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General principles on reliability for structures

Principes généraux de la fiabilité des constructions

ISO 2394:1998(E)

Contents

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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.

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.

International Standard ISO 2394 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 2, *Reliability of structures.*

This second edition cancels and replaces the first edition (ISO 2394:1986), which has been technically revised.

Annexes A to F of this International Standard are for information only.

Introduction

This International Standard constitutes a common basis for defining design rules relevant to the construction and use of the wide majority of buildings and civil engineering works, whatever the nature or combination of the materials used. However, their application to each type of material (concrete, steel, timber, masonry, etc.) will require specific adaptation to ensure a degree of reliability which, as far as possible, is consistent with the objectives of the code drafting committees for each material.

This International Standard is intended to serve as a basis for those committees responsible for the task of preparing national standards or codes of practice in accordance with the technical and economic conditions in a particular country, and which take into account the nature, type and conditions of use of the structure and the properties of the materials during its design working life. It will also provide a common basis for other International Standards (e.g. ENV 1991-1 EC1) dealing with load-bearing structures. Thus it has a conceptual character and it is of a fairly general nature.

It is important to recognize that structural reliability is an overall concept comprising models for describing actions, design rules, reliability elements, structural response and resistance, workmanship, quality control procedures and national requirements, all of which are mutually dependent.

The modification of one factor in isolation could therefore disturb the balance of reliability inherent in the overall concept.

It is therefore important that the modification of any one factor should be accompanied by a study of the implications relating to the overall reliability concept.

General principles on reliability for structures

1 Scope

This International Standard specifies general principles for the verification of the reliability of structures subjected to known or foreseeable types of action. Reliability is considered in relation to the performance of the structure throughout its design working life.

The general principles are applicable to the design of complete structures (buildings, bridges, industrial structures, etc.), the structural elements making up the structure and the foundations.

This International Standard is also applicable to the successive stages in construction, namely the fabrication of structural elements, the transport and handling of the structural elements, their erection and all work on site, as well as the use of the structure during its design working life, including maintenance and repair.

To allow for the differences in design practice between different countries, the national standards or codes of practice may be simpler or more detailed in comparison with this International Standard.

Generally the principles are also applicable to the structural appraisal of existing constructions or assessing changes of use. However in some respects this is associated with special aspects of the basic variables and calculation models. Such aspects are considered in clause 10.

NOTE — When this International Standard is applied in a particular country for the development of its standards, it is admissible not to use those clauses which are not in accordance with the regulations of that particular country.

2 Definitions

For the purposes of this International Standard, the following definitions apply.

NOTE — An alphabetical index of the definitions is given in annex H.

2.1 General terms

2.1.1 structure: Organized combination of connected parts designed to provide some measure of rigidity.

2.1.2 structural element: Physically distinguishable part of a structure.

EXAMPLES: Column, beam, plate.

2.1.3 structural system: Load-bearing elements of a building or civil engineering works and the way in which these elements function together.

2.1.4 compliance: Fulfilment of specified requirements.

2.1.5 life cycle: Total period of time during which the planning, execution and use of a construction works takes place. The life cycle begins with identification of needs and ends with demolition.

2.2 Terms relating to design in general

2.2.1 design situation: Set of physical conditions representing a certain time interval for which the design demonstrates that relevant limit states are not exceeded.

2.2. persistent situation: Normal condition of use for the structure, generally related to its design working life.

NOTE — "Normal use" includes possible extreme loading conditions due to wind, snow, imposed loads, earthquakes in areas of high seismicity, etc.

2.2.3 transient situation: Provisional condition of use or exposure for the structure.

EXAMPLE: During its construction or repair, which represents a time period much shorter than the design working life.

2.2.4 accidental situation: Exceptional condition of use or exposure for the structure.

EXAMPLES: Flood, land slip, fire, explosion, impact or local failure, which represent in most cases a very short time period (apart from situations where a local failure may remain undetected during a longer period).

2.2.5 serviceability: Ability of a structure or structural element to perform adequately for normal use under all expected actions.

2.2.6 failure: Insufficient load-bearing capacity or inadequate serviceability of a structure or structural element.

2.2.7 reliability: Ability of a structure or structural element to fulfil the specified requirements, including the working life, for which it has been designed.

2.2.8 reference period: A chosen period of time which is used as a basis for assessing values of variable actions, time-dependent material properties, etc.

2.2.9 limit state: A state beyond which the structure no longer satisfies the design performance requirements.

NOTE — Limit states separate desired states (no failure) from undesired states (failure).

2.2.10 ultimate limit state: A state associated with collapse, or with other similar forms of structural failure.

