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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	*j*th 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.

8.3.4 Vertical acceleration

Similar to horizontal acceleration demands, vertical acceleration demands for NSCS should be quantified using analogous factors for the vertical direction: the ground motion intensity factor, floor response amplification factor, and component amplification factor.

For the vertical ground motion intensity factor, the normalized vertical peak ground acceleration may be used. Where this information is not available, it may be taken as 1/2 to 2/3 of the normalized horizontal peak ground acceleration (see Annex G), except in the near-field of shallow focus earthquakes where vertical accelerations can be significantly higher. See Clause 8 and Annex E of ISO 3010:2001 for more information about vertical ground acceleration.

For NSCS design, in general, dynamic amplification of floor response with respect to ground acceleration in the vertical direction can be limited. Therefore, the component amplification factor $k_{R,p}$ for vertical floor response is generally taken as 1,0.

NOTE The out-of-plane response associated with certain types of flexible floors and roofs can amplify vertical response. In these cases, consideration of additional response amplification may be warranted. In addition, research indicates that vertical floor accelerations can be amplified in seismically isolated buildings. Finally, the attachment design of vertical acceleration-sensitive equipment, such as vibration-isolated equipment, should consider the possibility of additional resonant vertical seismic demands that exceed the vertical ground motion.

8.4 Seismic relative displacement demands

8.4.1 General

The NSCS relative displacement demands should be quantified for displacement-sensitive components as the seismic relative displacement expected between points of attachment of the component for both ULS and SLS earthquake levels. For NSCS connected between floors, such as glazing, the relative displacement demands are the relative displacements between floors of the same building. For NSCS which span across seismic separation joints, the relative displacement demand is the displacement (considering all applicable degrees of freedom) between the NSCS attachment points on each structure. For NSCS which span horizontally between flexible equipment on the same floor or different floors, such as piping, the seismic demand is the relative displacement between points of attachment to the equipment. Relative displacement demands are typically determined by elastic equivalent static analysis and are the demands expected for ULS and SLS ground motion levels unmodified by inelastic reduction factors.

NOTE The effect of seismic relative displacements should be considered in combination with displacements caused by other loads as appropriate. Specific details on determining relative displacement seismic demands are provided in Annex F.

8.4.2 Connection points within a single building

For two connection points at different levels in the same supporting building, the seismic relative displacement demands should be determined from the seismic drift ratio between the upper and lower attachment points of the NSCS obtained from the design structural analysis. Alternatively, if the structural analysis is unavailable, the seismic relative displacement demands are conservatively determined from the allowable storey drift as specified by regional and national standards for the ULS. Where the allowable storey drifts in regional and national standards are specified only for the SLS, they may still be used to establish displacement demands provided the NSCS displacement capacities have been appropriately adjusted for SLS demand levels.

For connection points that cross an isolation plane within a building the relative displacement demand should be determined from the design analysis of the building and isolation system at the ULS.

8.4.3 Connection points between two buildings

For NSCS which span between seismically separated building structures, the seismic relative displacement should be expressed in terms of displacement that must be accommodated both longitudinally and transversally. It should be typically assumed that the structures do not move in-phase. The relative displacement demand between structures should be determined as the square root of the sum of the squares of the horizontal displacement of each structure at the floor level under consideration by structural analysis. Alternatively, if the structural analysis is unavailable for both buildings, the seismic relative displacement demands for two connection points between the two buildings should be determined from the allowable storey drift following the same approach as noted in 8.4.2.

NOTE Conservatively, the relative displacement demand between structures may be taken as the sum of the absolute value of the displacements of each structure at the floor level under consideration.

8.4.4 Connection points between flexible equipment

For NSCS which span between flexible equipment, the relative seismic displacement demand should be based on rational seismic analysis. It is acceptable to determine the relative displacement demand between equipment items as the sum of the absolute values of the horizontal displacements of each equipment item at the connection point under consideration.

NOTE Displacement demands for flexible equipment in buildings are generally determined on the basis on observations from past earthquakes (experience data) and judgment.

8.5 Impact demand

The potential for impact between components that are in contact with or in close proximity to other structural elements or NSCS should be considered if it is judged to be both credible and significant. A credible impact is one that is likely to occur during a seismic event. A significant impact is one that will result in unacceptable damage to an NSCS or in inadequate performance of a critical NSCS, or of the impacted component/structure.

Where feasible, impact demand on NSCS should be avoided by providing adequate clearance or restraint. Required clearances to avoid impact are generally determined on the basis of observations from past earthquakes (experience data) and judgment. In cases where restraint is provided, connections should be provided with adequate flexibility to accommodate differential displacements.

Where impact cannot be avoided, impact force demands are determined by energy methods with consideration of mass, impact velocity, and inelastic behaviour of the impacting components.

9 Verification of NSCS

9.1 Performance acceptance criteria

The behaviour of NSCS should be evaluated and verified against performance objectives specified for the ULS and SLS in as required by this clause. The following four methods of verification are permitted:

a) verification by design analysis;

b) verification by seismic qualification testing;

c) verification by consensus procedures that determine acceptable seismic capacity on the basis of documented experience from past earthquakes (experience data);

d) a combination of a), b) and c).

Verification provides evidence that the performance objectives specified in Clause 5 are achieved by demonstrating that the capacity exceeds the demand. Depending on the importance of the facility (i.e. essential, non-essential) and the importance of the NSCS for achievement of post-earthquake performance expectations, demands are adjusted and enhanced levels of verification can be required.

To differentiate the demand and capacities that are required for NSCS, each NSCS is assigned a component category as described in Annex B. Adjustments to the ULS and SLS demands and specific capacity acceptance criteria (e.g. design requirements) which are to be satisfied for each component category are also provided in Annex B.

Verification by design analysis is typically used to evaluate the NSCS, bracing and anchorage for adequate structural capacity. Verification by testing or through the use of experience data are used to demonstrate that either acceleration or relative displacement capacity is greater than the acceleration or relative displacement demand. Experience data consists of substantiated evidence showing that similar NSCS have been subjected to equal or stronger seismic demands and have acceptably maintained their function following the earthquake. Specifics of these verification procedures are described in 9.2, 9.3 and 9.4.

