.2.22**reliability index**

β

substitute for the failure probability $\beta = -\Phi^{-1}(p_f)$ where Φ^{-1} is the inverse standardized normal distribution

2.2.23**target reliability (index)**

reliability (index) corresponding to acceptable safety or serviceability

2.2.24**semi-probabilistic or partial factors methods**

verification method in which allowance is made for the uncertainties and variability assigned to the basic variables by means of representative values, partial factors and, if relevant, additive quantities

Note 1 to entry: Partial factors may be related to individual random variables or global variables.

2.2.25**structural model**

idealisation of the structure, physical, mathematical, or numerical, used for the purposes of analysis, design, and verification

2.2.26**static system**

idealisation of the structure, used for the purposes of static analysis, design, and verification

2.2.27**levels of verification**

levels of the verification used to assess the compliance with the objectives for all design/assessment situations

Note 1 to entry: The following levels are commonly recognised: the risk level, the probabilistic reliability level, and the semi-probabilistic level.

2.2.28**First/Second Order Reliability Methods****FORM/SORM**

numerical methods used for determination of the reliability index β

2.2.29**reliability elements**

numerical quantities used in the partial factors format, by which the specified target reliability is assumed to be reached

Note 1 to entry: The reliability elements include partial factors and load combination factors.

2.2.30**characteristic value**

value 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.

2.2.31**reference period**

period of time used as a basis for assessing the design value of variable and/or accidental actions

2.2.32**nominal value**

value fixed on a non-statistical basis, for instance, on acquired experience or on physical constraints

2.2.33**alternative load path****ALP**

alternative for a load to be transferred from a point of application to a point of resistance

2.2.34**consequence reducing measures**

measure aiming at reducing the direct and indirect consequences of failure and thus the total risk

2.2.35**key element**

structural member upon which the ultimate limit state performance of the structure depends

2.2.36**code calibration**

determination of the reliability elements in a given code format in order to reach the reliability target

2.2.37**load testing**

test of the structure (or part of it) by loading to evaluate its behaviour or properties or to predict its load bearing capacity

2.3 Terms related to actions, action effects, and environmental influences**2.3.1****action**

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

2.3.2**individual action****single action**

action which can be assumed to be independent in time and space of any other action acting on the structure

2.3.3**permanent action**

action which is likely to act continuously throughout the design working life and for which variations in magnitude with time are small compared with the mean value

2.3.4**variable action**

action which is likely to act during a given design working life and for which the variation in magnitude with time is neither negligible nor monotonic

2.3.5**accidental action**

action which is unlikely to occur with a significant value during the design working life of the structure

2.3.6**fixed action**

action which has a fixed distribution on a structure such as its magnitude and direction are determined unambiguously for the whole structure when determined at one point of the structure

2.3.7**free action**

action that may have an arbitrary spatial distribution over the structure within certain limits

2.3.8**dynamic action**

action that may cause significant acceleration of the structure or structural members

2.3.9**static action**

action that will not cause significant acceleration of the structure or structural members

2.3.10**bounded action**

action that has a limiting value which cannot be exceeded and which is exactly or approximately known

2.3.11**design value of an action** **F_d**

value of an action used in semi-probabilistic verification calibrated to the reliability target

Note 1 to entry: In the partial factor method, the value is obtained by multiplying the representative value by the partial factor γ_F .

2.3.12**effect of actions**

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

2.3.13**prestress**

force applied intentionally to a structure by imposing deformations

2.3.14**geotechnical action**

action transmitted to the structure by the ground, fill, or groundwater

2.3.15**seismic action**

action caused by earthquake ground motions

2.3.16**imposed load**

load resulting from occupancy in buildings

2.3.17**construction load**

load specifically related to execution activities

2.3.18**environmental influences**

physical, chemical, or biological influences which may deteriorate the materials constituting a structure, which in turn may affect its serviceability and safety in an unfavourable way

2.3.19**load arrangement**

identification of the position, magnitude, and direction of a free action

2.3.20**representative value of an action**

one of the following quantities of an action: the characteristic value, nominal value, combination value, frequent value, and quasi-permanent value

2.3.21**combination value**

values 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

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

2.3.22**action model**

model describing the magnitude, position, direction, duration, etc. of the action

Note 1 to entry: Sometimes, there is an interaction between the components. There may, in certain cases, also be an interaction between the action and the response of the structure.

2.3.23**frequent value**

value 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 .

2.3.24**quasi-permanent value**

value 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 .

2.3.25**load case**

compatible load arrangement, set of deformations, and imperfections considered for a particular verification of a specific limit state

2.3.26**load combination**

design values of the different actions considered simultaneously in the verification of the reliability of a structure for a specific limit state

2.3.27**fundamental combination of actions**

combination of permanent actions and variable actions (the leading action plus the accompanying actions) in persistent and transient design situations used for verification of ultimate limit states in general

2.3.28**accidental combination of actions**

combination for accidental design situations, involving either an explicit accidental action (e.g. fire or impact) or the situation following an accidental event

2.3.29**characteristic combination of actions**

combination of permanent and variable actions used for verification of irreversible serviceability limit states

2.3.30**frequent combination of actions**

combination of permanent and variable actions used for verification of reversible serviceability limit states

2.3.31**quasi-permanent combination of actions**

combination of permanent and variable actions used for verification of long-term effects of serviceability limit states

2.4 Terms related to structural response, resistance, material properties, and geometrical quantities

2.4.1**material model**

model describing relations between internal forces or stresses and deformations including strain rates

Note 1 to entry: The parameters of such relations are modulus of elasticity, yield limit, ultimate strength, etc. which generally are considered as random variables. In some cases, they are time or space dependent. Often, there is a correlation between the parameters.

