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Bases for design of structures — Accidental actions

Bases du calcul des constructions — Actions accidentelles

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Contents

Page

Foreword

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

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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 3, *Loads, forces and other actions*.

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

Introduction

This document provides requirements and guidelines for the design and assessment of structures in relation to the possible occurrence of accidental actions induced by human activities. Fire and man-made earthquake, however, are not included.

This document is fully aligned with ISO 2394 and gives information for risk informed decision making and semi-probabilistic design and assessment. Like in most modern codes nowadays, attention is given to explicit modelling of hazard scenarios as well as to more implicit safety measurements following from robustness requirements.

This document aims at promoting harmonization of design practice internationally and unification between the respective codes and standards such as for actions and resistance 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.

The informative annexes included in this document provide support for the interpretation and the use of the principles contained in the normative clauses.

Bases for design of structures — Accidental actions

1 Scope

Accidental actions can be subdivided into accidental actions with a natural cause and accidental actions due to human activities. This document applies to reliability based and risk informed decision making for the design and assessment of structures subject to accidental actions due to human activities. However, fires and human-made earthquakes are not included.

The information presented in this document is intended for buildings and civil engineering works, regardless of the nature of their application and the use or combination of materials. The application of this document can require additional elements or elaboration in special cases.

This document is intended to serve as a basis for those committees that are 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. Where relevant, it can also be applied directly to specific cases.

This document describes how the principles of risk and reliability can be utilized to support decisions related to the design and assessment of structures subject to accidental actions and systems involving structures during all the phases of their service life. For the general principles of risk informed design and assessment, it is intended that ISO 2394 be considered.

The application of this document necessitates knowledge beyond that which it contains. It is the responsibility of the user to ensure that this knowledge is available and applied.

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 editions cited here apply. For undated references, the latest editions of the referenced documents (including any amendments) apply.

ISO 2394:2015, *General principles on reliability for structures*

ISO 8930, *General principles on reliability for structures — Vocabulary*

3 Terms and definitions

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/

For the purposes of this document, the terms and definitions given in ISO 2394 and ISO 8930 and the following apply.

3.1
barriers and shock absorbers
objects or structural devices intended to absorb part of the impact energy in order to protect the structure

3.2
burning velocity
rate of flame propagation relative to the velocity of the unburned dust, gas or vapour that is ahead of it

3.3
deflagration
propagation of a combustion zone at a velocity that is lower than the speed of sound in the unreacted medium

3.4
detonation
propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium

3.5
dynamic load
time variant load or action that causes significant dynamic effects in the structure or in structural elements

Note 1 to entry: This means that the acceleration is not negligible; as a consequence, equations of motion should be used instead of equations of equilibrium.

Note 2 to entry: In the case of impact, the dynamic load represents a force on an associated contact area at the point of impact.

3.6
equivalent static load
alternative and usually conservative representation of a *dynamic load* (3.6) suitable for a static structural analysis

3.7
explosion
physical and/or chemical process of abrupt release of energy leading to short pressure waves of very high intensity

3.8
flame propagation
speed of a flame front relative to a fixed reference point

3.9
impact
event occurring when one object comes into contact with another one, where the contact force is of short duration

3.10
impacting object
vehicle, ship, etc. colliding with a structure

3.11
key element
structural member upon which the stability of a part of remainder of the structure depends

3.12
local damage
localised failure of a part of a structure that is severely disabled by an accidental event

3.13
unidentified action
accidental action or event that is unknown or unforeseen and cannot be considered by explicit analysis in the design or assessment

3.14
venting panel
non-structural part of the enclosure (wall, floor, ceiling) with limited resistance that is intended to relieve the developing pressure from *deflagration* (3.4) in order to reduce pressure on other parts of the building

4 Symbols and abbreviated terms

4.1 General

The symbols listed in this clause 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.

4.2 Latin upper case letters

A accidental action, (cross sectional) area

A_d design value of an accidental action

D diameter

E modulus of elasticity, action effect, energy

E_{kin} kinetic energy

E_{def} deformation energy

F action, load in general, collision force

F_R frictional impact force

H height

K_G deflagration index of a gas cloud

K_{St} deflagration index of a dust cloud

L length

P probability

P_f probability of failure

P_{ft} target probability of failure

P_s probability of survival

R resistance

T temperature, period of time

T_e period of time to be considered in a damaged situation

T_{ref} reference period of time

U severity (magnitude) of the source of an action

4.3 Latin lower case letters

a	acceleration, geometric parameter
b	geometric parameter
c	wave propagation speed
f	the event of failure, material strength parameter
$f_X(x)$	probability density function of X with dummy variable x
$g(X, t)$	limit state function
h	height
h_a	height of the application area of a collision force
i	impulse per unit of area resulting from explosion
k	stiffness
l	length
m	mass
p	momentum (impulse); pressure
p_{stat}	static activation pressure that activates a vent opening when the pressure is increased slowly
r	distance parameter
r_{F}	reduction factor
t	time
u	displacement;
u_o	maximum possible displacement (crumble length of impacting object)
v	velocity