NOTE — This generally corresponds to the maximum load-carrying resistance of a structure or structural element but in some cases to the maximum applicable strain or deformation.

2.2.11 serviceability limit state: A state which corresponds to conditions beyond which specified service requirements for a structure or structural element are no longer met.

2.2.12 irreversible limit state: A limit state which will remain permanently exceeded when the actions which caused the excess are removed.

2.2.13 reversible limit state: A limit state which will not be exceeded when the actions which caused the excess are removed.

2.2.14 structural integrity (structural robustness) : Ability of a structure not to be damaged by events like fire, explosions, impact or consequences of human errors, to an extent disproportionate to the original cause.

2.2.15 design working life: Assumed period for which a structure or a structural element is to be used for its intended purpose without major repair being necessary.

2.2.16 maintenance: Total set of activities performed during the design working life of a structure to enable it to fulfil the requirements for reliability.

2.2.17 reliability class of structures: Class of structures or structural elements for which a particular specified degree of reliability is required.

2.2.18 basic variable: Part of a specified set of variables representing physical quantities which characterize actions and environmental influences, material properties including soil properties, and geometrical quantities.

2.2.19 primary basic variable: Variable whose value is of primary importance to the design results.

2.2.20 limit state function: A function g of the basic variables, which characterizes a limit state when $g(X_1, X_2,..., X_n) = 0$: $g > 0$ identifies with the desired state and $g < 0$ with the undesired state.

2.2.21 reliability index, β: A substitute for the failure probability p_f, defined by $\beta = -\Phi^{-1}(p_f)$, where Φ^{-1} is the inverse standardized normal distribution.

2.2.22 partial factors format: Calculation format in which allowance is made for the uncertainties and variabilities assigned to the basic variables by means of representative values, partial factors and, if relevant, additive quantities.

2.2.23 reliability element: Numerical quantity used in the partial factors format, by which the specified degree of reliability is assumed to be reached.

2.2.24 element reliability: Reliability of a single structural element which has one single dominating failure mode.

2.2.25 system reliability: Reliability of a structural element which has more than one relevant failure mode or the reliability of a system of more than one relevant structural element.

2.2.26 model: Simplified mathematical description or experimental set-up simulating actions, material properties, the behaviour of a structure, etc.

NOTE — Models should generally take account of decisive factors and neglect the less important ones.

2.2.27 model uncertainty: Related to the accuracy of models, physical or statistical.

NOTE — Further information is given in annexes D and E.

2.2.28 statistical uncertainty: Uncertainty related to the accuracy of the distribution and estimation of parameters.

2.2.29 assessment: Total set of activities performed in order to find out if the reliability of a structure is acceptable or not.

2.3 Terms relating to actions, action effects and environmental influences

2.3.1 action

1) An assembly of concentrated or distributed mechanical forces acting on a structure (direct actions).

2) The cause of deformations imposed on the structure or constrained in it (indirect action).

2.3.2 permanent action:

1) Action which is likely to act continuously throughout a given reference period and for which variations in magnitude with time are small compared with the mean value.

2) Action whose variation is only in one sense and can lead to some limiting value.

2.3.3 variable action: Action for which the variation in magnitude with time is neither negligible in relation to the mean value nor monotonic.

2.3.4 accidental action : Action that is unlikely to occur with a significant value on a given structure over a given reference period.

NOTE — Accidental actions are in most cases of short duration.

2.3.5 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 on the structure.

2.3.6 free action: Action which may have an arbitrary spatial distribution over the structure within given limits.

2.3.7 static action: Action which will not cause significant acceleration of the structure or structural elements.

2.3.8 dynamic action: Action which may cause significant acceleration of the structure or structural elements.

2.3.9 bounded action: Action which has a limiting value which cannot be exceeded and which is exactly or approximately known.

2.3.10 unbounded action: Action which has no known limiting values.

2.3.11 representative value of an action: A value used for the verification of a limit state.

NOTE — Representative values consist of characteristic values, combination values, frequent values and quasi-permanent values, but may also consist of other values.

2.3.12 characteristic value of an action: Principal representative value.

NOTE — It is chosen either on a statistical basis, so that it can be considered to have a specified probability of not being exceeded towards unfavourable values during a reference period, or on acquired experience, or on physical constraints.

2.3.13 combination value: Value chosen, in so far as it can be fixed on statistical bases, so that the probability that the action effect values caused by the combination will be exceeded is approximately the same as when a single action is considered.