NOTE Verification exclusively by analysis is insufficient to demonstrate that essential active components in the mechanical and electrical systems will maintain function following an earthquake.

9.2 Verification by design analysis

To provide verification of the adequacy of a NSCS by design analysis, a structural analysis is performed of the NSCS including its anchorage and bracing using the design lateral forces for the ULS and SLS as determined below in this clause. Each member and connection force resulting from the analysis is compared with the design capacity of the NSCS individual member, connection brace or anchorage provided in regional and national standards to verify that the capacity exceeds the demand. See Annex H for recommendations for performing design analysis evaluations.

To determine the design lateral force demand to be applied to NSCS in the design analysis, the elastic lateral force demand determined in Clause 8, whether determined from static or dynamic analysis, is modified as follows:

a) ULS (Ultimate Limit State);

The design lateral seismic force of NSCS attached at level i of the building structure for ULS, $F_{D,p,u,i}$, is determined by

$$F_{D,p,u,i} = \gamma_{n,E,p} \cdot k_{D,p} \cdot F_{E,p,u,i}$$

b) SLS (Serviceability Limit State);

The design lateral seismic force of NSCS attached at level i of the building structure for SLS, $F_{D,p,s,i}$, is determined by

$$F_{D,p,s,i} = \gamma_{n,E,p} \cdot F_{E,p,s,i}$$

where

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

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

($\gamma_{n,E,p}$) is the importance factor related to the required seismic reliability of the NSCS (see Annex B);

$k_{D,p}$ is the NSCS response modification factor to be specified according to its ductility and overstrength (see Annex E).

9.3 Verification by seismic qualification testing

9.3.1 General

Seismic qualification testing to verify NSCS capacities includes shake table testing, quasi-static displacement testing or quasi-static force testing. Detailed requirements for each testing approach are provided in 9.3.2 and 9.3.3..

NOTE 1 Production quality control testing is distinct from the testing discussed in this section, see Clause 11.

NOTE 2 Boundary conditions in verification testing (e.g. attachment to test fixture) should reflect the expected installed condition.

NOTE 3 Verification testing should be performed by an accredited testing laboratory to ensure that the qualification results are unbiased.

9.3.2 Verification by shake table testing

9.3.2.1 General

Verification of the capacity of NSCS by shake table testing is accomplished by subjecting the component to either computed or simulated elastic demand floor motions that are compatible with the floor response spectra determined in accordance with Annex G. The testing is intended to verify that the NSCS, their attachments and subassemblies satisfactorily meet the ULS and SLS performance objectives as specified in Clause 5.

NOTE 1 Shake table testing using motions compatable with floor response spectra permits capacities of NSCS to be generically determined irrespective of site- and building-specific response. Use of site- and building-specific demand parameters may also be used to establish table motions, but this approach is impractical for most cases.

NOTE 2 Rationalized test unit configurations permit verification of variable equipment product lines independent of how the equipment is attached to the shake table.

9.3.2.2 Shake table testing and qualification protocols

The development or selection of shake table testing and qualification protocols includes as a minimum (see also Annex I):

a) description of how the protocol meets the intent of the reference standard requirements and relevant interpretations of the standard;

b) definition of a test input motion with a response spectrum that meets or exceeds the ULS and SLS spectrum for project specific site requirements as established by the reference seismic design standard;

c) accounting for dynamic amplification due to above-grade equipment installations. Consideration of the actual dynamic characteristics of the primary support structure is permitted, but not required;

d) definition of how shake table input demands are derived and how they establish a qualification requirement which is relevant to the reference design standard;

e) definition and establishment of a verifiable pass/fail acceptance criterion for the seismic qualification based upon the equipment importance factor ($\gamma_{n,E,p}$) as established by the ULS and SLS performance objectives of the reference design standard.

9.3.2.3 Requirements for testing documentation

To document that the tested capacity satisfies the relevant regional or national standard, a manufacturer's certificate of conformity (also known as a certificate of compliance) is provided by the supplier of the NSCS to the design professional with a concise description of how it was tested and how the tested capacity was determined.

The certificate should address:

a) class of product enveloped by the testing;

b) regional and national standards for which compliance was evaluated and how the test protocol is relevant to the dynamic requirements of the reference seismic design standard;

c) testing standard used and, in those cases where the test criteria are not directly associated with the seismic design standard, a description of how the dynamic test criteria used for the testing meets the intent;

d) the acceptance criteria used to evaluate the shake table test response data and establish tested capacity;

e) performance objective and corresponding importance factor ($\gamma_{n,E,p}$);

f) tested seismic capacity for which the component is certified, including code and/or standard design parameters used to calculate seismic demand ($k_{I,u}$, $k_{H,i}$, etc.);

g) installation restrictions, if any.

NOTE Typically, shake table testing is performed on acceleration-sensitive NSCS and active electrical and mechanical equipment which are an integral part of an essential system and which should be capable of returning to operation after the earthquake. The qualification of mechanical and electrical components for seismic demands alone is not always sufficient to achieve performance objectives. Establishing a high degree of confidence that performance goals will be met requires consideration of the performance of structures, systems (fluid, mechanical, electrical, instrumentation, etc.), and their interactions (for example interaction of seismic and other loads) as well as compliance with installation requirements.

9.3.3 Verification by quasi-static cyclic seismic testing

9.3.3.1 General

Quasi-static cyclic seismic testing is either based on the imposition of either displacement or force demands. The common procedure for this type of testing begins with relatively small demands (force or relative displacement demands) that are applied cyclically to the test specimen. The demands are gradually increased until the test specimen is subject to the maximum test demand. Verification is pass-fail based on performance expectations at maximum test demand. Alternatively, NSCS capacity is established as the test demand at which performance expectations are still met.

NOTE These tests are typically performed at slow test speeds relative to actual seismic demand speeds. It has been observed that for relative displacement-sensitive NSCS, slow speed displacement tests adequately determine capacities associated with earthquake ground motions.