4.4 Greek letters

Δ	interval
β	reliability index
β_{t}	target reliability index
ε	strain
γ	partial factor
γ_{f}	partial factors for actions
λ	rate of relevant events

μ friction coefficient

ρ mass density

σ stress

4.5 Subscripts

i,j index of basic variable

k characteristic value

d design value

l leading action

max maximum value (often in time)

o initial (reference) value

p plastic

rep representative value

x,y,z coordinate directions

y yield (material)

5 General principles and conceptual approach

5.1 Types of accidental actions

Accidental actions due to human activities shall be considered in the design and assessment of buildings and other civil engineering structures. These actions include but are not limited to:

— Impact from vehicles, trains and tramways, ships, aircrafts, helicopters, forklift trucks, falling materials (rockfall, debris flow, dropped objects from cranes), machine related impacts like toppling cranes, wind turbines, parts detached from a rotary machine, blades detached from turbines, etc.;

— Internal and external explosions due to various sources like gas, dust, TNT, dynamite, etc.;

— Unidentified actions following from:

  — errors in design, errors during construction, service and operation and errors associated with maintenance and repair activities,

  — acts such as sabotage, vandalism, terrorism, etc. and their consequences.

Unidentified actions may be taken into account by specifying the resulting damage to the structure.

Design and assessment decisions related to the occurrence of accidental actions shall be made in accordance with the principles in ISO 2394.

This document shall, for a limited set of relevant actions, provide dedicated information on incident scenarios, load and resistance models, protection systems and calculation procedures.

NOTE Depending on the local circumstances, other actions can also require attention, as for instance avalanches, ice loading, floods resulting from storm surges, heavy rainfall or melting snow, log jams in rivers, sinkholes, etc.

Common impact actions (such as those resulting from stumbling persons, mooring of ships, etc.) should be considered as variable actions and are outside the scope of this document.

The extent and the depth of the design and analysis depend on the possible failure consequences and costs of mitigation.

5.2 Conceptual approach

5.2.1 Target reliability level

The appropriate degree of reliability shall, in accordance with ISO 2394, be selected with due regard to the possible consequences of failure, the associated expense and the level of efforts and procedures required to reduce the risk of failure and damage.

Target reliability levels for existing structures can differ substantially from those for new structures due to economic reasons. Ethical considerations, however, can impose bounds on the outcomes of an economic optimisation.

5.2.2 Strategies

Given the special character of accidental actions, the design approach shall focus on a combination of structural and non-structural measures to either prevent or limit:

— the occurrence of the action;

— the severity of the action;

— the effect of the action in terms of loading on the structure;

— the various direct and indirect consequences.

Direct consequences are damages caused directly by the action; indirect consequences are the result of direct damages, irrespective of the accidental action itself. The ratio between direct and indirect consequences can be seen as a measure of robustness (see ISO 2394).

In many cases, it can be economic, if not unavoidable, to accept some limited degree of direct local damage.

Special devices such as barriers and shock absorbers can be very helpful.

NOTE More information on effects of such devices is presented in Annex C.

5.2.3 Identified and unidentified actions

In the case of identified accidental actions, an assessment on the basis of physical models, reliability considerations and risk analysis shall be performed, depending on the consequence class of the structure.

Since not all possible actions can be foreseen in sufficient detail, the structure shall possess an adequate degree of robustness. In the context of this document, this means that, given the occurrence of local damage or degradation due to an arbitrary accidental action, the probability of a disproportionate collapse should be limited.

5.2.4 Types of analysis

Depending on the function of the structure and the possible consequences in case of failure, the type of analysis and degree of sophistication shall be chosen, both with respect to the physical modelling and to reliability and risk aspects (see 5.3).

The following types of analysis may be used, depending on the applicable risk/reliability aspects (see also ISO 2394):

a) a full risk analysis;

b) a probabilistic analysis based on predefined target reliability levels;

c) semi probabilistic specifications of actions or damage characteristics.

The following types of analysis may be used, depending on the physical modelling (see also 5.4):

— a non-linear dynamic analysis, including load structure interaction;

— a non-linear structural dynamic analysis based on specified external forces or damage characteristics;

— a static structural analysis using quasi static actions or damage characteristics.

Within each of the above analysis categories, further simplifications are possible. The ultimate simplification is to develop a set of prescribed rules. In such a case, the effectiveness of these rules on a global level shall be based on experience (observations), experiments (tests) or advanced analysis procedures. In case of observations and testing, statistical uncertainty as formulated in ISO 2394 shall be accounted for.

Risk and reliability analysis should be based on statistical data as far as possible. Where that is not possible, best estimates based on engineering judgment should be made; these values can also be regarded as nominal values.

5.2.5 Classification of structures based on consequences

The classification system of ISO 2394:2015, Annex F, shall be followed. This system distinguishes 5 classes of consequences, ranging from consequences class CC 1 (predominantly insignificant material damage) to CC 5 (catastrophic losses and large number of exposed persons). The consequence class is in general a useful indicator for both the level of safety measures and the method of analysis to be applied.

