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Bases for design of structures — General principles on risk assessment of systems involving structures

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of 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).

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

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

This second edition cancels and replaces the first edition (ISO 13824:2009), which has been technically revised. The main changes compared to the previous edition are as follows:

— risk-informed approach has been newly introduced to risk assessment in order to comply with the latest edition of ISO 2394 (ISO 2394:2015);

— requirements for treatment of uncertainty in risk estimation have been updated by introducing requirements related to sensitivity analysis;

— requirements for risk treatment have been updated by emphasizing the importance of optimization of prevention and mitigation measures including emergency preparedness;

— new informative annexes on examples of risk estimation of undesirable consequences caused by human-induced or natural events have been added.

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

Introduction

Systems involving structures in public and private sectors depend on civil engineering technologies and structures. Structures support missions and business functions of whole systems.

Structures are subject to multiple natural, technological and malevolent human-induced hazards. Hazards can have adverse impacts on performance of systems involving structures, quality of life, stakeholders' assets inside or near structures, operations and operability, functions and reputation, structural safety and sustainability of environment.

Given the significance of hazards, it is imperative that all stakeholders such as owners, occupants, designers, operators, regulators at all levels and at all phases of the lifecycle of systems involving structures understand their responsibilities for achieving adequate structural safety, structural functionality and managing risk.

This document provides a common basis for assessing risk relevant to planning, design, assessment, maintenance, decommissioning and removal of structures, in accordance with ISO 31000.

In risk assessment, hazard identification and the estimation of consequence are primary procedures. For these, it is essential to assess the risk of systems involving structures rather than just the structures, since structural failure has significant consequences for systems, and a failure of systems such as fire protection systems can cause serious damages. However, actions for risk treatment are taken within the scope of structural design. Such considerations are reflected in the title of this document.

This document is intended to serve as a basis, along with other relevant standards on risk management, for those assessing risk for systems involving structures.

Bases for design of structures — General principles on risk assessment of systems involving structures

1 Scope

This document specifies general principles of risk assessment for systems involving structures. The focus is on strategic and operational decision-making related to design, assessment, maintenance and decommissioning of structures. This also includes formulation and calibration of related codes and standards. Systems involving structures can expose stakeholders at various levels in society to significant risks. The aim of this document is to facilitate and enhance decision-making with regard to monitoring, reducing and managing risks, and preparing for emergency in an efficient, cost-effective and transparent manner. Within the broader context of risk management, risk assessment provides decision-makers with procedures to determine whether or not, and in what manner, it is appropriate to treat risks.

This document provides a general framework as well as a procedure for identifying hazards and estimating, evaluating and treating risks of structures and systems involving structures. This document also provides a basis for code writers as well as designers to set reasonable target-reliability levels, such as stated in ISO 2394, based on the result of risk considerations. For existing structures, it is intended that assessment of the risks associated with the events that were not considered in the original design or with changes in use be implemented according to the principles stated in this document. This document can also be used for risk assessment of exceptional structures upon specific adaptation and detailing, the design of which is not usually within the scope of existing codes.

2 Normative references

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

ISO 2394, *General principles on reliability for structures*

3 Terms and definitions

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

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

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

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

3.1
acceptable risk
level of *risk* (3.9) that an individual or society accepts or tolerates to secure certain benefits

3.2
cost/benefit analysis
analysis contributing to decision-making on whether to adopt a project or a plan by quantifying and comparing its costs and benefits

3.3
extraordinary event
very rare event that causes very severe consequences

3.4
failure
state which does not meet required performance objectives due to structural damage and/or loss of function

Note 1 to entry: Failure includes insufficient load-bearing capacity or inadequate serviceability of a *structure* (3.21) or structural member, or rupture or excessive deformation of the ground, in which the strengths of soil or rock are significant in providing resistance.

3.5
hazard
potential source of *undesirable consequences* (3.23)

Note 1 to entry: A hazard can be a *risk* (3.9) source (see ISO Guide 73). Examples of hazards include a possible abnormal action or environmental influence, insufficient strength or stiffness, or excessive detrimental deviation from intended dimensions (see ISO 2394).

