TECHNICAL
REPORT

ISO/TR
4553

First edition
2022-01

Deformations and displacements of buildings and building elements at serviceability limit states

Reference number
ISO/TR 4553:2022(E)

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Published in Switzerland

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

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

The underlying aim of this document is to provide guidance for the structural designer to identify those aspects of deformation that affect the suitability of a building for the purposes for which it was intended, and to suggest certain criteria by which the serviceability of the building in this respect can be assessed. In addition, numerical values for these criteria are provided to give some guidance where this might be appropriate.

Deformations of building structures can affect the serviceability of the building by causing damage to parts of the building and its finishes, by disturbing or harming users, or by preventing proper use of the building. Deformations can be caused by ground movements, by differential settlement of foundations, by environmental and occupational loads, by pre-stressing forces, and by movements of building materials due to creep under load, or changes in temperature, moisture content or chemical composition.

Prior to the 1960s, the allowable design stresses assigned to most engineering materials were low and design methods were conservative. This resulted in highly redundant building forms, typically with comparatively short spans and relatively massive elements. Such buildings were generally very stiff to the extent that deflection problems were uncommon. There was little need to realistically ascertain the actual deformation of elements since these seldom controlled design or element sizes.

In contrast, modern design methods result in structures that are generally lighter, possess less redundancy and are much more reactive to imposed loads. Modern structural design and material standards aim to realistically reflect the actual material properties and provide innovative designers with the tools to utilize the full potential of new materials. Material technology has also advanced, with higher strength materials allowing longer spanning elements, which are typically more susceptible to deformations and vibrations. Designers need to assess the response of each element to the appropriate combination of realistic actions, often modelling these using analytical and computer techniques. The engineering rationale inherent within such an approach is complex. Several assumptions are required to assess that response, both to reflect the actual condition of the element in service and to ascertain the response of that element to the applied action.

This document identifies and discusses many of the assumptions that are made when assessing elemental deformation control. This document provides more detailed background information to assist in assuring that these assumptions are appropriate and it provides guidance which allow the sensitivity of such assumptions to be assessed with regard to the member, its physical properties or its in-service condition.

Deformations and displacements of buildings and building elements at serviceability limit states

1 Scope

This document establishes the basic principles for the determination of deformations of buildings at the serviceability limit state when formulating national standards and recommendations. This document contains information on how serviceability for buildings and building elements is dealt with in some national standards.

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 8930:2021, *General principles on reliability for structures — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8930:2021 apply.

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

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

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

4 Limit state design

A structure or part of a structure, including a building and building elements, is considered unfit for use or to have failed when it exceeds a particular condition, called a limit state, beyond which its performance or use is impaired (e.g. ISO 22111:2019[21]). Generally, all designs are governed by the ultimate limit state and serviceability limit state.

The ultimate limit state primarily focuses on the maximum load-bearing capacity beyond which failure occurs. The application of ultimate limit state in designs is commonly based on the assessment of either the impact of failure on loss of human life or personal injury, or both, and economic, social and/or environmental consequences. In major standards, different buildings and structures are assigned structural importance, consequence or risk classifications. Examples of these classifications can be found in the following standards:

a) AS/NZS 1170.0:2002, 3.3 for New Zealand, and Annex F: F2 for Australia[9];

b) prEN 1990:2020, 4.3, A.1.3, A.1.4[11];

c) ISO 2394:2015, F.2[17];

d) Table 2.4.1 of Reference [23];

e) ASCE 7-16, 2.2.1, Table 2.2.1[10].

These classifications are summarized in Table 1.