9.3.3.2 Displacement testing

To verify the adequacy of the capacity of NSCS by the quasi-static cyclic relative displacement testing, a relative displacement test (often referred as a racking test) is performed that subjects NSCS to a maximum seismic relative displacement demand equal to or greater than that determined in 8.4. The testing verifies that NSCS, their attachments and subassemblies satisfy their ULS and SLS performance objectives as specified in Clause 5.

NOTE NSCS tested in this manner are glazing (e.g. window glass), cladding, stairs and piping systems. Generally, NSCS of this type are tested to maximum allowable drifts permitted for structural systems.

9.3.3.3 Force testing

To provide verification of the adequacy of a NSCS by quasi-static cyclic force testing, a cyclic force test is performed that subjects the component to at least the maximum force demand determined by analysis as determined in 8.2 or 8.3. The testing verifies that NSCS, their attachments and subassemblies satisfactorily meet their ULS and SLS performance objectives as specified in Clause 5.

NOTE NSCS tested in this manner are post-installed anchor bolts.

9.4 Verification by documented performance in past earthquakes (experience data)

To provide verification of the adequacy of a NSCS by experience data, a documented procedure is followed. The performance of NSCS is documented along with the estimated earthquake motions associated with that performance. From this procedure, the seismic capacity should be is estimated with some margin for uncertainty. The capacity is provided in terms of a bounding response spectra and presumed installation conditions. The bounding spectra is upper limit capacity of the component and the installation conditions are the specific conditions regarding details of the component and its installation under which the bounding spectra is considered valid. The verification procedure consists of confirmation that the component satisfies all of the relevant installation conditions and that the elastic demand response spectra is less than the bounding spectra. To verify the seismic load path, a design analysis as specified in 8.2 or 8.3 is performed. The experience data procedure verifies that NSCS, their attachments and subassemblies satisfactorily meet their ULS and SLS performance objectives as specified in Clause 5. See Annex J for more specific recommendations regarding experience data procedures.

9.5 Verification by a combination of procedures

Verification of large NSCS can be accomplished using a combination of the procedures provided in 9.2, 9.3 and 9.4.

In the case of NSCS consisting of a large housing containing multiple subassemblies, large scale shake table testing may not be feasible. For such cases, a permissible approach is to analyse the structural system of the NSCS, to obtain localized demands at the support locations of the vulnerable subassemblies and to verify the capacity of the components to withstand the localized demands by either shake table testing or experience data.

The subassemblies along with their interconnecting process piping and electrical wireways may be analysed for seismic demands listed in Clause 8. The subassemblies, housing and its seismic anchorage should be evaluated by the most appropriate methods (see Annex K). The installation and attachment of the active components should also be evaluated to ensure adequate seismic capacity.

The cumulative performance assessment of the subassemblies, their anchorages, associated conduits, wireways or process piping, skid structural system (or housing) and their seismic anchorage should be combined for an aggregate assessment of the performance objectives of the overall pre-assembled system to the ULS and SLS objectives specified in Clause 5.

NOTE Some portions of a facility system may be supplied in a pre-assembled modular housing or on as a skid mounted assembly of components. Examples would be a small scale water purification system, alternative on-site power source or a cooling tower. For those pre-assembled units where ULS functionality following an earthquake should be demonstrated and the complete assembly is too large or heavy to qualify by shake table testing it is acceptable for these systems to be divided into their vulnerable subassemblies, which may then be qualified by a combination of verification by testing, design or experience. Pre-assembled modular mechanical units may be considered as building structures supporting NSCS. The entire system (all modules assembled) can be assessed (e.g. by testing on a shake table) or the individual components may be assessed separately, whereby an analysis of the modular housing structure is required to assess overall stability.

10 Verification of seismic load path between NSCS and building structural system

A continuous load path of sufficient strength and stiffness between NSCS and the supporting building structure should be provided. Guidance for design of anchorage of NSCS to concrete is provided in Annex K. Local elements of the structure including connections are designed and constructed for the

NSCS demands where they control the design of the elements or their connections. The NSCS demands are those determined in 9.2.

NOTE Items of particular concern with regard to continuous load path are housekeeping pads for equipment, shallow topping slabs, concrete on metal deck floors, and attachments to light wood or metal partition framing.

11 Quality assurance and enforcement

Acceptable seismic performance of NSCS includes implementation of a detailed quality assurance (QA) program and enforcement of proper design and installation by government regulatory bodies. The QA and enforcement programs include assignment of responsibilities for:

a) seismic design of NSCS and review of qualification procedures and documentation used to verify that seismic capacity meets site seismic demands;

b) coordination of NSCS anchorage and bracing installation;

c) field inspection to verify that NSCS and their anchorage and bracing are installed in accordance with the contract documents and the applicable standards.

See Annex L for more details on these programs.

NOTE Historically, the earthquake resistance of NSCS is not given the same attention, both in terms of design and construction, as that accorded to the seismic detailing of building structural systems. The successful implementation of NSCS anchorage and bracing provisions is therefore largely dependent on appropriate inspection and enforcement provisions. See Annex L.

Annex A
(informative)

Identification of NSCS requiring seismic evaluation

A.1 General

This Annex provides guidance for identifying NSCS that require seismic evaluation. Guidance is also provided for specifically excluding certain NSCS.

A.1.1 Falling hazards

Suspended or attached NSCS that could detach either in full or in part from the structure during an earthquake are referred to as falling hazards and can represent a serious threat to property and life safety. Critical attributes that influence the hazards posed by these components include their weight, their attachment to the structure, their failure or breakage characteristics (e.g. as with certain types of glass), and their location relative to occupied areas (e.g. over an entry or exit, a public walkway, an atrium, or a lower adjacent structure). Architectural components that pose potential falling hazards include parapets, cornices, canopies, marquees, glass, large ornamental elements (e.g. chandeliers), and building cladding. In addition, suspended mechanical and electrical components (e.g. air handling plenums, piping, and ductwork) can represent serious falling hazards. Examples of components that generally do not pose a significant falling hazard include awnings and canopies made of fabric.

NOTE Equipment should be evaluated if it is permanently attached to utility services (electricity, gas, and water).