2.3.14 frequent value: Value determined, in so far as it can be fixed on statistical bases, so that:

— the total time, within a chosen period of time, during which it is exceeded is only a small given part of the chosen period of time; or

— the frequency of its exceedance is limited to a given value.

2.3.15 quasi-permanent value: Value determined, in so far as it can be fixed on statistical bases, so that the total time, within a chosen period of time, during which it is exceeded is of the magnitude of half the period.

2.3.16 design value of an action, F_d**:** Value obtained by multiplying the representative value by the partial factor γ_F.

2.3.17 load arrangement: Identification of the position, magnitude and direction of a free action.

2.3.18 load case: Compatible load arrangements, set of deformations and imperfections considered for a particular verification.

2.3.19 load combination: Set of design values used for the verification of the structural reliability for a limit state under the simultaneous influence of different actions.

2.3.20 environmental influence: Mechanical, physical, chemical or biological influence which may cause deterioration of the materials constituting a structure, which in turn may affect its serviceability and safety in an unfavourable way.

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

2.4.1 characteristic value of a material property: An *a priori* specified fractile of the statistical distribution of the material property in the supply produced within the scope of the relevant material standard.

2.4.2 characteristic value of a geometrical quantity: A quantity usually corresponding to dimensions specified by the designer.

2.4.3 design value of a material property: Value obtained by dividing the characteristic value by a partial factor γ_M or, in special circumstances, by direct assessment.

2.4.4 design value of a geometrical quantity: Characteristic value plus or minus an additive geometrical quantity.

2.4.5 conversion factor: Factor which converts properties obtained from test specimens to properties corresponding to the assumptions made in calculation models.

2.4.6 conversion function: Function which converts properties obtained from test specimens to properties corresponding to the assumptions made in calculation models.

3 Symbols

NOTE — The symbols used generally are listed below. Those which are not general and which are used only in one clause (and are explained there) are not listed.

3.1 Main letters

A Accidental action

C Serviceability constraint

F Action in general

F_0 Basic action variable

F_r Representative value of an action

G Permanent action

Q Variable action

R Resistance

S Action effect

W Action model variable

X Basic variable

Y Model output variable

a Geometrical quantity

Δa Additive geometrical quantity

f Material property

p_f Probability of failure

p_{fs} Specified value of p_f

t Time

β Reliability index

γ Partial factor

γ_f Partial factor for actions

γ_F Generalized partial factor for actions taking account of model and geometric uncertainties

γ_G Partial factor for permanent actions

γ_Q Partial factor for variable actions

γ_m Partial factor for material properties

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

γ_D Partial factor for model uncertainties

γ_n Factor by which the importance of the structure and the consequences of failure are taken into account

θ Parameter which contains model uncertainties

θ_S Value for action effects

θ_R Value for resistance

φ Function of action variables

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

3.2 Subscripts

i Basic variable (mainly action) number i

j Action number j

k Characteristic value

d Design value

4 Requirements and concepts

4.1 Fundamental requirements

Structures and structural elements shall be designed, constructed and maintained in such a way that they are suited for their use during the design working life and in an economic way.

In particular they shall, with appropriate degrees of reliability, fulfil the following requirements:

— they shall perform adequately under all expected actions (serviceability limit state requirement);

— they shall withstand extreme and/or frequently repeated actions occurring during their construction and anticipated use (ultimate limit state requirement);

— they shall not be damaged by events like flood, land slip, fire, explosions, impact or consequences of human errors, to an extent disproportionate to the original cause (structural integrity requirement).

The appropriate degree of reliability should be judged with due regard to the possible consequences of failure and the expense, level of effort and procedures necessary to reduce the risk of failure (see 4.2).

The measures that can be taken to achieve the appropriate degree of reliability include:

— choice of structural system, proper design and analysis;

— implementation of a quality policy;

— design for durability and maintenance;

— protective measures.

These items will be treated in 4.3 to 4.5.

4.2 Reliability differentiation of structures

The expression "with appropriate degrees of reliability" used in 4.1 means that the degree of reliability should be adopted taking account of:

— the cause and mode of failure implying that a structure or structural element which would be likely to collapse suddenly without warning should be designed for a higher degree of reliability than one for which a collapse is preceded by some kind of warning in such a way that measures can be taken to limit the consequences;

— the possible consequences of failure in terms of risk to life, injury, potential economic losses and the level of social inconvenience;

— the expense, level of effort and procedures necessary to reduce the risk of failure;

— the social and environmental conditions in a particular location.

Differentiation of the required degrees of reliability may be obtained by the classification of whole structures or by the classification of structural elements. Thus, as an example, degrees of reliability may be selected according to the consequences of failure as follows:

a) risk to life low, economic, social and environmental consequences small or negligible;

b) risk to life medium, economic, social or environmental consequences considerable;

c) risk to life high, economic, social or environmental consequences very great.

