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General principles on the design of structures for durability

Principes généraux du calcul des constructions pour la durabilité

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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.

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

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

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

ISO 13823 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 2, *Reliability of structures*.

Introduction

The limit-states method, as developed in ISO 2394, has been adopted and used for preparing and harmonizing national and regional structural design standards and codes around the world. Although ISO 2394 includes durability in its principles, the limit-states method has not been developed for failures due to material deterioration to the extent that it has for failures due to actions such as gravity, wind, snow and earthquake. Also, many premature failures have occurred because of a lack of understanding of material deterioration in the structural engineering profession.

The first objective in developing this International Standard is to improve the evaluation and design of structures for durability by the incorporation of building-science principles into structural-engineering practice. These principles are now being taught in engineering courses in many countries. This goal is achieved by the incorporation of these principles into the limit-states method currently used in structural engineering practice and defined in ISO 2394, and by the use of a common, user-friendly terminology for physical phenomena.

Developments have recently taken place in mathematical modelling of the mechanisms that cause material deterioration and failure. There is a need to harmonize the use of these models in practice by using the limit-states method and a common terminology.

The second objective in developing this International Standard is to provide a framework for the development of mathematical models to predict the service life of components of the structure. Such models are currently being developed, for example, for concrete slabs subjected to chloride diffusion from de-icing salts. These models are material-dependent and, therefore, are being developed by other ISO/TCs. The goal of this International Standard is to ensure that all analytical models are incorporated into the limit-states method, the same as currently used for the verification and design of structures for gravity, wind, snow and earthquake actions.

While this International Standard does not address design procedures for durability, it lays a solid foundation by identifying a process starting from the structure's environment, followed by mechanisms that transfer this environment into environmental actions on component materials leading to action effects, such as damage (see Figure 1). It is necessary to take this cause-and-effect process into account in developing methods for the prediction of service life.

This International Standard is intended to serve a similar unification role as ISO 2394 has had over the past 30 years for the verification and design of structures against failure due to mechanical actions, such as gravity, wind, snow and earthquake.

This International Standard does not directly address sustainability for structures, except through referencing in notes in 8.4 and Clause 10. Most considerations of sustainability, such as the choice of material as it affects waste and energy consumption, are outside the scope of this International Standard. Sustainability considerations in the future, however, are expected to increase the emphasis on choice of materials, technologies, inspectability, maintenance, repair and replacement in the planning and design of structures.

It is intended that this International Standard be used in parallel with ISO 15686 (all parts) on service-life planning for buildings and construction assets. Service-life prediction for structures based on experience and testing are contained in ISO 15686 (all parts). Service-life prediction of structures based on the modelling of durability, in addition to experience and testing, using conceptual as well as mathematical models, are described in this International Standard.

General principles on the design of structures for durability

1 Scope

This International Standard specifies general principles and recommends procedures for the verification of the durability of structures subject to known or foreseeable environmental actions, including mechanical actions, causing material degradation leading to failure of performance. It is necessary to ensure reliability of performance throughout the design service life of the structure.

Fatigue failure due to cyclic stress is not within the scope of this International Standard.

NOTE Reference can be made to ISO 2394 for failure due to fatigue.

2 Normative references

The following referenced documents are indispensable for the application 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 2394:1998, *General principles on reliability for structures*

ISO 3898:1997, *Bases for design of structures — Notations — General symbols*

ISO 8930:1987, *General principles on reliability for structures — List of equivalent terms*

ISO 13822:2001, *Bases for design of structures — Assessment of existing structures*

ISO 15686-5, *Buildings and constructed assets — Service-life planning — Part 5: Life-cycle costing*

ISO 15686-6, *Buildings and constructed assets — Service life planning — Part 6: Procedures for considering environmental impacts*

AS 5604, *Timber — Natural durability ratings*

3 Terms and definitions

3.1
action effect
S
effect of an environmental action on a component of a structure (e.g. damage, reduced resistance, internal force, displacement, change in appearance)

3.2
agent
chemical or biological substance or physical process (e.g. UV) or biological (e.g. insect attack) process that, alone or together with other agents, including contaminants in the material itself, acts on a structure or component to cause material degradation

3.3
basic variable
variable describing the structure environment, transfer mechanism, environmental action, action effect, material property or geometrical quantity

3.4
characteristic value of a basic variable
specified fractile of the variable determined in accordance with ISO 2394

3.5
characteristic service life
value of a predicted service life chosen either on a statistical basis, so that it has a specified probability of being more unfavourable (i.e. lower), or on a non-statistical basis, for instance based on acquired experience

3.6
component
any part of the structure and any non-structural part that may affect the durability of the structure

3.7
degradation
material deterioration or deformation that leads to adverse changes in a critical property of a component

3.8
design value of a basic variable
factored characteristic value of the variable determined in accordance with ISO 2394

3.9
design life
specified period of time for which a structure or a component is to be used for its intended purpose without major repair being necessary

NOTE This term is equivalent to **design working life** in ISO 2394:1998, 2.2.15.