A.1.2 Egress blockage

Components whose collapse during an earthquake could result in blockage of the means of egress should be evaluated. The term "means of egress" is used commonly in building codes, e.g. with respect to fire hazard exiting. Consideration of egress may include intervening aisles, doors, doorways, gates, corridors, exterior exit balconies, ramps, stairways, pressurized enclosures, horizontal exits, exit passageways, exit courts, and yards. Items whose failure could jeopardize the means of egress include walls around stairs and corridors, veneers, cornices, canopies, heavy partition systems, ceilings, architectural soffits, light fixtures, and other ornaments above building exits or near fire escapes. Architectural, mechanical, and electrical components that, if separated from the structure, will fall in areas that are not accessible to the public (e.g. into a mechanical shaft or light well) pose little risk to egress routes.

A.1.3 Release of hazardous materials

Components whose failure can lead to the uncontrolled release of contents can pose an immediate life safety risk and should be evaluated. Examples include fractured or leaking pipes, ruptured tanks, ruptured pressure vessels or storage bins and shattered laboratory equipment (e.g. reagent bottles). Where hazardous materials have been identified, the performance objectives for the containing structures (pipes, pumps, vessels, etc.) may be characterized broadly as "leak tightness". It is generally not necessary that the systems associated with the hazardous materials remain functional following an earthquake.

A.1.4 Disruption of operability of essential facilities

The term "essential facilities" is intended to encompass all buildings and associated structures that are necessary to post-disaster response. Included are most medical care facilities (hospitals, clinics, etc.) as well as fire, police and disaster response control stations.

Those components and systems whose failure can disrupt the post-earthquake performance of essential facilities should be evaluated. It may be acceptable for the function of certain NSCS to be temporarily interrupted during an earthquake (e.g. for the length of time required for emergency power to come on line) where the interruption of function does not disrupt critical data flows or cause other consequential damage.

NOTE Experience with earthquake damage in population centers indicates that grocery stores and supermarkets can constitute essential facilities for post-earthquake response, at least with respect to the orderly sale and distribution of food to the population. This may include provision for the protection of contents on racks as well as continuity of electrical power, e.g. for refrigeration.

A.1.5 Excessive financial loss

While not associated with the general goal of life safety, prevention of disproportionate financial loss can be critical to post-earthquake recovery.

Components whose failure can lead to disproportionate financial loss should be evaluated. Examples include failure of components housing or supporting irreplaceable museum artefacts, damage to data storage systems crucial to stability of the monetary system, and sprinkler pipe failures leading to flooding of valuable commercial facilities. Costs associated with extended loss of function, e.g. as in the case of critical exports, should also be included in the assessment of financial loss.

A.2 Identification of NSCS not requiring seismic evaluation

This International Standard applies only to permanently attached components. It is not applicable to furnishings, or temporary or relocatable components. Non-massive furnishings can slide during strong ground motion but generally pose minimal hazards provided they do not obstruct emergency egress routes.

NOTE 1 Storage cabinets, tall bookshelves, and other items of significant mass (e.g. large conference tables) do not fall into this category and should be evaluated.

Permanent components do not typically include items that remain in place only for short periods of time (e.g. months).

NOTE 2 Components equipped with wheels or mounted on skids that otherwise appear to be temporary in nature may require evaluation under this International Standard if they are intended to remain in place for a significant time period.

A.3 Example of rules for identifying NSCS requiring seismic evaluation

A.3.1 NSCS included

The following NSCS are included in the scope of these requirements unless specifically excluded in A.3.2:

a) architectural items permanently attached to the building, as well as their supports and attachments;

b) storage cabinets, tall bookshelves, and items of significant mass;

c) parapets;

d) mechanical, plumbing, heating, ventilating and electrical/communication systems and their supports and attachments;

e) fire suppression equipment and sprinkler systems;

f) egress stairs, elevators, and escalators.

A.3.2 NSCS excluded

The following NSCS are excluded from the scope of these requirements:

a) unless specifically noted in A.3.1, contents of buildings including furnishings, temporary items, and mobile units.

b) architectural components of normal importance in buildings subject to low seismic demand;

c) mechanical and electrical components of normal importance in buildings subject to low seismic demand;

d) mechanical and electrical components of normal importance in buildings subject to high seismic demand provided that the component is positively attached to the structure and

   1) the component weighs less than 0,1 kN, or

   2) the component is part of a distributed system (e.g. piping, conduit, bus duct, ventilation system) having a weight of 0,075 kN/m or less; or

   3) the component weighs less than 1,5 kN and has a centre of mass located 1 m or less above the adjacent floor level.

Annex B
(informative)

Principles for choosing importance factors for NSCS

B.1 General

Each NSCS has its own function in a building. The required degree of reliability of the NSCS after an earthquake depends on its importance to the continuous operation of the building in which the NSCS is located, as well as on the hazard to life safety that failure of the component may pose.

In determining the seismic demand on the NSCS its importance level should be chosen properly.

As a simplification, the degree of seismic reliability and performance are presumed to be proportional to the design capacity of the structure and the NSCS.

NOTE In some circumstances, reliability may be increased by improving the ductility of the component or attachments.

B.2 Example for establishment of importance factors $\gamma_{n,E,p}$

Importance factors are introduced into several calculation methods for designing building structures and are determined based on judgement. An example for how to approach the establishment of importance factors is given below in Table B.1 as a function of NSCS categories which are provided below in Table B.2:

Table B.1 — Example for table of importance factors

Importance of building structure	Importance factors, $\gamma_{n,E,p}$, by NSCS category				
	A	B	C	D	E
Low (barns, sheds)	0,8	1,0	not applicable	not applicable	not applicable
Normal (office, residential)	1,0	1,0	1,5	1,5	not applicable
Important (schools, auditoriums)	1,0	1,5	1,5	2,0	not applicable
Highly important (essential facilities)	1,0	1,5	2,0	2,5	3,0