Table 1 — Summary of relationship between structural importance/risk classification and consequence of failure for major standards

Consequence of failure	**Structural importance/risk classification**				
	AS/NZS 1170.0:2002[9]	**prEN 1990:2020**[11]	**ISO 2394:2015**[17]	**Reference [23]**	**ASCE 7-16**[10]
Low	1	CC0 CC1	1	Not considered	1
Ordinary	2	CC2	2	III	2
High	3	CC3	3	II	3
	4		4		4
Exceptional	5	CC4	5	I	5

Additional considerations are given to special and essential buildings and infrastructures in order either to mitigate the hazards posed to community or to maintain functionality in the event of failure, or both. The design of this category of buildings and structures is usually governed by special guidelines and hence is beyond the scope of regular national standards.

Serviceability limit state deals with the loss of functionality related to normal use. This document focuses on the serviceability limit states relating to the deformations and displacements of buildings and building elements.

5 Serviceability limit state guidelines for buildings and building elements

Serviceability limit states for buildings and building elements are related to users' comfort, loss of intended functionality to normal use and gradual deterioration. In these states, the modes of failure, i.e. undesirable states, include:

a) Unacceptable deflections/displacements (deformations): the acceptable limits are subjective and depend on human perception. A building with visible deflections (horizontal or vertical) is not acceptable by some members of the public, even when it is structural safe. The displacements limits often govern the design of a structure.

b) Excessive vibrations: they can cause discomfort to people or affect non-structural elements or functioning of equipment. The acceptability criteria are highly subjective and depend on human perception. The design for vibration very often requires a dynamic analysis.

c) Local damage including cracking: They affect the appearance and functional reliability of the building. In concrete structures, they lead to steel corrosion, spalled concrete, salt penetration, and loss of concrete tensile strength.

It is important to distinguish reversible and irreversible serviceability limit states (e.g. ISO 2394:2015[17]). A reversible serviceability limit state is a state in which the effects of actions do not remain when the actions are removed, while an irreversible serviceability limit state is one in which the effects of actions remain even after the actions are removed.

It is noteworthy that in practice, many serviceability requirements are subject to agreement between the owner and the designer.

This document focuses on serviceability limit states relating to the deformations and displacements of buildings and building elements.

6 Design procedure for serviceability limit states

Most national standards recommend design procedure for buildings and building elements for serviceability limit states. These design procedures comply with the serviceability limit state design methodology adopted by individual national standard, such as those presented in:

a) AS/NZS 1170.0:2002, 2.1, 2.3[9];

b) ISO 22111:2019, D.1, D.3[21];

c) Japanese standards summarized in Reference [26];

d) ASCE 7-16, Annex CC[10].

Generally, the design procedure for serviceability limit state includes, but is not limited to, consideration of the following:

a) properties of materials and geometry of the structure relevant to the serviceability of the building or building element;

b) structural importance, consequence, risk, probability of exceedance or reliability classification of the building for serviceability;

c) serviceability actions, including permanent actions, variable actions and accidental actions such as seismic actions;

d) combinations of actions for serviceability limit states and the corresponding design values;

e) serviceability response of the building or building element;

f) limiting values for the serviceability design conditions.

7 Probability of exceedance and reliability index for serviceability

In a fully probabilistic framework, target reliability level can be expressed through a probability of exceeding (failure) the limit state P_f or a reliability index β. Examples of different probabilistic frameworks adopted for serviceability limit state can be found in the following standards:

a) AS/NZS 1170.0:2002, 3.4, Table 3.3, Annex C[9];

b) prEN 1990:2020, C3.3.2.2[11];

c) ISO 22111:2019, 6.1, 6.2, 6.3, C.1, C.2, C.3[21];

d) Housing Performance Display Standard (2001)[22], AIJ Recommendations for Loads on Buildings (2015)[7];

a) ASCE 7-16, Annex CC[10].

Typical reliability levels in terms of reliability index and the corresponding probabilities of exceedance, according to The JCSS probabilistic model code (2001)[24], are given in Table 2.