2.4.2**stiffness**

property relating deformation to the action causing it

2.4.3**characteristic value of a material property**

priori specified fractile of the statistical distribution of the material property in the relevant category

2.4.4**design value of a material property**

value of material property used in semi-probabilistic methods obtained by dividing the characteristic value by a partial factor γ_M or, in special circumstances, by direct assessment

2.4.5**conversion factor or function**

factors or functions which convert properties obtained from test specimens to those in calculation models

2.4.6**characteristic value of a geometrical quantity**

quantity usually corresponding to dimensions (nominal values) specified by the designer

2.4.7**geometrical properties**

geometrical data (dimensions, angles, etc.) describing the structure and the structural members

Note 1 to entry: A structure can generally be described by a model consisting of one-dimensional member, two-dimensional members and three-dimensional members. The geometrical quantities which are included in the model generally refer to nominal values.

2.4.8**design value of a geometrical quantity**

characteristic value adjusted by an additive or multiplicative quantity

3 Symbols**3.1 General**

The following symbols listed below are used generally throughout the document. Symbols which are used only in one section are explained there and not listed here. All the symbols are based on ISO 3898.

3.2 Latin upper case letters

A	accidental action
A_d	design value of an accidental action
A_{Ed}	design value of seismic action
A_{Ek}	characteristic value of seismic action
C	serviceability constraint
F	action in general
F_k	characteristic value of an action
F_{rep}	representative value of an action
F_d	design value of an action
G	permanent action
G_d	design value of a permanent action
$G_{d,inf}$	lower design value of a permanent action

$G_{d,sup}$	upper design value of a permanent action
$G_{k,j}$	characteristic value of a permanent action j
$G_{k,j,inf}$	lower characteristic value of a permanent action j
$G_{k,j,sup}$	upper characteristic value of a permanent action j
P	prestressing action
Q	variable action
Q_d	design value of variable action
Q_k	characteristic value of a variable action
$Q_{k,1}$	characteristic value of the leading variable action 1
$Q_{k,j}$	characteristic value of a variable action j
R	resistance
R_d	design value of the resistance
R_k	characteristic value of the resistance
S	action effect
S_d	design value of an action effect
$S_{d,dst}$	design value of destabilizing actions
$S_{d,stb}$	design value of stabilizing actions
X	basic variable
Y	model output variable

3.3 Latin lower case letters

a	geometrical quantity
Δa	additive geometrical quantity
m	material property
p_f	probability of failure
p_s	probability of survival
p_{ft}	target probability of failure
p_{fs}	specified value of p_f
t	time

3.4 Greek letters

β	reliability index
---------	-------------------

β_t	target reliability index
γ	partial factor
γ_f	partial factors for actions
γ_F	generalized partial factors for actions taking account model and geometric uncertainties
γ_G	partial factors for permanent actions
γ_Q	partial factors for variable actions
γ_m	partial factors for material properties
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
γ_I	factor by which the importance of the structure and the consequences of failure are taken into account
θ	factor of model uncertainties
θ_s	factor of model uncertainties for action effects
θ_R	factor of model of uncertainties for resistance
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
$g(X,t)$	limit state function

3.5 Subscripts

i	basic variable (action) number
j	basic variable (action) number
k	characteristic value
d	design value
1	leading action

4 Fundamentals

4.1 General

In this Clause, the aims and requirements, conceptual basis, approaches, and documentation to ensure an adequate level of risk and reliability for structures are outlined with an emphasis on the principles. In the subsequent clauses, the most central of these principles are described in more detail. In the Annexes to this International Standard, additional guidance and information is provided with respect

to aspects of special importance for its application including the role and use of quality control as an underlying prerequisite for its practical relevance.

4.2 Aims and requirements to structures

4.2.1 Fundamental requirements to structures

Structures shall be designed, operated, maintained, and decommissioned such as to support societal functionality and enhance sustainable societal development during their service life.

NOTE 1 Societal functionality encompasses the context of the structures with a focus on the functions structures provide for society. For example, an electricity mast is not just carrying electrical cables, but is providing electricity for industry and hospitals. The consequences of failure and thus also the requirements set for the performance of structures should be appreciated in this light.

In particular, the structures shall, with appropriate degree of risk and reliability, fulfil the following performance requirements:

- Function adequately under all expected actions throughout their service lives; providing service and functionality.
- Withstand extreme and/or frequently repeated and permanent actions, as well as environmental exposures occurring during their construction, anticipated use, and decommissioning; providing safety and reliability with respect to damage and failures.
- Be robust such as not to suffer severe damage or cascading failure by extraordinary and possibly unforeseen events like natural hazards, accidents, or human errors; providing sufficient robustness.

NOTE 2 Sustainability can be related to performance indicators such as the following:

- safety for people;
- reliability with respect to fulfilment of purposes;
- qualities of the environment;
- cost efficiency;
- minimized emission of CO₂;
- minimized consumption of natural resources;
- minimized use of energy.

The service life of a structure shall be accounted for and optimized with due consideration of the context of the structure and a holistic perspective to design and assessment. Fundamentally, decisions concerning service lives for structures shall be based on the duration of the need of the structure and the possibility to optimize service life benefits from the structure with a differentiated strategy for its individual components. Durability-based concepts for the design of structures are treated in ISO 13823.

4.2.2 Target performance level

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.

To ensure acceptable levels of risk, safety, and reliability of structures within the context of structural design and assessment decision making, acceptance criteria and other requirements shall be formulated, assessed, and complied with. Some of these requirements shall relate to demands on safety for personnel and environment set by the society. Others shall relate to the reliability of the functionality of the structures as specified by the owners.

The fundamental principle of the marginal lifesaving costs for the regulation of life safety applies and is recommended. The use of the marginal lifesaving principle ensures that the safety for people using or otherwise exposed to a structure has a certain level, such that the costs associated with saving additional lives through additional safety measures exceed the corresponding marginal lifesaving costs.