3.5.1
hazard identification
process to find, list and characterize *hazards* (3.5)

3.5.2
hazard curve
exceedance probability of a specified *hazard* (3.5) intensity for a specified period of time

3.5.3
hazard screening
process of identifying significant *hazards* (3.5) for consideration during *risk assessment* (3.11) of *systems* (3.22) involving the *structures* (3.21)

3.6
option
possible measure for managing *risk* (3.9)

Note 1 to entry: Doing nothing can be one of the feasible options.

3.7
residual risk
risk (3.9) remaining after *risk treatment* (3.17)

3.8
resilience
ability of a *system* (3.22) to reduce likelihood of *failure* (3.4), to absorb effects of such failure if it occurs and to recover quickly after failure

3.9
risk
effect of uncertainty on objectives

Note 1 to entry: Risk is generally described as a combination of the probability or frequency of occurrence of an event and the magnitude of its consequence.

Note 2 to entry: From the viewpoint of the decision theory, risk is defined as the expected value of all undesirable consequences, i.e. the sum of all the products of the consequences of an event and their probabilities. (see ISO 2394).

[SOURCE: ISO 2394:2015, 2.1.40, modified — Note 1 has been added.]

3.10
risk acceptance
decision to accept a *risk* (3.9) to secure certain benefits

3.11
risk assessment
overall process of establishment of *structural engineering context* (3.19), definition of *system* (3.22), identification of *hazards* (3.5) and consequences, *risk estimation* (3.15), *risk evaluation* (3.16) and evaluation of treatment *options* (3.6)

3.12
risk communication
exchange or sharing of information about *risk* (3.9) among the decision-makers and *stakeholders* (3.20)

Note 1 to entry: The information can relate to the existence, nature, form, probability, severity, acceptability, treatment or other aspects of risk.

Note 2 to entry: Engineers are the main source for risk information and should encourage decision-makers and stakeholders to communicate with each other. Some engineers are part of, or support, the decision-makers.

3.13
risk control
actions implementing risk-management decisions

Note 1 to entry: Risk control can involve monitoring, re-evaluation and compliance with decisions.

3.14
risk criteria
criteria against which the significance of the results of the *risk* (3.9)analysis is evaluated

Note 1 to entry: The criteria are generally based on regulations, standards, experience, and/or theoretical knowledge used as a basis for risk acceptance.

Note 2 to entry: Risk criteria can depend on associated costs and benefits, legal and statutory requirements, socio-economic and environmental aspects, the concerns of stakeholders, priorities and other inputs to the assessment.

3.15
risk estimation
process of assigning values to the probability of occurrence of events and their consequences

3.16
risk evaluation
process of comparing the estimated *risk* (3.9) with given *risk criteria* (3.14) to determine the significance of the risk

Note 1 to entry: Risk evaluation is the process for assisting in the decision to accept or to treat a risk.

3.17
risk treatment
process of selection and implementation of measures to mitigate *risk* (3.9)

3.18
scenario
description of sequences or combinations of events in time and space and their inter-relationship given the occurrence of a *hazard* (3.5)

3.19
structural engineering context
background or reasons why the *risk assessment* (3.11) is implemented from structural perspectives

3.20
stakeholder
any individual, group, organization or authority that can affect, be affected by, or perceive itself to be affected by, a *risk* (3.9)

Note 1 to entry: The decision-maker is sometimes categorized as one of the stakeholders.

3.21
structure
arrangement of materials that is expected to withstand certain actions and to perform some intended function

3.22
system
delimited group of interrelated, interdependent or interacting objects that is assessed for a *risk* (3.9)

Note 1 to entry: This definition implies that the system is identifiable and is made up of interacting elements or subsystems, that all elements are identifiable, and that the boundary of the system can be identified.

Note 2 to entry: A system involving structures includes the structural system defined in ISO 2394 as a subsystem.

3.23
undesirable consequence
direct and indirect harm due to structural damage, functionality loss, etc., stated in terms of personal injury, death, environmental damage, societal harm and/or monetary loss

Note 1 to entry: There can be more than one undesirable consequence from an event.