3.10
durability
capability of a structure or any component to satisfy, with planned maintenance, the design performance requirements over a specified period of time under the influence of the environmental actions, or as a result of a self-ageing process

3.11
environmental action
chemical, electrochemical, biological, physical and/or mechanical action causing material degradation of a component

NOTE 1 See Figure 1.

NOTE 2 See also environmental influences in ISO 2394:1998, 6.3.

3.12
failure
loss of the ability of a structure or component to perform a specified function

3.13
initiation limit state
ILS
state that corresponds to the initiation of significant deterioration of a component of the structure

NOTE See 6.6.

3.14
limit state
state beyond which a structure or component no longer satisfies the design performance requirements

3.15
maintenance
combination of all technical and associated administrative actions during a component's **service life** (3.21) with the aim of retaining it in a state in which it can perform its required functions

3.16
model

simplified conceptual or mathematical idealization or test set-up simulating the structure environment, transfer mechanisms, environmental action, action effects and structural behaviour that can lead to failure

NOTE See Figure 1.

3.17
partial factor method

calculation format in which allowance is made for the uncertainties and variabilities of the basic variables by means of characteristic values, partial factors and, if relevant, additive quantities

3.18
predicted service life

service life (3.21) estimated from recorded performance, previous experience, tests or modelling

3.19
reliability

ability of a structure or component to satisfy the specified design performance requirements within the design service life

3.20
repair

restoration of a structure or its components to an acceptable condition by the renewal or replacement of worn, damaged or deteriorated components

3.21
service life

actual period of time during which a structure or any of its components satisfy the design performance requirements without unforeseen major repair

3.22
serviceability limit state
SLS

state that corresponds to conditions beyond which specified serviceability requirements for a structure or its components are no longer satisfied

NOTE See 6.6.

3.23
structure environment

external or internal influences (e.g. rain, de-icing salts, UV, humidity) on a structure that can lead to an environmental action

NOTE See Figure 1.

3.24
transfer mechanism

mechanism by which influences in the structure environment are, over time, transferred into agents on and within components or prevent such transfer

NOTE See Figure 1.

3.25
ultimate limit state
ULS

state associated with collapse, or with other similar forms of structural failure

NOTE See 6.6.

4 Symbols

P	probability
P_f	probability of failure
P_target	target probability of failure
$P_\mathrm{target,SLS}$	target probability of failure, serviceability limit state
$P_\mathrm{target,ULS}$	target probability of failure, ultimate limit state
R	resistance
$\overline{R}$	mean resistance
S	action effect
$\overline{S}$	mean action effect
S_lim	serviceability limit
t	time, expressed in years
t_D	design life, expressed in years
t_exposed	time after initiation of degradation, expressed in years
t_ref	reference service life, expressed in years; see 9.3.2
t_S	service life, expressed in years, that occurs or that is represented by a mathematical probability function
t_Sk	characteristic value of t_S, expressed in years
t_SP	predicted service life, expressed in years
t_start	time to initiation of degradation, expressed in years
X_i	basic variable for modelling t_start, S and R
Y_i	basic variable for modelling t_exposed, S and R
γ_S	partial factor for predicted service life; see Equation (4)

5 Application

It is the intention that the general principles in the verification and design of structures and components for durability in this International Standard be used whenever a minimum service life is required, for new structures as well as for the assessment of existing structures.

The considered components include non-structural components that can affect the durability of the structure.

NOTE Because of the complex nature of the degradation and damage of structures, durability of structures is related not only to structural components but also to non-structural components. However, non-structural components, such as equipment, are generally not included in this International Standard because they are normally easily replaced.

The general principles apply to the design phase as well as to planning maintenance, repair and replacement measures, in failure investigations, etc. However, additional considerations can apply to existing structures.

For existing structures, procedures and criteria in this International Standard may be modified to take into account inspection and test results concerning the quality of workmanship, conditions of maintenance and variation in the durability of materials. In addition, if they can be justified (see ISO 13822), lower target reliability levels may be used for existing structures.