Table 2 — Typical reference target reliability levels for serviceability limit state with associated probabilities of exceedance for a one-year reference period

Type of serviceability limit state	Relative cost and effort of safety measures	Reference target reliability index β	Probability of exceeding the limit state P_f
Irreversible	High	1,3	0,10
	Normal	1,7	0,05
	Low	2,3	0,01

For serviceability limit states, target reliability or probability of failure values are generally related to the relative cost and effort of implementing safety measures necessary for achieving sufficient reliability. A qualitative assessment of cost and effort is necessary to determine the consequences of exceeding a given limit state for a structural member, usually for a range of target reliability levels, typically ±0,3.

It is noteworthy that for reversible serviceability limit states, the frequency of exceeding the limit state is an important consideration. For some existing structures, the target reliability levels are different, usually more conservative, than those presented in this clause. For example, ISO 13822:2010[20] suggests a target reliability index $\beta = 0$ for a reference period equal to the intended remaining working life of an existing structure, with a corresponding probability of exceeding the limit state $P_f = 0{,}5$. Importantly, if the considered serviceability limit state results in the possibility of occurrence of an ultimate limit state in a structure or its structural load bearing elements, it is prudent to consider higher values of target reliability levels.

8 Verification methods for serviceability

8.1 General

Most national standards adopt similar principles and methods for the verification of serviceability limit state. The detailed principles and methods can be found in the following standards:

a) AS/NZS 1170.0:2002, 4,1, 4.3, Annex C[9];

b) prEN 1990:2020, 8.4, A.1.6.2, Table A.1.7[11];

c) ISO 22111:2019, Clauses 7, 8, 9, B.1, B.2, B.3[21];

d) References [1] and [4];

e) ASCE 7-16, Annex C, Annex CC[10].

The following is a summary of these principles and methods, mostly based on prEN 1990:2020[11].

Checking serviceability limit states involves verification according to Formula (1):

$$E_d \leq C_d \tag{1}$$

where

E_d is the design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination of actions;

C_d is the limiting design value of the relevant serviceability criterion.

Many national standards specify a comprehensive list of serviceability criteria. These will be discussed in Clause 9 by presenting selected serviceability criteria and the associated limiting design values for common design examples.

8.2 Actions

The actions that give rise to a design value requiring verification for serviceability limit state can be classified as permanent (G), variable (Q), accidental (A), and seismic (A_E). The effects of these actions and their relevant combinations are integral to the design of buildings and building elements at serviceability limit states.

Permanent actions (G), which vary little in time and magnitude, include, but are not limited to, the following:

a) self-weight of the structure;

b) supported constructions;

c) earth pressure, ballast, fluids with well-defined pressure; actions from movement due to differential settlement;

d) pre-stressing, imposed deformation from construction processes.

Variable actions (Q), which are characterized by frequent and large variations, include, but are not limited to, the following:

a) action imposed due to use and occupancy;

b) wind action;

c) snow action;

d) seismic action;

e) action due to ponding of either water or hail, or both;

f) action due to fluids, where variable, including ground water and floods;

g) atmospheric and floating ice action;

h) action due to currents and waves;

i) action due to moving loads and their effects;

j) action due to forces and effects arising from contraction or expansion resulting from climatic changes or technological temperature changes such as heating and cooling, moisture changes;

k) environmental influences.

Accidental actions (A), which are considerable in magnitude but have a small probability of occurrence relative to the anticipated time of use, include, but are not limited to, the following:

a) action due to explosion;

b) action due to collision;

c) seismic action (A_E);

d) action due to erosion;

e) action due to fire.

8.3 Design values of the effects of actions

The design value of the action-effects E_d for a specific combination of actions can be determined according to Formula (2):

$$E_d = E\{F_d; a_d; X_d\} \tag{2}$$

where

$E\{...\}$ is the combined effect of the enclosed variables;

F_d is the design value of actions, which is presented in 8.4, where the partial factor that takes account of unfavourable deviation of an action from its characteristic value $\gamma_F = 1,0$;

a_d is the design value of geometrical parameters, which is presented in 8.5;

X_d is the design value of material properties, which is presented in 8.6.