Note 2 to entry: Consequences can be expressed qualitatively or quantitatively.

Note 3 to entry: Both immediate and long-term consequences are included.

3.24
undesirable event
event that can have *undesirable consequences* (3.23)

Note 1 to entry: Undesirable events are sometimes caused by natural, technological and human-induced hazards.

4 Fundamentals of risk assessment of systems involving structures

Risk assessment of system involving structures shall be done within the scope of the prescribed risk management; see Annexes A and B. Risk assessment shall consist of the following elements: the establishment of the structural engineering context, the definition of system, the identification of hazards and consequences, the risk estimation, the risk evaluation and the evaluation of options for risk treatment.

NOTE 1 A risk management process typically consists of the establishment of risk-management goals, a risk assessment, a risk treatment, communication and consultation, and a monitoring and review; see Annex A. The establishment of risk-management goals includes the development of risk criteria; see 9.1.

NOTE 2 A risk management process is not a one-way process but an iterative process; see Annexes A and B.

There shall be thorough communication and appropriate consultation with the stakeholders for each element of the risk assessment. After the risk assessment is complete, its results shall be conveyed in a suitable manner so that appropriate decisions can be made and the stakeholders can understand them. The decision concerning structures shall conform to requirements specified in ISO 2394.

The appropriateness of all elements of the risk assessment shall be reviewed in order to ensure continuous improvement of the risk management process, including risk assessment; see Annexes A and B.

The results of risk assessment shall be documented for future reference to guarantee that decisions are understood and to assist in the continuous improvement of the process; see Clause 11.

5 Establishment of structural engineering context

5.1 Structural engineering context

Structural engineering context shall be established as the first step of risk assessment. Typical structural engineering contexts or typical applications of risk assessment of systems, including structures, are the following:

a) establishment of design basis;

b) assessment of existing structures;

c) assessment of exceptional structures and/or extraordinary events; see Annexes C and K;

d) providing support for decisions in other contexts.

Stakeholders shall be identified based on the established structural-engineering context.

NOTE 1 Examples of decisions in other contexts include situations related to operation such as inspection and maintenance planning as well as performance and functional level during emergency situation.

NOTE 2 This document considers only structural engineering contexts; however, there are other relevant contexts; see Annexes A and B and ISO 31000.

5.2 Establishment of design basis

For establishment of the design basis, a series of criteria for the design of structural members shall be developed. The criteria should be determined based on the target reliability levels.

5.3 Assessment of existing structures

In the event that an existing structure, including a heritage structure, is damaged or has a change of usage, then a risk assessment shall be undertaken. If the assessed risk is excessive, then actions shall be undertaken to mitigate the risk and notify the relevant stakeholders.

The risk due to extraordinary events, or beyond the events considered in the original design, should be assessed to verify that it is within the acceptable level (see 9.1).

NOTE For risk assessment of existing structures, ISO 13822 can be used.

5.4 Assessment of exceptional structures or extraordinary events

Risk assessment of exceptional structures shall be carried out if their failures can have serious consequences. Risk assessment shall be conducted for unfavourable events, such as fires and other extraordinary event scenarios including progressive collapse (see Annex C).

5.5 Providing support for decisions for other contexts

When several options, strategies, or concepts are available, an optimal selection shall be based on the following objectives, considering the result of risk assessment:

a) to minimize risk given constraints such as limited economic resources;

b) to determine the optimal level of investment in risk reduction.

NOTE Prioritization of risk treatment actions to be taken is one of the optimization approaches to reduce the risk of group of exposures over certain period of time.

In both situations, the optional use of economic resources shall be considered to examine whether it results in optimal risk reduction.

Options should be compared according to net utility, cost/benefit or cost-effectiveness; see Annex I. If the aim of decision-making is to minimize risk within economic constraints, the results of the comparison may be used provided that all technical solutions are consistent with best practice.

6 Definition of the system

6.1 General

The system definition shall support decision-making and thus, the extent of the system that is considered in risk assessment shall be clearly identified based on the structural engineering context described in Clause 5.

