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Bases for design of structures — Loads, forces and other actions — Seismic actions on nonstructural components for building applications

Bases du calcul des constructions — Charges, forces et autres actions — Actions sismiques sur les composants non structurels destinés aux applications du bâtiment

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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. www.iso.org/directives

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The committee responsible for this document is ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

Introduction

This International Standard presents basic principles for the evaluation of seismic actions on architectural, mechanical and electrical components and systems (i.e. nonstructural components) in building applications. The seismic actions described are fundamentally compatible with ISO 2394.[1]

This International Standard is intended to be a companion document to ISO 3010, *Basis for design of structures — Seismic actions on structures*. It includes not only principles of seismic design but also procedures for the verification of component and system capacity to ensure that those capacities exceed seismic demands. Full verification of components and systems adequacy generally includes other actions not addressed by this International Standard in combination with seismic actions.

This International Standard includes limit states associated with post-earthquake functionality of nonstructural components. Some of these limit states address the overall safety of the building occupants, while others address the safety of the surrounding community impacted by functional failure of the facility. It therefore includes requirements for equipment and systems that demonstrate that they will function as needed to achieve the overall safety goals following the earthquake.

The approach used in this International Standard is to first define the goals and performance objectives and then determine the seismic demands on nonstructural components and systems. The seismic demands, which are complex in nature, are initially described in a general way. Then, based on reasonable assumptions, seismic demands are quantified in a simple manner that is efficient for use in most situations. The simplified demands are based on the assumption that the seismic response of nonstructural components and systems have a negligible effect on the primary response of the structure. A series of annexes included with this International Standard provide informative guidance on determining simplified coefficients, performing evaluation of components, and implementing alternative testing/empirical procedures used for verification including those needed to demonstrate functionality to achieve the overall post-earthquake safety goals.

Bases for design of structures — Loads, forces and other actions — Seismic actions on nonstructural components for building applications

1 Scope

1.1 General

This International Standard establishes the means to derive seismic actions on nonstructural components and systems (NSCS) supported by or attached to new or existing buildings. It also provides procedures for the verification of NSCS seismic capacities. NSCS include architectural elements, mechanical and electrical systems, and building contents.

This International Standard is not a legally binding and enforceable code. It is a source document that is utilized in the development of codes of practice by the competent authority responsible for issuing structural design regulations. This International Standard is intended for application by regional and national standards committees when preparing standards for the seismic performance of NSCS.

This International Standard does not specifically cover industrial facilities, including nuclear power plants, since these are dealt with separately in other International Standards. However, the principles in this International Standard can be appropriate for the derivation of seismic actions for NSCS in such facilities.

NOTE 1 This International Standard has been prepared mainly for NSCS associated with engineered buildings. The principles are, however, applicable to non-engineered buildings.

NOTE 2 Procedures for the verification of the supporting building structure for gravity and seismic actions applied by the NSCS are outside the scope of this International Standard and are provided in ISO 3010.

1.2 Relationship with ISO 3010

This International Standard is a companion document to ISO 3010, *Basis for design of structures — Seismic actions on structures*. ISO 3010 and its annexes provide basic seismic design criteria to be used in the design of structures but they do not provide design criteria for NSCS (except for those that can influence the structural response). For consistency, the terms and definitions that are in common with ISO 3010 are also used in this International Standard.

The same ground motion criteria specified in ISO 3010 are also used in this International Standard. The demand on NSCS is directly related to the response of the building in which they are located. Therefore, the procedures used to determine the design ground motion and building seismic response are directly referenced by this International Standard.

1.3 Components requiring evaluation

Evaluation of NSCS for seismic actions is required where any of the following apply:

a) the NSCS poses a falling hazard;

b) the failure of the NSCS can impede the evacuation of the building;

c) the NSCS contains hazardous materials;

d) the NSCS is necessary to the continuing function of essential facilities after the event; and

e) damage to the NSCS represents a significant financial loss.

Guidance for identification of NSCS that require seismic evaluation is provided in Annex A.

NOTE Pre-assembled modular mechanical and electrical units (e.g. heating and cooling modules) may be treated as an assembly of components supported by the modular unit housing structure (see 9.5).

1.4 Components excluded

The requirements of this International Standard are not intended for application to furnishings, or temporary or relocatable components (see Annex A).

With the exception of parapets (as described in Annex A), application of this International Standard to components in buildings subject to low levels of seismic hazard may not be warranted.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3010:2001, *Basis for design of structures — Seismic actions on structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3010 and the following apply.