NOTE 1 The marginal lifesaving costs principle facilitates differentiation of requirements to risk and reliability ensuring that efforts of lifesaving are directed on activities and situations for which the efficiency of lifesaving is the highest. This principle can be seen to be coherent with the general formulation of the ALARP principle as described in [Annex G](#). To quantify the marginal lifesaving costs, a suitable method such as the Life Quality Index (LQI) applies. The same principle also forms the basis for the identification of target reliability levels for semi-probabilistic design codes, where target reliabilities are provided as a function of consequences of failure and safety improvement efficiency (see [Annex G](#)).

Depending on the characteristics of specific projects, structural performance requirements related to damages to the qualities of the environment, usage, and commitment of resources, as well as emissions to the atmosphere, can be relevant and shall be considered. In such cases, requirements shall be specified and fulfilled in terms of maximum annual frequencies of events of specified severities or expected values of total usage and/or emissions accordingly. These requirements shall then be seen and accounted for within an economic optimization as constraints or alternative objectives as described in [4.4.2.1](#).

NOTE 2 Requirements to the qualities of the environment, usage and commitment of natural resources and emissions to the atmosphere have as of yet not been formulated in general terms. However, in specific projects where the possible consequences in this respect are considerable, such as in offshore oil and gas exploitation in vulnerable environments, large dam project, etc., specific considerations with respect to such requirements should as a rule be part of the decision basis.

4.3 Conceptual basis

4.3.1 Decisions concerning structures

Decisions concerning structures shall be understood to encompass all decisions related to the process of designing, constructing, operating, maintaining, and decommissioning structures.

NOTE Decisions concerning structures affect the structures in terms of their resistances, deformations, movements, durability characteristics, safety, economy, material and energy consumption, etc. and thereby also their performances and their impact on sustainable developments. Typical decisions can, at the level of individual projects, include choices of the following:

- structural system;
- materials;
- cross-sectional properties;
- joints and structural detailing;
- inspection, testing, and monitoring in the laboratory and on site;
- active and passive measures of damage detection, prevention, and reduction;
- assessment, maintenance, and repair;
- retrofitting/strengthening;
- decommissioning;
- renewal.

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 of 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 (see also [Annex A](#)). In particular, for individual projects, the quality management and quality assurance shall address the following:

- quality plans;
- quality control of design;
- quality control of construction;
- quality control of materials, tools, and fabrication;
- quality control of worker qualifications, workmanship, and procedures;
- quality control of assumptions;
- documentation of quality control and quality management.

4.3.2 Structural performance modelling

Design decisions shall be assessed through the performance requirements listed in [4.2.2](#). Therefore, models should be established for these performance requirements, which allows for their quantification. The modelling of the performance requirements shall address all relevant issues concerning the intended use of the structures, the safety of people, as well as the qualities of the environment and economy throughout the entire life cycle of the structure (see also [4.2.2](#)). Special considerations shall be given to the modelling of the interaction between the structure and its surroundings (i.e. any exposure the structure is subjected to and also the exposures which the structure might influence), dependencies between the structure and, for example, possible mechanical and electrical systems, as well as the influence of human and organizational errors. The models shall be established taking basis in a scenario description of the different sequences of events which affect the performance, taking into account their likelihood of occurrence and their consequences.

In the identification and description of the scenarios of events which are relevant, the following events shall be differentiated:

- Exposure events; actions, human errors and chemical environment.
- Constituent damage and failure events; direct consequences.
- Loss of function and/or cascading failures (progressive failure); indirect consequences.

NOTE 1 The exposure events represent all events which can cause damage or otherwise affect the performance indicators for the structure. Examples hereof include operational and environmental loads, aggressive chemicals, human errors, poor quality of design, materials and construction, etc. It is important to represent also scenarios of exposure events such as, for example, jointly acting loads and other environmental and chemical processes.

NOTE 2 The constituent damage and failure events are those associated with damage or failure of parts of the structure, such as individual cross sections and joints. The modelling of the performance of the individual constituents, that is, to which degree they are damaged or fail for a given scenario of exposures, is supported by the formulation and analysis of limit state functions (see [Clause 5](#)).

NOTE 3 Loss of function and/or cascading failures of the structure which can follow constituent damages and failures and lead to indirect consequences is related to robustness. The quantification of the associated risks is described in [Annex F](#) (see, for example, [Formula F.4](#)).

4.3.3 Uncertainty and treatment of knowledge

Decisions concerning structures shall account for all uncertainties of relevance for their performances such as inherent natural variability (aleatory uncertainty) and lack of knowledge (epistemic uncertainty).

Uncertainties shall be represented in the decision process through probabilistic models such as random variables, stochastic processes, and/or random fields. The probabilistic modelling shall address the representation of temporal and spatial dependency among the considered uncertainties and events. Moreover, possible non-ergodic phenomena, such as effects of climate changes and demographical developments shall be addressed in the modelling.

NOTE 1 The Bayesian probability theory forms the basis for full risk and reliability-based design and assessment (see [4.4.2](#) and [Clause 6](#)). Moreover, Bayesian probabilistic modelling forms the basis for semi-probabilistic design standards and regulations (see [4.4.3](#)) through calibration (see [Annex E](#)).

The quantification of uncertainties and their probabilistic representation shall facilitate for the incorporation of both subjective information and available evidence.

NOTE 2 When a new structure is designed, the knowledge about several aspects is still at a very generic level. The associated uncertainties are therefore relatively large and are modelled taking into account data and experience accumulated over time which is representative for given quality control schemes and other specifications (see [Annexes A](#) and [C](#)). In the context of existing structures and in connection with testing, monitoring and inspection, and maintenance planning, it is important to take benefit from (Bayesian) updating of probabilistic models (See [Annex B](#)). In this manner, as more and more evidence in terms of observations are brought into the assessment, risks and reliabilities will gradually be updated.