Table B.2 — Example of table of NSCS category definitions

NSCS category	Definition	Examples
A	NSCS not listed below	partitions, glazing over unoccupied spaces, low storage cabinets
B	components that pose a hazard to individuals	suspended mechanical equipment, piping containing non-hazardous substances
C	building systems necessary for life safety	fire sprinklers, egress stairs
D	components that pose a hazard to crowds or whose failure would cause disproportionate financial loss	vessels and piping containing toxic, explosive or otherwise hazardous substances (e.g. biological hazards), suspended ceiling over an auditorium, stadium scoreboard, significant art works
E	components necessary for continued operability of essential facilities	electrical, mechanical, plumbing and ventilation systems, uninterruptable power supplies, emergency generators

Annex C
(informative)

Principles for choosing the floor response amplification factor (height factor)

C.1 General

The floor response amplification factor of the building structure at attachment location at level i ($k_{H,i}$) relates the maximum floor acceleration over the height of the building to the zero-period acceleration at the base of the building. This factor is primarily a function of:

a) the natural periods of vibration of the building structure;

b) the type of building lateral-load resisting system;

c) the relative location of the point of attachment of the NSCS to the average roof elevation of the structure with respect to grade elevation; and

d) the inherent damping and degree of inelastic behaviour of the building structure which are dependent on the severity of the ground motion.

NOTE The maximum accelerations of the floor and ground are best characterized as the average spectral acceleration over a range of periods such as 0,1 to 0,6 s adjusted with an amplification factor, e.g. 2,5.

C.2 Determination using dynamic analysis

The floor response amplification factor may be determined by performing a modal analysis of the linear elastic building structure. For linear elastic low-rise buildings, the floor response amplification factor tends to increase with height. Linear elastic mid-rise and high-rise buildings exhibit a more uniform distribution of floor acceleration response factors over the height of the building structure.

C.3 Determination using simplified static analysis

A trapezoidal distribution of floor accelerations within the supporting building may be assumed when simplified static analysis procedures are implemented. This trapezoidal distribution is of the form:

$$k_{H,i} = \left[1 + \alpha\left(\frac{z_i}{H}\right)\right] \quad \text{(C.1)}$$

where

α is a parameter that is a function of the type of lateral-load resisting system ($\alpha \leq 2,5$)

i is the level in the building structure of the point of attachment of the NSCS relative to grade elevation ($0 \leq i/H \leq 1,0$)

z_i is the elevation of level i relative to grade elevation

H is the average roof elevation of the structure relative to grade elevation.

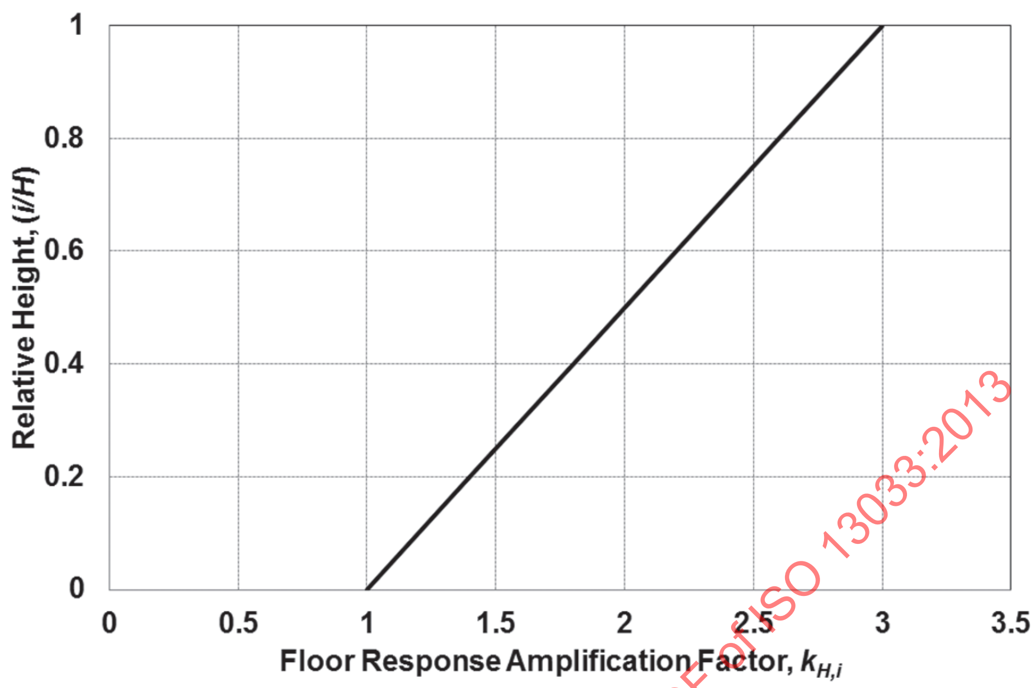


Figure C.1 — Example of trapezoidal variation of floor response amplification factor with building height (Formula C.1 with α = 2,0)

NOTE 1 Inelastic behaviour of the building structure tends to limit the magnitude of the floor response amplification factor. In some cases, e.g. when the inelastic behaviour of a building structure is limited to one or just a few adjacent stories, the floor response amplification factor can increase with respect to the value obtained for a linear elastic building structure.

NOTE 2 Additional refinements of the trapezoidal representation have been proposed for differing structural systems and building heights. Additional research is necessary to provide more representative simplified expressions for floor response amplification factors that explicitly account for the primary issues identified in this Annex.

Annex D
(informative)

Principles for choosing the component amplification factor (resonance factor)

D.1 General

The component amplification factor ($k_{R,p}$) relates the NSCS acceleration response to the floor acceleration at the points of attachment of the component. It is applicable to cases where the NSCS has not been explicitly integrated into the building model. This factor is primarily a function of:

a) the component period (T_C) relative to the significant natural periods of the building structure;

b) the NSCS damping ratio;

c) the general configuration of the NSCS;

d) the method of attachment of the NSCS to the building structure; and

e) the inherent damping and degree of inelastic behaviour of the building structure which are dependent on the severity of the ground motion.

Maximum component amplification factors are generally obtained when the component period is in the vicinity of one of the modal periods of the building structure, i.e. $T_C/T_\mathrm{j} \approx 1{,}0$. (where T_j represents the jth modal period of the building structure). If the component is rigid (stiff) and rigidly attached to the supporting building, the component amplification factor is taken as 1,0 since the NSCS response is assumed to be unaffected by the building response.