The required reliability related to structural safety or serviceability may be achieved by suitable combinations of the following measures.

a) Measures relating to design:

    — serviceability requirements;

    — the choice of the values of action variables;

— the choice of the degree of reliability for the design calculations;

— consideration of durability;

— consideration of the degree of structural integrity (robustness), see 4.3;

— the amount and quality of preliminary investigations of soils and possible environmental influences;

— the accuracy of the mechanical models used;

— the stringency of the detailing rules.

b) Measures relating to quality assurance to reduce the risk of hazards in:

— gross human errors;

— design;

— execution.

4.3 Structural design

A failure of a structure or part of it may occur due to:

— an extremely unfavourable combination of actions, material properties, geometrical quantities, etc., all of which are associated with ordinary use and other ordinary circumstances;

— effects of exceptional but foreseeable actions or environmental influences, for example, collision or extreme climatic influences;

— consequences of an error, such as lack of information, omission, misunderstanding and lack of communication, negligence, misuse, etc.;

— influences that are not foreseen.

NOTE — The term "exceptional" refers to circumstances and/or actions that are present only during a small portion of the life and/or with a low probability. Depending on the type of structure, these actions may or may not be considered explicitly in design.

No structure can be expected to function adequately in all cases if exceptional actions or exceptionally low resistance occur, but the foreseeable scope of damage should be limited to an extent not disproportionate to the original cause. Thus measures should be taken to counter such events. The measures would basically consist of one or more of the following.

a) Designing and maintaining the structure according to the rules given in the following clauses for conditions associated with ordinary use and other ordinary circumstances.

b) Design of the essential load-bearing members of a structure for specified exceptional actions which may be caused by accidents or similar occurrences.

NOTE — The intention of such design criteria is that they should also cover the effect of the majority of unforeseen events.

The structural layout should be checked to identify "key" structural elements, whose failure would cause the collapse of more than a limited portion of the structure close to the element in question. Where such structural elements are identified and the structural layout cannot be revised to avoid them, the design should take their importance into account.

c) Protection against foreseeable actions and elimination of errors.

A careful check should be made and appropriate action taken to ensure that there is no inherent weakness in the structural layout and that adequate means exist to transmit all loads safely to the foundations.

Protective measures should be introduced, for example, safeguarding against vehicular impact by the provision of additional protection such as bollards.

The probability of gross design and construction errors should be reduced by appropriate quality assurance and/or quality control measures, as described in 4.4.

d) Design of the structure in such a way that local damage does not lead to immediate collapse of the whole structure or a significant part of it.

As a design assumption, the following may be chosen to represent local damage. The structure shall be designed and detailed so that any load-bearing elements other than the "key" structural elements can be removed without causing the collapse of more than a limited portion close to the element in question. In the event of the removal of a non-key structural element, a less than normal reliability for the remaining structure will be considered acceptable provided that the structure is repaired to normal reliability standard within a reasonably short period of time after damage.

4.4 Compliance

To achieve adequate confidence that the completed construction works fulfil the specified requirements for quality and, in particular, the fundamental requirements (4.1), an appropriate quality policy should be adopted and implemented by parties involved in the management of all stages of the life cycle of the construction works.

NOTE — For further details, see annex A and ISO 9000, ISO 9001, ISO 9002, ISO 9003 and ISO 9004.

This quality policy should comprise:

a) definition of quality requirements;

b) organization measures and controls at the stages of design and execution and during the use and the maintenance of the structure.

The quality management selected for implementing the quality policy should include consideration of:

— the type and use of the structure;

— the consequences of quality deficiencies (e.g. accidents resulting from structural failures); and

— the management culture of the involved parties.

In the structural design of the construction works, reliability is the most important aspect to consider to achieve quality. Standards for structural design should provide a framework to achieve structural reliability as follows:

— by providing requirements for reliability;

— by specifying the rules to verify the fulfilment of the requirements for reliability;

— by specifying the rules for structural design and associated conditions.

The conditions to be fulfilled concern, for example, the choice of structural system, level of workmanship and maintenance regime, and are normally detailed in the structural design standards. The conditions should also take into account the variability of material properties, the quality control and the criteria for material acceptance. They also include consideration of the use of information technology with regard to the design and the execution process including supply chains with regard to delivering of material and testing of material.

NOTES

1 For example the conditions are given as "assumptions" in Eurocode 1: Part 1, Basis of Design.

2 See also annex A.