For design of structures based on codified load and resistance factor or partial safety factor design (see [4.4.3](#)), uncertainties shall be represented through design values and characteristic values together with specified design equations, load cases, and load combination factors. The characteristic values shall, when relevant, account for available information relating, for example, to loads and material properties. Semi-probabilistic approaches to design and assessment of structures are treated in detail in [Clause 9](#).

4.4 Approaches

4.4.1 General

Design and assessment decisions shall take basis in information concerning their implied risks. When the consequences of failure and damage are well understood and within normal ranges, reliability-based assessments can be applied instead of full risk assessments. Semi-probabilistic approaches as a further simplification are appropriate when in addition to the consequences also the failure modes and the uncertainty representation can be categorized and standardized.

Risk- and reliability-based approaches shall be applied for the calibration of semi-probabilistic approaches, as well as for supporting design and assessment decisions for special structures and projects which are not covered by semi-probabilistic codes.

4.4.2 Risk-informed and reliability-based approaches

4.4.2.1 Risk-informed decisions concerning design and assessment

In a risk-informed design and/or assessment, the decisions shall be optimized with due consideration of the total risks, considering loss of lives and injuries, damages to the qualities of the environment, and monetary losses. The time horizon to be considered in the assessment of the total risks shall be determined on the basis of the duration of the functionality which the structure shall provide.

The assessment of the total risk shall take basis in a scenario representation (see also [Annex E](#)) and by probabilistic models of the exposures, the constituent damage, and failure events, as well as the direct and indirect consequences.

The performances of structures related to life safety and qualities of the environment, should be assessed with respect to their acceptability (see 4.2, [Clause 7](#), and [Annex G](#)). Within these constraints, decisions shall be optimized on the basis of a maximization of the expected value of benefits; in this process, other indicators can be considered, insofar as these are consistent with the principles contained in this Clause. Acceptance criteria as described in 4.2.2 shall be considered as constraints to the optimization and should be included in the verification of the design and assessment decisions. The principle is illustrated in [Figure 1](#).

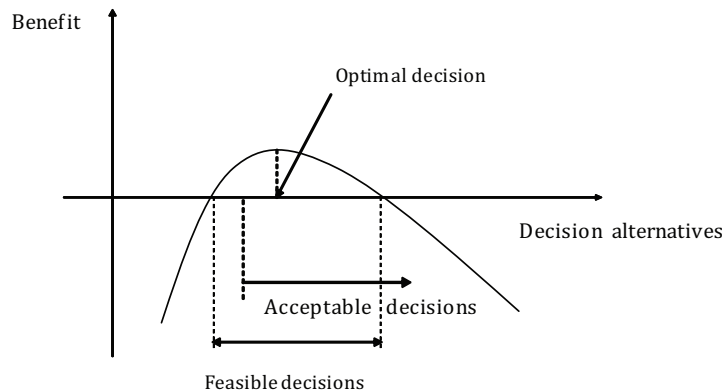


Figure 1 — Illustration of the optimization principle for the maximization of benefits

NOTE 1 The possible decision alternatives are arranged along the x-axis in [Figure 1](#), corresponding to increasing reliability. The benefit indicated on the y-axis is representative for the expected net benefits associated with the different decisions over the considered period of time. In the illustration in [Figure 1](#), the decisions are of a continuous nature; however, discrete decisions or combinations hereof can be organized and illustrated in a similar manner. From [Figure 1](#), it is seen that only some decisions are feasible in the sense that they yield a positive net benefit. One of the feasible decisions is optimal but this decision might or might not be acceptable.

All anticipated future consequences shall be accounted for in the assessment of the risks. This includes both the consequences which are associated with uncertainty and the consequences which are deterministically related to decisions, such as committed future costs due to planned inspections and maintenance or compensation costs for lives which potentially can be lost during the lifetime of the structure (as explained in [Annex B](#) and [Annex G](#)).

In the assessment of the net present value of future costs, the interest rate to be used shall be chosen carefully. Considering decisions regarding structures which are made on behalf of society, the default annual discounting rate is the long-term annual economic growth rate and varies by country. The same applies when assessing the net present value of expenditures committed for lifesaving activities.

For structures where failure and damage can imply very serious consequences, a risk-based robustness assessment shall be undertaken as a part of the design and/or assessment verification.

NOTE 2 [Annex F](#) describes the methodology for risk-based robustness assessments. For operational purposes, it might be convenient to introduce a categorization of structures in accordance with their consequences of failure and, on the basis of this categorization, decide whether a risk-based robustness assessment is necessary or not. [Annex F](#) also contains a suggestion for such a categorization.

4.4.2.2 Reliability-based design and assessment

As an alternative to risk-based design and assessment of structures, a reliability-based approach can be chosen. This approach shall utilize an assessment and minimization of costs and/or minimization of committed resource usage subject to given reliability requirements for the structure. The reliability requirements shall be assessed on the basis of a full risk-informed assessment as described in [4.4.2.1](#)

and will thus facilitate reliability differentiation in dependency of consequences of failure and costs of reliability improvements.

NOTE 1 The reliability requirements will, in general, depend on societal capacity to invest into lifesaving activities and will thus be specific from nation state to nation state. In [Annex G](#), it is shown how reliability requirement as a function of failure consequences and costs of reliability improvements can be established for a given nation state.

The general principles for reliability based design and reliability informed decision making are specified in [Clause 8](#).

4.4.3 Semi-probabilistic approaches

For structures for which the consequences of failure and damage are well understood and the failure modes can be categorized and modelled in a standardized manner, semi-probabilistic codes are appropriate as basis for design and assessment. Standards shall serve to ensure the quality of analysis, design, materials, production, construction, operation and maintenance, and documentation, and thereby explicitly or implicitly account for the uncertainties which influence the performance of the structures. The specifications given in standards should be developed such that they quantify all known uncertainties.