6 Basic concepts for verifying durability

6.1 General

This International Standard recommends the use of the limit-states method shown in Figure 1 for the design and verification of structures for durability. For any component of the structure, this requires an understanding of the structure environment (6.2), the transfer mechanisms (6.3), the environmental action (6.4), leading to action effects (6.5) that can result in the failure of the component.

For examples of the application of the limit-states method in Figure 1, see Annex A.

NOTE Environmental action can also occur as the result of a self-ageing process (see 6.3, Note 3).

6.2 Structure environment

The structure environment contains influences, such as air, rain, contaminants, temperature, biological life and solar radiation, that provide agents such as moisture and oxygen that can affect the durability of components. These influences occur outside (climate, ground or body of water) or inside (climate, chemicals) the structure.

For examples of influences in the structure environment, see Annex B.

6.3 Transfer mechanisms

Transfer mechanisms, such as gravity, condensation and drainage, promote or prevent transfer of environmental influences into agents causing environmental action on or within the components of the structural system.

For examples of transfer mechanisms, see Annex C.

NOTE 1 Modelling of the deterioration process requires an understanding of the transfer mechanisms and environmental actions leading to failure. These are based on knowledge of the materials of the components and the microclimate in the vicinity of the components of the structure.

NOTE 2 Moisture, with or without contaminants, is the most important agent causing premature deterioration. The application of building science principles permits the generation of models — conceptual, mathematical or test set-up — for predicting the mechanisms, paths, volumes and forms of moisture that components are required to accommodate and to resist.

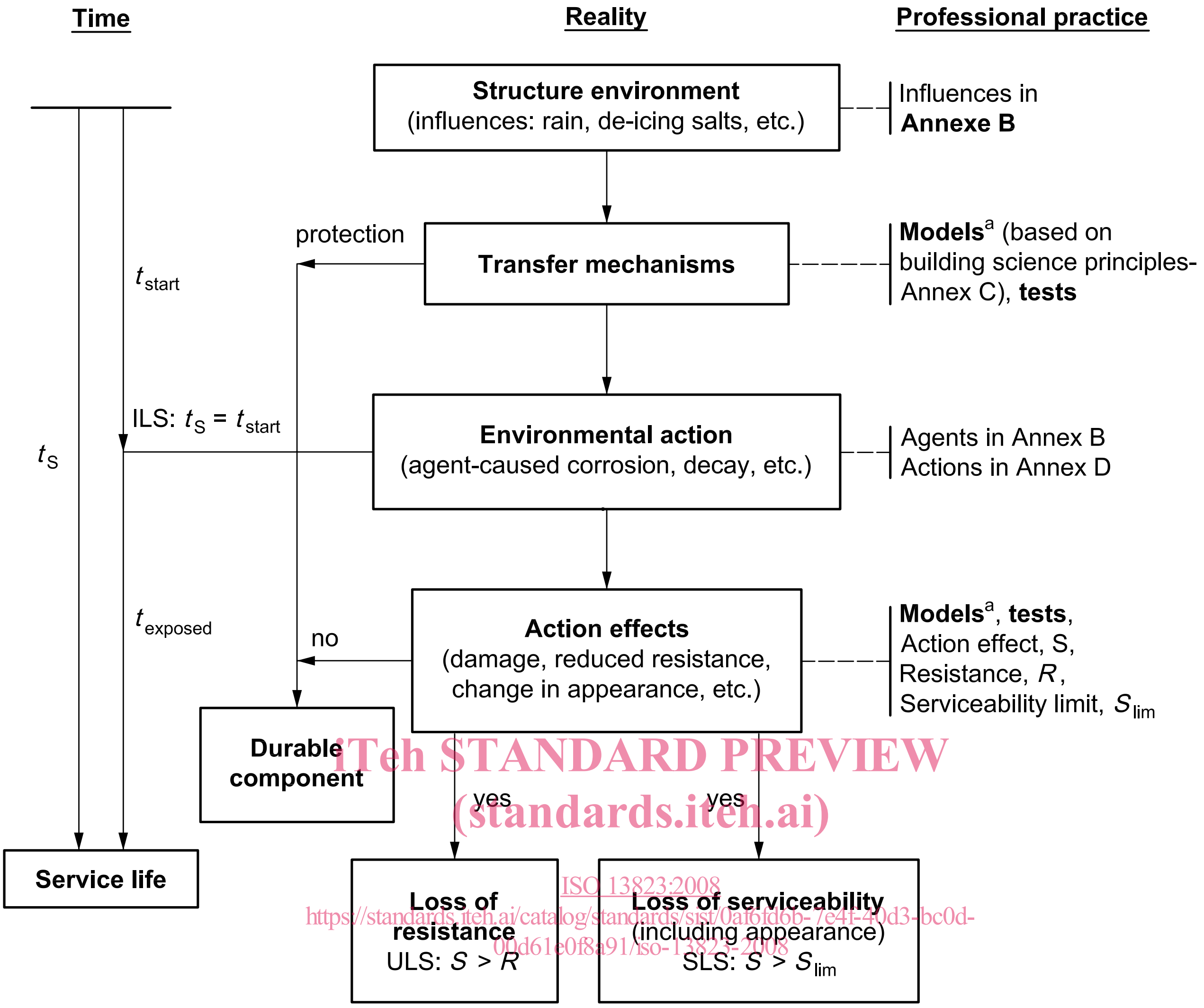
NOTE 3 Transfer mechanisms can also include a manufacturing process that results in a self-ageing degradation without agents transferred from the structure environment, for example the addition of sea sand into the concrete mix.