For the purpose of determining the amplification factor where the building natural period is known, a reasonable assumption for the boundary between rigid and flexible components is as follows:

$$\frac{T_1}{T_C} \geq 5 \quad \text{stiff}$$

$$\frac{T_1}{T_C} < 5 \quad \text{flexibile}$$

Where the building natural period is unknown, it may be assumed that stiff components are those with a natural frequency, including supports, greater than 10 Hz.

Component amplification factors for flexible components and/or components with flexible attachment are given in Table D.1. The value of 2,5 in the table accounts for the possibility of resonant response but assumes some inelastic behaviour of the building structure. If elastic behaviour is assumed, the amplification factor corresponding to resonance can be significantly greater than 2,5 depending on the level of damping.

Table D.1 — Examples of component amplification factors ($k_{R,p}$) for 5 %-damped NSCS

Typology see Figure D.1	Flat (plate) element			Linear element		
Method of attachment to building structure	All face fixed (either front side or back side)	Fixed along upper and lower edges, right and left edges, or all edges	Fixed along one edge only	Fixed along length of component	Both ends fixed	One end fixed
Stiff NSCS	1,0	1,0	1,5	1,0	1,0	1,5
Others	1,0	1,5	2,5 or more	1,0	1,5	2,5 or more

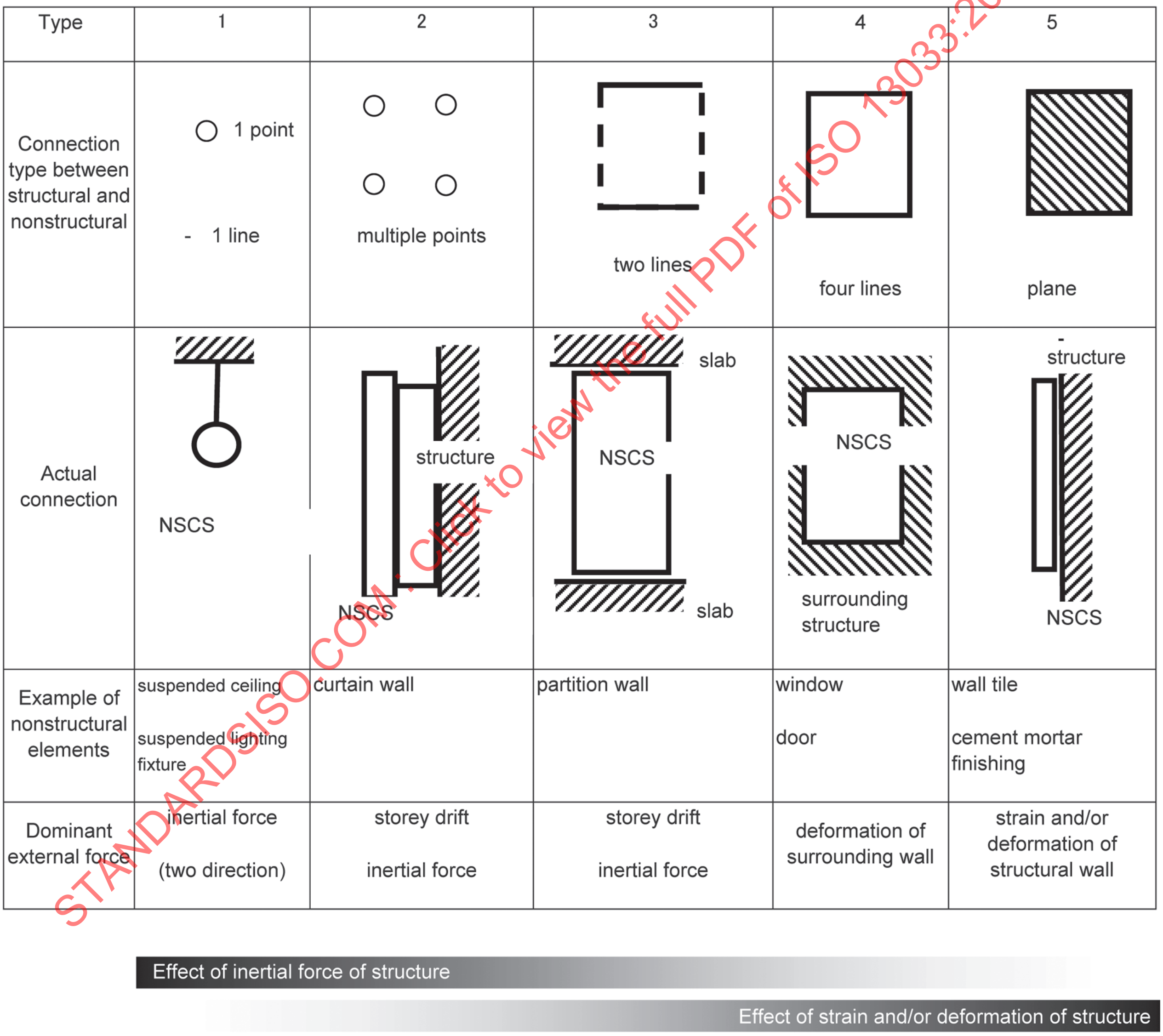


Figure D.1 — Typology of the connection between structural members and NSCS

Annex E
(informative)

Principles for determining response modification factors

E.1 General

Seismic force demands for NSCS may be reduced by a NSCS response modification factor ($k_{D,p}$). NSCS damping, ductility, overstrength characteristics, and NSCS connection details influence NSCS response modification factor values. For example, piping components made of high ductility materials such as steel or copper can accommodate relative displacements inelastically. However, piping with threaded or compression coupling connections exhibit moderate ductility under inelastic displacements and should be assigned a larger NSCS response modification factor value.