Semi-probabilistic design and assessment codes shall comprise a safety format prescribing the design equations and/or analysis procedures which shall be used for the verification of design and assessment decisions. The safety format shall also cover the load combinations which should be considered, as well as the scheme for calculating design values for actions and action effects, material properties, and other parameters associated with uncertainty of relevance for the design.

NOTE 1 The principles for the modelling of limit states, resistances, loads, and actions with due consideration to the relevant uncertainties are described in [Clause 5](#) and [Clause 6](#).

The design values applied for verification of design and assessment decisions shall be related explicitly to structural reliability using principles of reliability analysis as described in [Clause 9](#). When developing design and assessment codes, design values shall be calibrated such that the level of reliability achieved for a structure of a certain type and use designed according to the code is close to the prescribed target nominal reliability (See [4.2](#), [8.3](#), and [Annex G](#)).

NOTE 2 In the text above, reference is made to nominal reliabilities with the aim to emphasize that the actual structural reliability can deviate from the reliability which is modelled and quantified. Such deviations are mainly caused by exclusion of human and organizational errors in the modelling.

For design and assessment of structures based on load and resistance factors or partial factors, the system performance shall be ensured, depending on the consequences of system failure, either through risk-based robustness assessments or through robustness provisions. The latter includes critical member design, structural ties, and structural segmentation and depends on the structural system and the consequences of system failure (See [Annex F](#)).

4.5 Documentation

Decisions related to the design of structures, as well as their verification with respect to acceptance criteria, shall be documented in a manner that is tractable and transparent for all involved stakeholders. This concerns design and assessment of individual structures, as well as development and calibration of design codes.

The documentation shall include all relevant information utilized for the design and assessment of the structures, including site-specific data, test results, models of the performance indicators, inspection results, information regarding damages, as well as maintenance and repairs, acceptance criteria and their verifications, quality control schemes and results, etc.

In addition, all relevant assumptions shall be identified, discussed with respect to their significance for the risk and reliability of the structure, and documented. This also includes assumptions concerning

the use of the structures, envisaged maintenance, as well as possible requirements to the performance specified by the owner of the structure.

NOTE More details and suggestion on the documentation of decision related to structures can be found in [Annex A](#), where also a birth certificate is suggested in certain cases.

5 Performance modelling

5.1 General

5.1.1 Structural performance and limit state concept

In order to assess the structural performance of a structure, the possible structural responses shall be assessed and divided into two domains consisting of desirable and undesirable states. The boundary between these domains is called the limit state and entering the undesirable domain is defined as failure. The limit state concept is elaborated further in [5.3](#).

NOTE 1 In general, this limit state concept is very helpful in assessing the performance of a structure. In some cases, however, there is a more gradual transition from desirable to undesirable behaviour with increasing costs of malfunctioning.

NOTE 2 The desirable performance can depend on the stakeholders like founders, owners, residents, operators, users, neighbours (if construction interferes with them), and contractors. Other stakeholders are the government and the society. Generally, the latter group is primarily interested in issues like safety and sustainability.

5.1.2 Performance and performance indicators

The performance of a structure relates to the structure as a whole or parts of it. In order to assess the performance, one shall select a set of quantitative performance indicators, which express physical states that can be used in relation to the performance requirements. Performance indicators can be defined on various levels of abstraction for the following:

- structural characteristics (e.g. stiffness/flexibility, load bearing capacity);
- response parameters (e.g. internal forces, stresses, deflections, accelerations, crack sizes);
- utilization factors;
- functionalities (e.g. safety for people, energy consumption, robustness, usability, availability, failure probabilities).

Models shall be set up to establish the relation between the various levels (see [Clause 6](#)).

5.1.3 Basic performance requirement and design situations

The performance requirements of [Clause 4](#) shall be met for all relevant design/assessment situations, which can be classified as

- persistent situations, which refer to conditions of normal use of the structure,
- transient situations, which refer to temporary conditions of the structure, in terms of its use or its exposure, and
- accidental situations, which refer to exceptional conditions of the structure or its exposure.

In the elaboration of the performance requirements for the various design situations, spatial aspects, time variability, and deterioration shall be taken into account where relevant.

5.1.4 Levels of verification

In order to verify whether the structure is in compliance with the objectives for all design/assessment situations, one of the following levels shall be chosen:

- a) Risk based: It shall be proven that, provided human safety aspects are taken care of in consistency with [Clause 4](#) and/or local public law and codes, the sum of all costs (building costs, maintenance etc.) and economic risks (with respect to failure or malfunctioning) is at a minimum.
- b) Reliability based: The structure shall fulfil a set of reliability requirements formulated as maximum admissible failure probabilities or minimum values for the reliability levels.
- c) The semi probabilistic level: The structure shall fulfil a set of inequalities using certain design values of the basic variables.

The risk-informed level of verification is to be considered as the highest level. Lower levels of verification shall be calibrated to the higher levels using code calibration principles as per [Clause 9](#).

NOTE Usually this calibration is performed by code committees allowing the designer to use level 3 verification methods; only for special structures a reliability or risk-based verification will be performed.

At all levels, use shall be made of limit state concepts and performance models (see [5.2](#) and [5.3](#)).

5.2 Performance model

5.2.1 General

To establish the relation between exposures and structural properties on the one hand and the performance indicators on the other, a set of models shall be used.

Models shall be established to represent the structure itself, the environment (soil, water, air), as well as all relevant interactions of a mechanical, physical, chemical, biological, or anthropogenic nature. In many cases, it might be relevant to consider models for a system consisting of several structures, environmental entities, non-structural elements, devices and machinery, control systems, etc.

The degree of accuracy of models shall be chosen such that it is adequate for the application at hand; the corresponding uncertainties in the models shall be identified and defined as measurable quantities.