3.1
ductility
ability to deform beyond the elastic limit under cyclic loading without significant reduction in strength or energy absorption capacity

3.2
interstorey drift
lateral displacement within a storey

3.3
moderate earthquake ground motion
moderate ground motion caused by earthquakes which can be expected to occur during the service life of the building

3.4
overstrength
increase in strength of a structural element above that designed or specified

Note 1 to entry: For nonstructural components, overstrength is used to provide an additional margin in the design of anchorage and bracing to prevent premature failure of these elements. Overstrength factors are based on judgment.

3.5
restoring force
force exerted on the deformed component which tends to move the component to the original position following earthquake motions

3.6
seismic hazard zone factor
factor to express the relative seismic hazard of the region

3.7
serviceability limit state
limit state beyond which the serviceability criteria of NSCS are no longer satisfied

3.8
structural factor
factor to reduce seismic design forces, taking into account ductility, acceptable deformation, restoring force characteristics and overstrength (overcapacity) of the structure

3.9
ultimate limit state
limit state beyond which NSCS collapse, overturning, release of hazardous contents, or, in the case of critical facilities, loss of function is expected to occur

Note 1 to entry: See Clause 5 a) for NSCS performance criteria for ultimate limit states.

4 Symbols and abbreviated terms

A_{Di} acceleration at level i obtained from a dynamic analysis (see Annex G)

A_i ordinate of the normalized floor response spectrum at level i

$A_{flexible}$ parameter defining the normalized floor response spectrum for flexible components

A_{rigid} parameter defining the normalized floor response spectrum for rigid components

f_0, f_1, f_2, f_3 frequencies defining floor response spectrum (see Annex G)

$F_{D,p,u,i}$ ($F_{D,p,s,i}$) design lateral seismic force of the NSCS attached at level i of the building structure for ULS (SLS)

$F_{E,p,u,i}$ ($F_{E,p,s,i}$) elastic lateral seismic force of the NSCS attached at level i of the building structure for ULS (SLS)

$F_{G,p}$ weight of the NSCS

H average roof elevation of the structure relative to grade elevation

i level in the building structure of the point of attachment of the NSCS relative to grade elevation

$k_{D,p}$ nonstructural component response modification factor, to be specified according to its ductility and overstrength

$k_{H,i}$ floor response amplification factor for attachment location at level i

$k_{I,u}$ ($k_{I,s}$) ground motion intensity factor to be provided by regional and national standards;

$k_{R,p}$ component amplification factor considering the effect of the natural periods of the NSCS and the building

$k_{R,p,flexible}$ NSCS amplification factor for flexible systems ($k_{R,p,i,flexible} > 1{,}0$)

$k_{R,p,i,rigid}$ NSCS amplification factor for rigid systems ($k_{R,p,i,rigid} = 1{,}0$)

$R_{p,s}$ inverse of the nonstructural factor $k_{p,s}$ (see Annex E)

$R_{p,u}$ inverse of the nonstructural factor $k_{p,u}$ (see Annex E)

T_C component period

T_j jth modal period of the building structure

z_i elevation of level i relative to grade elevation

α parameter to account for increase in floor acceleration response over the height of the building, that can be a function of the type of lateral-load resisting system

β ratio of vertical response to horizontal response

$\gamma_{n,E,p}$ importance factor related to the required seismic reliability of the NSCS

5 Seismic design objectives and performance criteria

The fundamental seismic design objectives for NSCS are, in the event of an earthquake:

— to prevent human casualties associated with falling hazards and blockage of egress paths;

— to ensure post-earthquake continuity of life-safety functions within the building (e.g. sprinkler piping);

— to ensure continued post-earthquake operation of essential facilities (e.g. hospitals, fire stations);

— to maintain containment of hazardous materials;

— to minimize damage to property

To achieve the seismic design objectives, this International Standard establishes the following basic performance criteria.

a) NSCS subjected to the severe earthquake ground motions that are specified at the building site (ultimate limit state: ULS) should be designed, qualified by testing or qualified by experience data to demonstrate that:

1) NSCS will not collapse, detach from the building structure, overturn or experience other forms of structural failure, breakage or excessive displacement (sliding or swinging) that could cause a life safety hazard;

2) NSCS will perform as required to maintain continuity of life safety functions (e.g. fire-fighting systems, elevators, and other similar vital life safety systems);

3) NSCS will remain leak tight as required to prevent unacceptable release of hazardous materials (e.g. vessels, tanks and piping and gas circulation systems that contain hazardous materials);

4) NSCS will operate as necessary immediately following the earthquake event to ensure continued post-earthquake function of essential facilities.

b) NSCS subjected to the moderate earthquake ground motions specified at the building site (serviceability limit state: SLS), will perform within accepted limits including limitation of financial loss.