NOTE NSCS response modification factor values may be adjusted due to the detailing, construction or functionality of NSCS. For example, cladding elements, which are often very stiff in-plane, should be isolated so that they do not restrain and are not loaded by drift of the supporting building due to thermal movements. Therefore, connection systems are generally detailed to be statically determinate. Since the resulting support systems often lack redundancy, exacerbating the consequences of a single connection failure, fasteners of the connecting system, such as bolts or anchors, should be designed for amplified forces. On the other hand, connecting members, such as steel plates or angles, should be ductile. The intent is to restrict inelastic behaviour to the connecting members while the less ductile fasteners remain essentially elastic. To achieve this intent, the NSCS response modification factor value should be adjusted to make fastener design forces larger than connecting members.

E.2 Development of response modification factors

Considering that most NSCS lack the desirable attributes of supporting buildings (such as ductility, toughness, and redundancy) that permit the use of greatly reduced lateral design forces, values for the NSCS response modification factor, $k_{D,p}$, are generally smaller than structure response modification factor values for supporting buildings, i.e. structural factor, k_D, in ISO 3010. The analogous parameter for supporting buildings, structural factor (k_D), is expressed as the product of $k_{D,\mu}$ and $k_{D,s}$, where $k_{D,\mu}$ is related to ductility, acceptable deformation and restoring force characteristics, and $k_{D,s}$ is related to overstrength. NSCS response modification factors may be determined utilizing collective wisdom and experience. In general, the benchmark values given in Table E.1 may be used to address both deformation capacity and reserve strength:

Table E.1 — Inverse of NSCS response modification factors

Level of reserve capacity[a]	$R_{p,\mu}$[b]	$R_{p,s}$[b]	R_p
Low	1,0	1,0	1,0
Medium	2,0	1,5	3,0
High	3,0	2,0	6,0

[a] Deformation and strength.

[b] $R_{p,\mu}$ and $R_{p,s}$ are the inverse of the NSCS factors $k_{p,\mu}$ and $k_{p,s}$, respectively:

$$k_{D,p} = k_{p,\mu} \cdot k_{p,s} \quad \text{(E.1)}$$

$$k_{D,p} = \frac{1}{R_{p,\mu}} \cdot \frac{1}{R_{p,s}} = \frac{1}{R_p} \quad \text{(E.2)}$$

NOTE Examples of low reserve capacity systems include piping made of glass and ceramic electrical isolators. Examples of high reserve capacity systems are welded steel piping and ductwork.

Annex F
(informative)

Principles for determining seismic relative displacements for drift-sensitive components

F.1 Seismic relative displacements

The demands on drift-sensitive components are based on the relative movement of the attachment points. The relative movements can arise in a variety of ways:

a) interstorey drift;

b) displacement between buildings;

c) displacement between NSCS;

d) displacement between NSCS and building elements;

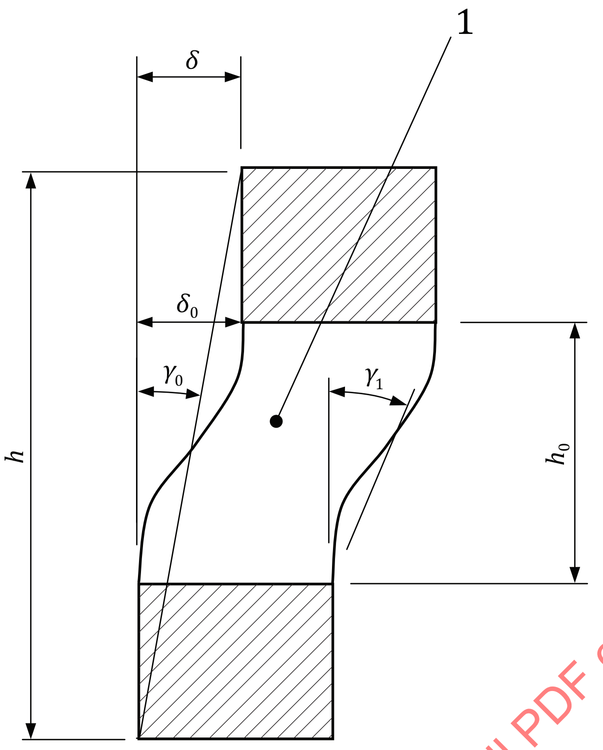
e) displacements across the isolation plane.

These are discussed in more detail below.

F.2 Interstorey drift

Interstorey drift is the relative horizontal displacement between two adjacent storeys. Interstorey drift is not necessarily uniform across a given floor level depending on the type of structural system and the stiffness of the floor slab. The interstorey drift used for design of NSCS should correspond to the displacement of the points of attachment at the floor levels above and below. The interstorey drift should reflect the inelastic behaviour of the structure (best estimate of actual building drift at the ULS). For further discussion see ISO 3010:2001, Annex B. The maximum drift demand is usually associated with the allowable building drift at the ULS as established by regional and national standards. Interstorey drift may also be determined at the SLS.

Where NSCS comprised of stiff and flexible elements extend between floors, interstorey drift is distributed to the elements of the NSCS according to relative stiffness. When a relatively flexible or weak NSCS is located between two stiff NSCS (hatched areas) as shown in Figure F.1, the interstorey drift (δ) needs to be accommodated by the more flexible or weak component. For example, a glazing system installed between two rigid precast concrete spandrel panels will be required to accommodate the entire displacement demand in the remaining storey height. In this case, this is accomplished by detailing the containment for the glazing.



Key

1 target NSCS

Figure F.1 — Special case of distribution of the interstorey drift to a nonstructural cladding component

F.3 Displacement between buildings

When NSCS extend between two adjacent buildings or sections of a building that are seismically separated, the relative displacement between the two buildings or portions of the building should be accommodated in the design of the NSCS.

Displacement between buildings may be conservatively estimated as the absolute sum of the horizontal displacements of two adjacent buildings at the points of attachment. Alternatively, it may be taken as the square root of the sum of the squares (SRSS) of the calculated displacements. The calculated displacements should include the inelastic behaviour of both structures. For further discussion see ISO 3010, Annex B.

F.4 Displacement between NSCS

When linear NSCS such as piping extend between NSCS on the same floor, the relative displacement between the points of attachment resulting from response of the NSCS should be accommodated in the design of the linear connecting NSCS. Where the points of attachment of the linear NSCS occur at different floor levels or between buildings, the interstorey drift and/or inter-building drift should be included in the calculation of relative displacement as well. See F.2 and F.3.