6.2 Functions of the system

The definition of the system involving structures shall include a clear identification of the functions focusing on critical functions provided by the elements of the system and how these functions are supported by the structural components.

6.3 Identification of the subsystems

The characteristics of each subsystem, such as type of structure(s), codes and standards used in the design of the structure(s), use, importance, location and design/remaining service life, shall be identified. The limit states of the system shall also be specified.

7 Identification of hazards and undesirable consequences

7.1 Identification of possible hazards

The hazards that can cause undesirable events during their service lives of structures shall be identified. Temporal and spatial characteristics of hazards such as simultaneous occurrence of multiple hazards (and more) shall be taken into consideration. Possible simultaneous occurrence of multiple hazards should be considered.

NOTE For the detailed procedure on scenario analysis for fire, see ISO 16732 (all parts) and ISO 16733 (all parts).

7.2 Identification of scenarios

Scenarios shall be identified as the sequences or combinations of events or processes necessary for system failure and resulting undesirable consequences for the system involving structures. The scenarios should include collapse or damage of the structure(s), loss of functionality, loss of lives or injury and other economic and/or societal impacts caused by or to the stakeholders.

NOTE The essential techniques used for schematic representation of scenarios include fault trees, event trees, failure modes, effects and criticality analysis (FMECA) and layer of protection analysis (LOPA).

7.3 Identification of undesirable consequences

Undesirable consequences resulting from the hazards and following events shall be identified. They should be described in terms of human fatalities and injuries, environmental damage and/or monetary loss. Some consequences can be identified by scenario analyses considering the extent of influences due to failure of the structures in time and space.

NOTE When conducting scenario analyses, influences of failure of subsystems other than structures are taken into consideration if such failure can cause damages to structural elements.

7.4 Hazard screening

7.4.1 General

Hazards important to a system shall be screened on the basis of the significance of risk associated with those hazards and incorporated in the risk assessment. As each hazard has its inherent characteristics and possible undesirable consequences, it is recommended that the hazards be categorized on the basis of the original cause, the degree of quantification, and the significance of the consequences. The screening of hazards in accordance with their importance for risk assessment can then be performed based on the experience and expertise of the engineer. The results of the hazard screening shall be documented.

7.4.2 Hazard screening criteria

Preliminary risk estimation (see 8.1) shall be carried out to identify the significant risks. The criteria for the hazard screening should, in principle, be based on the magnitude of the risk from the preliminary risk estimation. The frequency of the hazard and/or significance of the relevant consequences can also be useful criteria. Hazards with obviously negligible risk compared with the acceptable risk level may be screened out.

The hazard screening criteria shall be clearly described in terms of frequency of the event and magnitude of its consequence. They may be based on the past experience, human perception and relevant values specified elsewhere.

8 Risk estimation

8.1 Types of risk estimation

8.1.1 General

Risk estimation shall be undertaken according to the purpose of the estimation, required degrees of details, information, data and resources available. The types of estimation fall into three broad categories, qualitative, semi-quantitative, and quantitative, depending on the circumstances.

NOTE In practice, qualitative estimation is often used as a preliminary risk estimation to obtain a general indication of the level of risk and to reveal the risks that shall be considered. Later, it can be necessary to undertake more specific or quantitative estimation on the revealed risk.

8.1.2 Qualitative estimation

In qualitative estimation, risk shall be estimated and ranked in a descriptive manner. Qualitative estimation should be used, in the following cases:

a) as an initial screening activity to identify risks that require more detailed estimation;

b) where the qualitative estimation provides sufficient information for decision-making;

c) where the numerical data or resources are insufficient to allow a quantitative estimation.

NOTE Tools like “what-if” analysis, checklists, event trees, fault trees, influence diagrams, barrier block (bow-tie) diagrams, hazard and operability (HAZOP) studies and failure mode and effects and criticality analysis (FMECA) can be used for qualitative estimation of risk.

8.1.3 Semi-quantitative estimation

In semi-quantitative estimation, a ranking scale more expanded than the one usually achieved in qualitative estimation shall be adopted.