NOTE 1 Recommendations for determining the severe (ULS) and moderate (SLS) design ground motions for a given build site are provided in ISO 3010.

NOTE 2 It is recognized that complete protection against earthquake damage is not economically feasible for most types of NSCS.

NOTE 3 Following an earthquake, earthquake-damaged buildings may need to be evaluated for safe occupation during a period of time when aftershocks occur. This International Standard, however, does not address actions on NSCS that can be expected due to aftershocks. In this case a model of the damaged building and components is required to evaluate seismic actions.

6 Sources of seismic demand on NSCS

6.1 General

The following three sources of seismic demand should be considered when evaluating NSCS:

a) inertial acceleration demands;

b) relative displacement demands between points of attachment;

c) impact force demands resulting from interactions with other components or structural members.

These seismic demands are described in more details in 6.2 through 6.4 below. Principles for determining these seismic demands are provided in Clause 7 and quantification of these seismic demands in terms of recommended force equations are provided in Clause 8.

NOTE NSCS are generally classified as acceleration-sensitive or relative displacement-sensitive depending upon which demand causes the most damage to the component during an earthquake. Anchored mechanical equipment is typically considered acceleration-sensitive while building cladding is typically considered sensitive to relative displacements (drift sensitive). For some NSCS, both demands are significant.

6.2 Inertial demand

All NSCS attached to buildings or their foundations are subjected to inertial demands. These inertial demands are most generally described as acceleration motions at the points of attachment of the NSCS and the structure. For points of attachment at the ground level or foundation level, these acceleration motions are generally taken for design purposes as the earthquake design ground motions. At points of attachment above the ground, the acceleration motions are modified by the dynamic response of the building structural system to the earthquake ground motions. The modifications that have an influence on these acceleration motions include the fundamental dynamic characteristics of the building structural system (natural periods, damping, etc.), the relative location of the point of attachment within the structure and the level and type of nonlinear behaviour that the building structural system experiences during the earthquake. Most generally, the acceleration motion demand for NSCS are characterized in terms of floor acceleration response spectra of the structural element (e.g. floor) to which the NSCS is attached. For the most general case, both horizontal and vertical floor acceleration response spectra are defined.

In structural design, inertial demands are usually expressed in terms of force. The inertial force demand on an individual component is a function of inertial acceleration demand at the points of attachment and the dynamic properties of the components itself including its mass, stiffness, and nonlinear response properties. For design purposes, this is often simplified as the product of a seismic coefficient and the component weight.

A primary assumption of the inertial acceleration demand is that the dynamic response of the NSCS has a negligible effect on the building response. If the effect is significant more complex methods are required to determine the demand. See 7.3.

6.3 Relative displacement demand

Relative displacement demands occur during earthquake motions when the NSCS attachment (or support) points experience unequal displacements (e.g. see Figure F.1). Sources of relative displacements are:

a) relative displacements of attachment points that are located at different floor levels of a building;

b) relative displacements of attachment points that are located on independent, seismically separated buildings;

c) relative displacements of attachment points that are located on two NSCS attached to the same or different floors, including components on vibration isolators;

d) relative displacements of attachment points located on NSCS and the building;

e) relative displacements of attachment points that are located on seismically isolated building and its foundation or between seismically isolated floors.

Relative displacement demands are predominately horizontal in nature although vertical relative displacement demands are also possible. Inter-storey drifts of a building are transformed into relative displacement demands by multiplying the earthquake-caused drift ratio by the vertical distance between points of attachment. As with the inertial demand, the relative displacement demands are a function of the earthquake displacement response of the building structure to which the NSCS is attached and for some situations, the earthquake displacement response of the NSCS is also important.

Stresses from relative displacement demands are typically determined from static analysis where points of attachment are displaced. Stresses in NSCS induced by relative displacement demands should be within acceptable limits.

Relative displacement demands may also result in loss of bearing support. Bearing seat width should be adequate to accommodate relative displacement demands.

A primary assumption of the above approach for determining relative displacement demand is that the strength, mass and stiffness of the connecting NSCS will have a negligible effect on the building response. If the effect is significant, the NSCS should be included in the structural model or more complex methods are required to determine the demand (see 7.2).

6.4 Impact demand

Impact demands on NSCS are the result of collisions with the structural system or other NSCS. These collisions occur when the clearance between adjoining NSCS or between NSCS and the building is insufficient. To avoid impact demands of NSCS with other NSCS or structural systems, either adequate clearance or seismic restraints should be provided. In some instances this impact is unavoidable, as in the case of seismic snubbers supporting vibrating equipment. Where adequate clearance or restraint cannot be provided, it may be necessary to accept the damage from impact. The determination of impact demands requires higher order analysis and testing. The determination of adequate clearances to avoid damaging impact demands also requires special evaluation.