NOTE In general, it might be helpful to start with a risk-screening procedure followed by the definition of a set of hazard scenarios. The term hazard scenario refers to a set of situations, transient in time, that a system might happen to undergo and which can endanger the system itself, people, and the environment.

5.2.2 Time-dependent aspects

Performance models should consider ergodic, as well as non-ergodic (random and systematic), time variability of loads and structural properties.

In particular, one shall consider the following:

- time variability when analysing load effects due to simultaneous actions;
- dynamic effects when inertia forces are significant;
- degradation mechanisms, which can be of a mechanical nature (like fatigue, load duration effects), a physical/chemical nature (corrosion, chloride ingress,) or a combination thereof (stress corrosion).

In the last case, it might be necessary to include inspection, monitoring, and maintenance in the model.

NOTE See [Annex B](#).

5.2.3 System aspects

The verification of the performance requirements shall consider and include the following:

- all relevant failure modes;
- interaction between failure modes;
- interactions between the structure and its environment (wind, water, soil, use);
- non-structural elements (partitions, ceilings, finishing, relevant electric, hydraulic, and mechanical devices);
- inspection and repair activities, quality management;
- functionality;
- environmental aspect (energy consumption, noise production);
- sustainability aspects (impact on human health, social property, biodiversity).

An adequate system level for the assessment procedure shall be selected; proper attention shall be given to a correct formulation of the physical and functional boundary conditions.

NOTE The latter is often achieved by code committees defining a set of constraints; for environmental and sustainability aspects, these constraints are still under development.

5.3 Limit states

5.3.1 Ultimate limit state

Ultimate limit states pertain to the following undesirable states (non-exhaustive):

- loss of equilibrium of the structure or part of it considered as a rigid body;
- instantaneous attainment of the maximum capacity of cross sections, members or connections by yielding, rupture or excessive deformations;
- failure of members or connections caused by fracture, fatigue, or other time-dependent accumulation effects;
- instability of the structure or part of it;
- sudden change of the assumed structural system to a new system (e.g. snap through, large crack formation);
- foundation failure.

The exceedance of an ultimate limit state is almost always irreversible and the first time that this occurs causes failure. The ultimate limit state can be the result from a single extreme action event or from a deterioration process over time followed by a (less) extreme action event.

Ultimate limit states can refer to structural elements, as well as to global structural systems; the latter including the effects of robustness (see [Annex F](#)).

5.3.2 Serviceability limit states

Serviceability limit states deal with loss of intended functionality related to normal use and can in particular pertain to the following undesirable states (non-exhaustive):

- 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;
- local damage (including cracking) which can reduce the durability of the structure or make the structure unsafe for use.

NOTE The last category is often referred to as the durability limit state (as for instance in ISO 13823).

In the cases of permanent local damage or permanent unacceptable deformations, the exceedance of a serviceability limit state is called irreversible and the first time that this occurs causes failure.

In other cases, the exceedance of a serviceability limit state can be reversible and then failure occurs:

- The first time the serviceability limit state is exceeded, if no exceedance is considered as acceptable.
- If exceedance is acceptable but the time when the structure is in the undesirable state is longer than accepted.
- If exceedance is acceptable but the number of times that the serviceability limit state is exceeded is larger than specified.
- If a combination of the above criteria occur.

These cases can involve temporary local damage (e.g. temporarily wide cracks or leakage), temporary large deformations, and vibrations. Limit values for the serviceability limit state should be defined on the basis of their consequences.

5.3.3 Condition limit states

The condition limit states can correspond to the following situations:

- An approximation to the real limit state that is either not well defined or difficult to calculate. Examples are the use of the elastic limit as ultimate limit state and the use of depassivation as a limit state for durability (often also referred to as the initiation limit state).

NOTE 1 Theoretically, the requirement for sufficient durability is already covered by the fact that safety and serviceability are required for a certain period of time. However, for practical reasons it might be helpful to add specific durability related limit states (as in ISO 13823 and ISO 13822) or limit states referring to certain (non-critical) conditions. The reliability requirement for the condition limit state should be consistent with the original ultimate limit state.

- Local damage (including cracking) which can reduce the durability of the structure or affect the efficiency or appearance of structural or non-structural elements.
- Additional limit state thresholds in the case of a continuously increasing loss function.

NOTE 2 As mentioned in Note 1 of [5.1.1](#), a limit state presupposes the occurrence of a sudden loss when the exposure or circumstances only change little. If however in some case the losses occur gradually, a solution might be to introduce a subdivision of the undesired outcome space corresponding to several loss levels. As an example, it can be useful to define it like the limit states of initial damage, repair, and collapse in earthquake analysis.

5.3.4 Limit state function

For each specific limit state model, which describes the behaviour/performance of a structure, where available, a limit state function shall be established and the relevant basic variables shall be identified.

The limit state function is denoted as $g(\mathbf{X})$, where $\mathbf{X} = (X_1, X_2, \dots)^T$ are the basic (random) variables.

Formula (1)

$$g(\mathbf{X}) = 0 \quad (1)$$

is called the limit state equation and the inequality

$$g(\mathbf{X}) < 0 \quad (2)$$

identifies the undesirable domain.

The set of basic variables $\mathbf{X}$ shall be defined in such a way that it contains all necessary random input information for the model; in general, the set of basic variables will consist of the following:

- a) physical quantities, which characterize actions, environmental influences, material and soil properties, and geometrical dimensions;
- b) model parameters that specify the model itself;
- c) parameters that describe requirements related to the performance of the structural system (serviceability limits).

The limit state function can also contain explicit deterministic parameters and the time, t .

NOTE 1 For ultimate limit states and irreversible serviceability limit states, the minimum value $g(\cdot)$ during the anticipated working life usually is decisive; for reversible limit states, a number of crossings or a certain (cumulated) time spent in the failure domain can be acceptable.