NOTE 1 If the ranking scale chosen cannot properly reflect relativities, this can lead to inconsistent, anomalous or inappropriate outcomes.

NOTE 2 Tools like risk matrix and criticality, accessibility, recuperability, vulnerability, effect and recognizability (CARVER) analysis can be used for semi-quantitative estimation of risk.

8.1.4 Quantitative estimation

In quantitative estimation, numerical values shall be used for both undesirable consequences and probability of occurrence based on data from a variety of sources.

NOTE The quality of the estimation depends on the scenario credibility, accuracy and completeness of the numerical values and the validity of the models used.

8.2 Data for risk estimation

8.2.1 Data collection

Data for risk estimation shall be taken from appropriate sources of information. The most pertinent information sources and techniques should be used when estimating probability as well as undesirable consequences. Information sources can include the following:

a) past records;

b) practice and relevant data (field data collection);

c) relevant published data (incident data);

d) experiments and prototypes;

e) engineering or other models;

f) specialist and expert judgment (expert opinions).

8.2.2 Treatment and modelling of uncertainty

All uncertainties associated with data relevant to estimating probability as well as undesirable consequences shall be identified and taken into consideration.

8.3 Risk representation

The results obtained in risk estimation may be converted to a common scale such as potential fatalities, expected monetary loss (see Annex I). These may be related to the probability of occurrence of various hazards and may be compared with other hazardous activities or another risk level.

In qualitative risk representation, risk shall be rated in a descriptive manner. In quantitative representation, the whole profile of risk shall be presented by a combination of probability and undesirable consequence. The expectation of the consequence may be used for risk representation; see Annex E.

NOTE A risk curve is also one of the pictorial representations of risk, where undesirable consequences and associated probability of occurrence are plotted for different scenarios of system failure (see Annex E).

8.4 Estimation of probability

8.4.1 General

In quantitative estimation, probability estimates may be obtained from any or all of the following three approaches:

a) direct statistical estimation from data;

b) uncertainty propagation using model analysis tools;

c) expert opinion elicitation (see Annex D).

NOTE For the purposes of risk evaluation as well as risk communication, it is sometimes preferable to differentiate between aleatory uncertainty (inherent natural variability) and epistemic uncertainty (model uncertainties and statistical uncertainties). For risk assessment of safety-critical facilities where decision making has an impact on a variety of stakeholders, aleatory and epistemic uncertainties are sometimes treated separately. Uncertainty analysis is conducted to quantify the effects of epistemic uncertainty on estimated probability.

8.4.2 Probability of occurrence of hazard

The probability of occurrence of each hazard identified in Clause 7 shall be estimated based on past data, if available. If data are not available, expert judgement should be used; see Annex D.

NOTE It is important to reflect the characteristics of the hazard, although a hazard is often represented simply in terms of a hazard curve; see F.2.2.1, J.3.1 and K.2.

8.4.3 Probability of failure of structures

The probability of failure of structures shall be estimated using all of the following procedures, taking into account the design/remaining service life (see Annexes F, J and K):

a) modelling of action;

b) modelling of capacity;

c) response analysis of structures to the action.

NOTE Modelling of capacity can include functional capacity of subsystems in addition to structural resistance.

8.5 Estimation of undesirable consequence

Undesirable consequences shall be determined by modelling the outcomes of an event or a set of events, or by judging from experimental studies or past data. A scenario analysis shall be performed from the occurrence of an initiating event with regard to the extent of the consequences, as specified in 7.2.

A quantitative estimation of undesirable consequence should be expressed numerically to define the extent of human fatality and injuries, economic loss and environmental damage caused by structural damage and functional loss. In addition to direct consequences, indirect consequences should be included when estimating undesirable consequence of failure of structures. Uncertainty associated with estimation of undesirable consequences should also be considered.

NOTE Indirect consequences are caused by subsequent effects of failure and are related to robustness as well as resilience (see ISO 2394).

8.6 Sensitivity and bounding analysis

When some risk estimation results are not sufficiently robust for decision-making, a sensitivity analysis shall be carried out to investigate the effect of uncertainty in assumptions, models and data. A higher