See 8.5 for additional discussion.

7 General conditions for determining seismic demand on NSCS

7.1 General

The determination of seismic demands imposed on NSCS should consider the response of the supporting building to ground motion and the interaction of the structure and the NSCS. In this International Standard, it is generally assumed that the response of the NSCS has a negligible effect on the building structure earthquake response. This assumption is valid if certain conditions specified in 7.2 are satisfied.

7.2 Determining seismic demand assuming NSCS does not influence building response

For NSCS which are primarily inertial demand sensitive, it is acceptable to treat the NSCS as a secondary component

a) if the mass of the NSCS is small relative to the building mass or the mass of that portion of the building structure to which the component is attached, or

b) if the participation of the NSCS mass in the overall seismic response (even though relatively large compared to the building mass) is distributed uniformly over the building structure or a larger part of the building structure (e.g. cladding, piping systems).

If the NSCS is not directly attached to the building structure (e.g. attached to ground floor slab) or is attached in a manner that prevents it from influencing the overall building seismic response it is always acceptable to exclude the NSCS dynamic model from the building dynamic model.

For NSCS which are primarily sensitive to relative displacements of the building, it is acceptable to assume that the NSCS does not influence the building response

a) if the strength and/or stiffness of NSCS which are attached at more than one level of a building are small relative to the strength and stiffness of the lateral force resisting system of the building, or

b) if the presence of the NSCS does not alter the boundary conditions of the building structure or its structural components that would have unfavourable effects on the seismic response of the building or the NSCS itself.

7.3 Determining seismic demands assuming NSCS influences building response

For situations where the NSCS response can influence the building response, the potential influence of the NSCS on the building seismic response should be considered. NSCS that influence the overall building seismic response whether due to mass, strength or stiffness contribution, or change to boundary condition should be included in the building structural model as required by 6.3 of ISO 3010:2001.

NOTE In general, the mass of NSCS should be included in the building structural analysis, either explicitly or as an allowance regardless if the nonstructural response does not influence the building response.

8 Quantification of elastic seismic demand on NSCS

8.1 General

Seismic demands on NSCS are typically quantified as design seismic forces and or design seismic relative displacements. This section quantifies the determination of elastic baseline seismic demands in terms of:

a) accelerations;

b) relative displacements between different floors of the supporting building;

c) relative displacements between supporting buildings or other items to which NSCS are attached;

d) interactions with other NSCS.

Elastic baseline inertial force demands (see 8.2) may be modified for needed reliability as expressed through importance factors (Annex B) and overstrength and energy-dissipation characteristics of NSCS as represented by response modification factors (Annex E). These modifications are addressed in 9.2 of this International Standard.

NOTE The term elastic seismic demand implies that demand is determined assuming the NSCS remains elastic and that the response is not modified to account for factors such as required reliability (importance), overstrength or energy-dissipation characteristics of the NSCS. It is not meant to imply that the building structure also remains elastic when determining the demand.

8.2 Inertial force demands determined by dynamic analysis

Inertial force demands on NSCS should be quantified as the product of the acceleration demand and the component mass. It is always acceptable to obtain acceleration demands on NSCS by dynamic analysis of supporting building(s). The acceleration demands are expressed either in terms of the peak floor acceleration, peak inertial acceleration of the component, floor response spectra or acceleration time histories of the floor motion. The type of demand should be consistent with the method of verification as specified in Clause 9 of this International Standard.

Floor response spectra may be established for a specific case or generically for a wide range of buildings. Specific floor response spectra are developed from dynamic analysis of supporting buildings, while generic spectra are typically determined using static coefficient values derived from the simplified equivalent static force equations (see 8.3.2). For specific floor response spectra, nonlinear response of the supporting buildings should be considered due to the possibility of modification of seismic demands on NSCS resulting from the building inelastic response. See further discussion of floor response spectra in Annex G, and more details of performing dynamic analysis of supporting buildings in Clause 9 of ISO 3010:2001.

Dynamic analysis of both the building and NSCS in a combined single model can be required for certain cases. Specifically, where there can be significant interaction between more massive components and the supporting structure, such a procedure is recommended. (See 7.3 and Annex G of this International Standard.) In this case detailed modelling of the connection to the structure as well as the local structural members that support the NSCS, should be considered to develop the inertial force demands. The design of the structure for the combined effects should be evaluated in accordance with 6.3 and 9.5 of ISO 3010:2001.