6.4 Environmental action

An environmental action, such as corrosion, decay or shrinkage, is a chemical, electrochemical, biological (e.g. insect attack), physical (e.g. UV) or mechanical action causing material deterioration or deformation. Except for mechanical action, an environmental action is the consequence of the expected environmental agents, such as moisture, oxygen and temperature, the chemical, electrochemical and physical properties of the materials of the components, and the interaction of the different components, including electrochemical (e.g. galvanic corrosion) and physical (e.g. deformation) interactions. Environmental actions, such as corrosion of steel, decay of wood, shrinkage or freeze-thaw of cement-based materials such as masonry or concrete, can result in loss of performance.

For examples of agents affecting different materials, see Annex B.

For examples of environmental actions, see Annex D.



[a] Both conceptual and mathematical.

Figure 1 — Limit-states method for durability

6.5 Action effects

Action effects include damage, loss of resistance, internal force/stress or unacceptable appearance due to material deterioration, or displacement due to material deformation. An action effect can result in the loss of performance as defined by one or more of the limit states given in 6.6.

For examples of action effects, see Annex D.

6.6 Limit states

6.6.1 Ultimate limit state

For material deterioration resulting in failure due to loss of resistance, the ultimate limit state is defined when the resistance of the component or structure becomes equal to, or less than, the internal mechanical force. See Clauses A.1 and A.2.

6.6.2 Serviceability limit states

For material degradation, the serviceability limit states are defined by

- local damage (including cracking) or change in appearance that affects the function or appearance of structural or non-structural components,
- relative displacements that affect the function or appearance of structural or non-structural components.

6.6.3 Initiation limit state

This limit state is defined by the initiation of deterioration of a component that precedes the occurrence of the serviceability or ultimate limit states. The time to reach this limit state is designated by t_{start} in Figure 1. See Clause A.3.

NOTE 1 A deterioration or deformation occurring on or inside a structure does not necessarily mean failure. Therefore, it is important to consider not only the environmental action and action effects, but also the limit states (e.g. fracture, movements, gaps, appearance, material weakening) that correspond to functional failure of the component for its intended use. Examples are given in Annex D of the forms of failure associated with prevalent environmental actions for materials.

NOTE 2 Although not within the scope of this International Standard, mould growth due to moisture accumulation on components can also serve as a limit state affecting human health.

7 Durability requirements

7.1 Basic durability requirement

Structures and their components shall be conceived, designed, constructed and operated, inspected, maintained and repaired in such a way that, under foreseeable environmental conditions, they maintain their required performance during their design lives with sufficient reliability for the safety and comfort of users and the intended use of the structure.

The service life, t_S, of the structure and its components shall meet or exceed the design life, t_D, as expressed in Equation (1):

$$t_S \geqslant t_D \tag{1}$$

When a component is protected against agents (e.g. concrete cover of reinforcement, zinc coating of steel, preservative treatment of wood), the service life, t_S, can be determined as given in Equation (2) (see Figure 1):

$$t_S = t_{\text{start}} + t_{\text{exposed}} \tag{2}$$

where

t_{start} is the time of the initiation of deterioration;

t_{exposed} is the service life after initiation of the deterioration.

The service life of the structure is based on the service lives of all the components, management procedures, inspection, maintenance, repair and replacement strategies for the structure and its components to ensure functionality over the design life of the structure.

Components whose predicted service life is less than the design life of the structure shall be inspectable and replaceable.

In the event of renovation, the design life of the revised structure shall be reconsidered.