NOTE 2 The serviceability limit state can be defined by introducing a serviceability constraint, for instance, a displacement limit that is equal to c times the span L of a structural member. The constraint constant c (e.g. $c = 1/500$) in those cases can be interpreted as the design value of an underlying random variable. In that case, c can also be introduced as a random basic variable.

NOTE 3 In a component analysis where there is one dominating failure mode, the limit state condition can normally be described by a single equation according to [Formula \(1\)](#). In a system analysis, where more than one failure mode can be governing, there are several such equations. In a general system, the various failure modes can be represented in the form of mixtures of logical series and parallel systems.

6 Uncertainty representation and modelling

6.1 General

6.1.1 Types of uncertainty

Basic variables as defined in [5.3.4](#) can be representing one or more sources of uncertainty, as for instance inherent natural variability, statistical uncertainties, measurement uncertainties, uncertainties such as related to the precision of new information, and model uncertainties. All main sources of uncertainty shall be identified.

NOTE 1 The physical uncertainties are typically uncertainties associated with the loading environment, the geometry of the structure, and the material properties and are often referred to as aleatory uncertainties.

NOTE 2 Uncertainties arising from insufficient information, for example, due to a small number of materials tests or idealized models, are often referred to as epistemic uncertainty.

NOTE 3 A random variable can represent both aleatory and epistemic uncertainties. Furthermore, uncertainty can change nature in different phases of the lifetime of a structure. For example, a material property is considered as aleatory uncertainty before the construction of a structure; once the structure is constructed, it can be considered as epistemic uncertainty.

NOTE 4 In geotechnical design, the predominant sources of uncertainties are the soil properties and the calculation model uncertainty. These main sources of uncertainties are characterized in [Annex D](#). Furthermore, [Annex D](#) presents the probabilistic modelling and incorporation of uncertainty into reliability analysis and design of geotechnical structures.

6.1.2 Treatment of uncertainty

All uncertainties that are considered to be of importance for the reliability assessment of a structural system shall be considered in the analysis using the theory of probability.

NOTE In the structural reliability analysis, no distinction should be made between the treatment of aleatory and epistemic uncertainties. This differentiation is introduced only for the purpose of setting focus on how uncertainty can be reduced by additional testing or more detailed research. It can also be a relevant issue in risk communication and the updating of structural reliability (see [Annex B](#)).

6.1.3 Interpretation of probability

In structural reliability analysis, the Bayesian interpretation of probability should be considered as the most adequate basis for the consistent representation of uncertainties, independent of their sources. It facilitates the joint consideration of purely subjectively assessed uncertainties, analytically assessed uncertainties and evidence as obtained through observations.

NOTE 1 In the Bayesian probability theory, the values for probabilities are estimated on basis of an adequate combination of data, theoretical arguments, and judgment. There is no distinction in the treatment between aleatory and epistemic uncertainty. If large amounts of data are available, the Bayesian interpretation coincides with the frequentistic one.

NOTE 2 Considering the probabilistic modelling of a random basic variable X , the principle in the Bayesian probability analysis is to model one or more of the parameters θ (e.g. the mean or standard deviation) of the probabilistic model (e.g. the probability distribution function) as random variables themselves. The frequentistic or subjective information available about X can then be used in the probabilistic modelling of θ .

6.1.4 Probabilistic models

Depending on the nature of the reliability problem, basic variables can be represented as random variables, random processes, and random fields, discrete as well as continuous.

The probabilistic models shall describe the characteristics of the uncertainties of individual random basic variables, but also accommodate the consideration of the dependencies among them.

NOTE 1 Dependencies often arises due to causality, spatial and/or temporal correlations and/or ergodic states of underlying phenomena, as well as statistical and/or model uncertainties that commonly affect the uncertainties of the individual variables.

NOTE 2 Although in some cases it is necessary to model uncertain phenomena through random processes/fields, it is often convenient and acceptable to focus only on extremes and represent them through extreme value distributions, as far as ultimate limit states are concerned.

The probabilistic models should also accommodate the updating of the models by additional information, which can become available with, for example, experiments, tests, inspection, and monitoring. The Bayesian updating formula provides the operational basis for this.

NOTE Detailed information can be found in [Annexes B](#) and [C](#).

6.1.5 Population/outcome space

The description of uncertain quantities by probabilistic models shall correspond to well-defined outcome spaces (or populations) and the results of the reliability analyses are only valid for the same sets.

NOTE 1 The word population seems to be more appropriate for aleatory variables, while outcome space is used for epistemic uncertainties.

The basis for the definition of an outcome space or population is in most cases given from the physical phenomenon defining or influencing the variable. Factors which can characterize the population are the following:

- Nature and origin of a random quantity.
- Spatial conditions (e.g. the geographical region considered).
- Temporal conditions (e.g. the design service life). The choice of a population shall be made with due consideration to the objective of the analysis and the amount and nature of the available data.

NOTE 2 It can, for instance, be convenient to subdivide a population into sub-populations (micro-zonation). When the results are used for design in a national or international code, it might be necessary or convenient to put the sub-populations together to the large population again in order not to get too complicated rules. This implies that the variability within the population is increased.

6.1.6 Hierarchical modelling of uncertainty

A hierarchical modelling is recommended for modelling different kinds of actions and materials, where applicable. The hierarchical model assumes that a random quantity X can be written as a function of several variables, each one representing a specific type of variability:

$$X_{ijk} = f(Y_i, Y_{ij}, Y_{ijk}) \quad (3)$$

The variables Y_i , Y_{ij} , Y_{ijk} represent various origins, time scales of fluctuation, or spatial scales of fluctuation.