8.3 Inertial elastic force demands determined by equivalent static analysis

8.3.1 General

It is permitted to determine inertial elastic force demands on NSCS using equivalent static analysis force procedures. The equivalent static force elastic demand may be computed directly from a combined dynamic analysis of the building and NSCS. For those NSCS which may be assumed to not influence the building response, the equivalent static elastic force demands may be determined from:

a) floor response spectra using the ratio of natural frequencies of NSCS and supporting building; or

b) the elastic equivalent static force in 8.3.2.

See 9.2 for more information on static coefficients and Annex G for more information on floor response spectra.

8.3.2 Basic elastic equivalent static forces

The elastic equivalent static seismic forces for ULS and SLS earthquake levels are given as follows:

a) ULS (Ultimate Limit State);

The elastic seismic force on NSCS attached at the *i*th level of the building structure for ULS, $F_{E,p,u,i}$, is given by

$$F_{E,p,u,i} = k_{I,u} \cdot k_{H,i} \cdot k_{R,p} \cdot F_{G,p}$$

b) SLS (Serviceability Limit State);

The elastic seismic force on NSCS attached at the *i*th level of the building structure for SLS, $F_{E,p,s,i}$, is given by

$$F_{E,p,s,i} = k_{I,s} \cdot k_{H,i} \cdot k_{R,p} \cdot F_{G,p}$$

where

$F_{E,p,u,i}$ ($F_{E,p,s,i}$)	is the elastic lateral seismic force on the NSCS attached at the *i*th level of the building structure for ULS (SLS);
$k_{I,u}$ ($k_{I,s}$)	is the ground motion intensity factor to be provided by regional and national standards;
$k_{H,i}$	is the floor response amplification factor at the attachment at level i (see Annex C);
$k_{R,p}$	is the component amplification factor considering the effect of the natural periods of the NSCS and the building (see Annex D);
$F_{G,p}$	is the weight (m·g) on the NSCS.

8.3.3 Horizontal acceleration

The horizontal equivalent static elastic acceleration demand is the product of the ground motion intensity factor ($k_{I,u}$, $k_{I,s}$), floor response amplification factor ($k_{H,i}$), and the component amplification factor ($k_{R,p}$). The procedures for determining these factors are given in 8.3.3.1, 8.3.3.2 and 8.3.3.3.

8.3.3.1 Ground motion intensity factor (normalized peak ground acceleration)

The ground motion intensity factor ($k_{I,u}$, $k_{I,s}$) is related to the regional seismicity, local site effects, and the designated earthquake levels. In general, peak ground acceleration values are represented by the ground motion intensity factor normalized to gravitational acceleration (in units of g). If the peak ground velocity or other spectral ordinates are given, those values should be transformed into acceleration and normalized to develop the value of the ground motion intensity factor.

The ground motion intensity factor corresponds to that used for the supporting building. In accordance with ISO 3010, the ground motion intensity factor ($k_{I,u}$, $k_{I,s}$) is given by:

$$k_{I,u} = k_Z \cdot k_{E,u}$$

$$k_{I,s} = k_Z \cdot k_{E,s}$$

where

k_Z is the seismic zoning factor;

$k_{E,u}$ is the seismic ground motion intensity.for ULS

$k_{E,s}$ is the seismic ground motion intensity.for SLS

8.3.3.2 Floor response amplification factor (height factor)

The floor response amplification factor ($k_{H,i}$) represents the dynamic amplification of the specified floor acceleration response over the height of the building with respect to the ground acceleration. The floor response amplification factor is generally determined as a function of the ratio of the height of the point of attachment of the NSCS to the average height of the building in which the component is located.

Considering effects from higher modes of the supporting building, the floor response amplification factor can be determined using a modal analysis of the supporting building. Alternatively, the floor response modification factor may be determined using simplified analysis proceedures as described in Annex C.

8.3.3.3 Component amplification factor (resonance factor)

The component amplification factor ($k_{R,p}$) represents the dynamic amplification of NSCS response as a function of the ratio of the natural frequencies of the NSCS and supporting building. Component amplification factors can be obtained from a floor response spectrum based on the natural frequencies of the NSCS. The natural frequencies of supporting building can be obtained from a representative model of the building developed in accordance with ISO 3010. The natural frequencies of NSCS may be obtained by calculation, pull-and-release tests, impact tests, or shake table tests. The method used should be appropriate to the type of component being assessed. Nevertheless, considering that the natural frequencies of the supporting building and the NSCS are usually unavailable in practice, component amplification factors of NSCS may be tabulated according to the rigid or flexible characteristics of the NSCS. See Annex D for more information.