5.2.6 Appropriate methods of analyses based on consequences

The extent and the depth of the analysis methods and the appropriate level of mitigation shall be chosen in accordance with the expected consequences.

An appropriate analysis method and level of mitigation shall contain, as a minimum, the following elements depending on the applicable consequence class:

CC 1: No specific consideration of robustness.

CC 2: Simplified analysis based on idealized action and structural performance models and/or prescriptive design/detailing rules.

CC 3: Systematic identification of scenarios leading to structural collapse. Addressing strategies to deal with the identified scenarios. Analyses of structural performance may be based on simplified and idealized models but should be subject to justification. Prescriptive design and detailing rules may be utilized but should specifically address the identified scenarios. Reliability and risk analyses addressing direct and indirect consequences should be used as the basis for simplifications and idealizations.

CC 4: Detailed studies and analyses of scenarios leading to structural collapses utilizing input from experts on all relevant subject matters. Such analyses include detailed assessments using dynamic and non-linear structural analyses and risk analyses rigorously addressing direct and indirect consequences.

CC 5: Same as for CC 4 but with the addition of the involvement of an external expert/review panel for quality control.

From a reliability point of view, simplified models may always be used as long as they are conservative. Whether the degree of conservatism is acceptable or not is an economic issue to be decided by the decision maker.

NOTE The decision maker can be the owner or the competent authority.

5.3 Modelling of accidental actions

5.3.1 Identified actions

The model for extreme hazards such as explosions or collisions resulting in identified accidental actions shall be based on the following:

a) a triggering event at some point in time and place;

b) the amount of energy involved in the event and other relevant parameters;

c) the physical interactions between the event, the environment and the structure, leading to the exceedance of various subsequent limit states in the structure.

All of the above three aspects shall be treated as random quantities and/or random processes as follows:

— The occurrence of the triggering event may often be modelled as events in a Poisson process of intensity λ (t, x) per unit of volume and unit of time, t representing a point in time and x the spatial coordinates (x_1, x_2, x_3).

— The amount of energy may be treated as a random quantity described by a (multidimensional) probability distribution.

— Finally, the physical interactions determining the details of the action and structural response may also be modelled using uncertain variables and properties.

Given these uncertainties, the probability of structural failure (for constant λ and small probabilities) can be expressed as:

$$P_f\left(T_{\mathrm{ref}}\right) \approx \lambda T_{\mathrm{ref}} \int_0^{\infty} P\left(f \mid U=u\right) f_U\left(u\right) \mathrm{d}u \tag{1}$$

where

λ is the number of potential trigger events (e.g. vehicles passing by) per unit of time;

T_{ref} is the reference period under consideration (usually one year or the lifetime of the structure;

f is the failure event to be described by physical models of the structure and the environment;

$f_U(u)$ is the probability density function of the severity (energy) of the hazard, given a trigger event;

U represents the severity (magnitude, amount of available energy) of the hazard;

u is a specific value of U (dummy variable).

The probability of failure can depend on the distance between the structure and the location of the event. In that case, an explicit integration over the area or volume of interest is necessary. If there is more than one hazard, the resulting failure probabilities shall be added, taking into account possible correlations.

Failure in Formula (1) may refer to local or global consequences. The failure probability according to Formula (1) should be less than a specified annual target value, depending on the consequences.

NOTE Target values are usually set between 10^{-6} and 10^{-4} per year (see also ISO 2394).

5.3.2 Unidentified accidental actions

In the case of unidentified accidental actions, the effect of the action shall be modelled as a specific damage (for instance the removal of a specific beam or column). For the remaining part of the structure, for a relatively short period of time T_e (for instance defined as the time to evacuate people out of the building, or the time to repair), the structure shall withstand applicable actions .The corresponding conditional probability of failure shall not exceed a prescribed target reliability, as given by Formula (2):

$$P\left\{R<E \text{ in } T_e \mid \text{local damage occurred}\right\} \tag{2}$$

where

R is the resistance of the damaged structure after the occurrence of the unidentified accidental action;

E is the applicable action (effect) after the occurrence of the unidentified accidental action.

The target reliability in this case shall be aligned with the safety target for the building under non-accidental loading, the period T_e under consideration (hours, days or months) and the estimated probability that the local damage under consideration can develop (by causes other than those already considered in design).

NOTE Depending on the circumstances, values between 0,001 and 0,1 can be taken as appropriate.

For unconventional structures (e.g. structures with novel design concepts or using new materials), the probability of having an unspecified cause of failure should be considered as substantial. As a consequence, the target reliability value applicable to Formula (2) sometimes needs to be lowered.

5.3.3 Representative values for accidental actions

Based on the probabilistic approach outlined in 5.3.1 and 5.3.2, appropriate representative values for dynamic or quasi static accidental actions may be derived for use in simplified semi-probabilistic design and analysis.

NOTE Representative values for selected types of accidental actions, based on statistical or other approaches, are presented in Annexes A to C.