NOTE For instance, Y_i can represent the constant in time variability, Y_{ij} a slowly fluctuating time process, and Y_{ijk} a fast-fluctuating time process. In the case of wind, we can have Y_i as the (model) uncertainty in the wind pressure coefficient C_p , Y_{ij} the mean hourly wind speed v_h , and Y_{ijk} the zero mean gust process $v(t)$:

$$X_{ijk} = \frac{1}{2} \rho C_p (v_h^2 + 2v_h v) \quad (4)$$

where

ρ is the air density.

For concrete strength, Y_i can represent the building-to-building variation, Y_{ij} the floor-to-floor variation in building i , and Y_{ijk} the point-to-point variation on floor j .

6.2 Models for structural analysis

6.2.1 General

The decisive factors for describing the physical behaviour of the structural systems can be categorized as

- actions and environmental influences,
- geometrical properties,
- material properties and/or properties of structural elements, and
- active and passive control measures.

Models shall enable to describe the behaviour of structural systems up to the limit state under consideration. Models should generally be regarded as simplifications which take account of decisive factors and neglect the less important ones. Uncertainties in the models themselves are treated in [6.4](#).

The reliability of active and passive control measure (e.g. sprinkler installations or active dampers) shall also be modelled and incorporated in the overall risk analysis, but specific guidance on this is outside the scope of this International Standard.

6.2.2 Actions and environmental influences

6.2.2.1 General

Action descriptions shall be based on suitable mathematical models, describing the temporal, spatial, and directional properties of the action across the structure. The choice of the level of richness of details shall be guided by a balance between the quality of the information available and a reasonably accurate modelling of the action effect. The choice of the level of realism and accuracy in predicting the relevant action is, in time, guided by the sensitivity of the implied design decisions to variations of this level and the economical weight of these decisions. Thus, the same action phenomenon can give rise to different action models dependent on the effect and structure under investigation.

NOTE The environment, in which structural systems function, gives rise to internal forces, deformations, material deterioration, and other short-term or long-term effects. The causes of these effects are termed actions. The environment from which the actions originate can be of natural or man-made character, for example, snow, earthquake, fire. The following concepts are useful to characterize the aspects of actions:

- An action is an assembly of concentrated or distributed forces acting on the structure. This kind of direct action is also denoted as load.
- An action is the cause of imposed displacements or thermal effects in the structure. This kind of action is often denoted by indirect action.

Similar requirements hold for environmental influences that can cause changes with time in material properties or structural dimensions.

6.2.2.2 Classifications

Actions can be classified according to a number of characteristics. With respect to the type of the actions, the following non-exhaustive list shall be considered:

- Self weight of structural and non-structural components.
- Imposed loads in buildings, e.g. loads from persons and equipment.
- Loads caused by industrial activities, e.g. silo loads.
- Loads caused by transport: traffic, liquids in pipelines, cranes, impact, etc.
- Climate actions, e.g. snow loads, wind loads, outdoor temperature, etc.
- Indoor temperatures, fire.
- Hydraulic loads, e.g. water and ground water pressures.
- Geotechnical actions from soil or rock, including earth pressures, earth slides and earthquakes, sub-soil vibrations, settlements.
- Loads specific for the production and construction stages.

This classification does not cover all possible actions, but most of the common types of actions can be included in one or more classes. Some of the classes belong as a whole either to uncontrollable actions or to controllable actions. Other actions can belong to both, e.g. water pressure.

With respect to the variations in time, actions shall be considered as

- permanent actions,

- variable actions, and
- accidental actions.

Actions shall be classified as permanent actions if the variations in time around the mean is small and slow (e.g. self-weight, ballast, earth pressure) or monotonically change to a limiting value (e.g. prestressing, imposed deformation from construction processes, effects from temperature, moisture variation, or settlements).

Actions shall be classified as variable actions 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).

Actions shall be classified as accidental actions 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).

NOTE 1 In this International Standard, an accidental action is not necessarily related to an accident.

NOTE 2 For some structures or at some locations, impacts or earthquakes can happen so often that they should be considered as a variable action.

As far as the spatial fluctuations are concerned, it is useful to distinguish between fixed and free actions. Fixed actions have a given spatial intensity distribution over the structure. They are completely defined if the intensity is specified in a particular point of the structure (e.g. earth or water pressure). For free actions, the spatial intensity distribution is variable (e.g. regular occupancy loading).

6.2.2.3 Action model

Where possible, complete action models shall be considered, consisting, in general, of several constituents which describe the magnitude, the position, the direction, the duration, etc. of the action. Sometimes, interactions between the components shall be taken into account. There can in certain cases also be an interaction between the action and the response of the structure.

In many cases, two kinds of variables shall explicitly be distinguished, i.e. F_0 and ω describing an action F , that is

$$F = \varphi(F_0, \omega) \quad (5)$$

where

- F_0 is a reference action variable that is directly associated with the event causing the action and should be defined so that it is, as far as possible, independent of the structure (for example, for snow load, F_0 is the snow load on ground, on a flat horizontal surface);
- ω is a conversion factor or model type parameter appearing in the transformation from the basic action to the action F , which affects the particular structure; the parameter ω can depend on the form and size of the structure, etc. (for the snow load example, ω is the factor, which transforms the snow load on ground to the snow load on roof, which depends on the roof slope, the type of roof surface, etc.);

$\varphi(\cdot, \cdot)$ is a suitable function, often a simple product.

The short-term, as well as long-term, time variability, is normally included in F_0 whereas ω can often be considered as time independent. A systematic part of the space variability of an action is in most cases included in ω , whereas a possible random part can be included in F_0 or in ω . [Formula \(4\)](#) should be regarded of principal character. For one action there can be several variables F_0 and several variables ω .

Any action model contains a set of parameters and variables that shall be evaluated before the model can be used. In probabilistic modelling, all action variables are in principle assumed to be random variables, random processes, or random fields, while other parameters can be time or spatial