Displacement between NSCS may be conservatively estimated as the absolute sum of the horizontal displacements of two components at the points of attachment. Alternatively, it may be taken as the square root of the sum of the squares (SRSS) of the calculated displacements. The calculated displacements should include the inelastic behaviour of the NSCS (e.g. by increasing the elastic displacements by the response modification factor). Where the NSCS are mounted on vibration isolators, the potential increase in the relative displacements should be accounted for.

Annex G
(informative)

Floor response spectra

G.1 General

The floor response spectrum is the acceleration response spectrum at the point of NSCS attachment. It may be used to perform generic dynamic analyses or to conduct shake table testing of NSCS with natural frequencies greater than a minimum value, f_0.

G.2 Estimation of floor response spectrum

G.2.1 General

A floor response spectrum is typically obtained from a dynamic analysis of the building structure as described in 8.2. Alternatively, for a given component frequency, the floor response spectrum may be estimated as the ratio of seismic force at level i of the building structure ($F_{E,p,i}$) to operating weight of the component ($F_{G,p}$), where these forces are obtained from the simplified equations in 8.3, and where the importance factor ($\gamma_{n,E,p}$) and the component nonstructural response modification factor ($k_{D,p}$) are taken as unity.

NOTE The importance factor should be taken as unity because it should not modify the seismic test input motion. When a shake table test is conducted, the component will respond to the shaking and the inelastic behaviour and component response modifications will occur naturally. Thus, a component nonstructural response modification factor equal to one is appropriate.

Where the simplified equations of 8.3 are used, the ordinates of the normalized horizontal floor response spectrum for a component located at level i of the building structure are determined as given by Formula (G.1):

$$A_i = F_{E,p,i} / F_{G,p} = k_{I(u \text{ or } s)} \cdot k_{H,i} \cdot k_{R,p} \quad \text{(G.1)}$$

where

$A_i \leq A_{flexible}$ for components with first-mode frequencies less than f_2;

$A_i \geq A_{rigid}$ for components with first-mode frequencies greater than f_2;

$k_{I(u \text{ or } s)}$ is the ground motion hazard level of interest for ULS and SLS (see 8.3.3.1).

For vertical response, a fraction of the values from Formula (G.1) may be used with $k_{H,i}$ evaluated at grade level for all elevations. For a given component frequency, the ratio of vertical to horizontal response can be represented by the parameter β where β is typically assumed to vary from 1/2 to 2/3.

Figure G.1 depicts the general shape of the floor response.

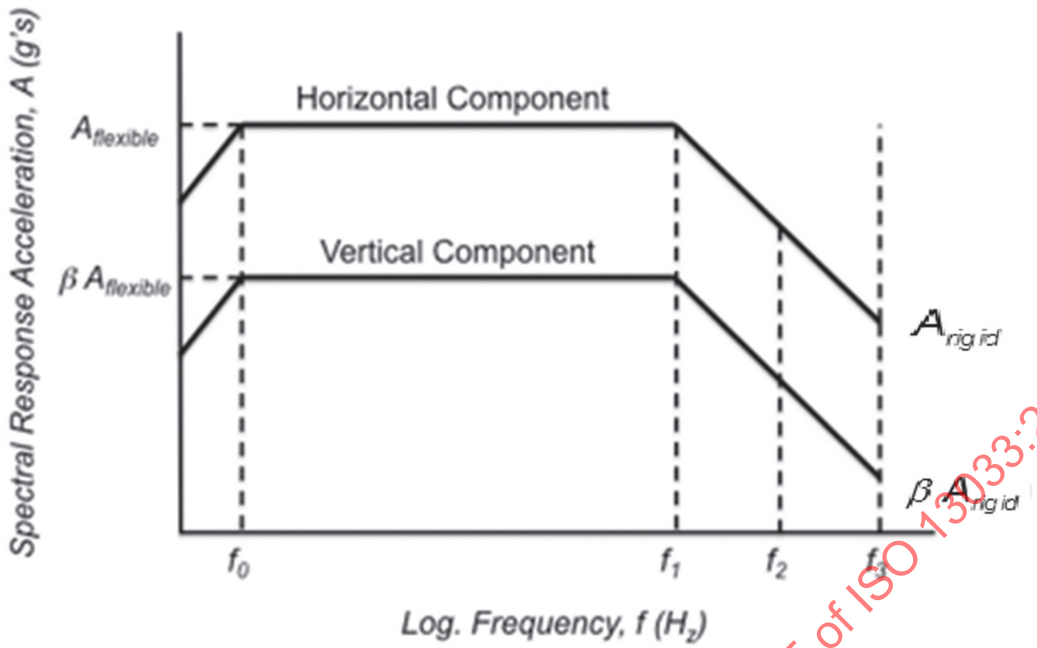


Figure G.1 — Floor response spectrum

Typical assigned values for the control points for the floor response spectrum are:

f_0 = 1,3 to 2,5 Hz

f_1 = 7,5 to 8,3 Hz

f_2 = 10 to 16,67 Hz

f_3 = 33,3 Hz

A representative damping ratio for this spectrum is 0,05.

The parameters $A_{flexible}$ and A_{rigid} are determined based on information on the building and NSCS dynamic characteristics.

G.2.2 Building-generic floor response spectrum – horizontal motion

When the building dynamic characteristics are not known,

$$A_{flexible} = k_{I(u\ or\ s)} \cdot k_{H,i} \cdot k_{R,p,flexible} \quad (G.2)$$

$$A_{rigid} = k_{I(u\ or\ s)} \cdot k_{H,i} \cdot k_{R,p,rigid} \quad (G.3)$$

where

$k_{H,i}$ is the floor response amplification factor given by Formula C.1 (see Annex C);

$k_{R,p,flexible}$ is the NSCS amplification factor for flexible systems ($k_{R,p,i,flexible}$ > 1,0, see Annex D); and

$k_{R,p,i,rigid}$ is the NSCS amplification factor for rigid systems ($k_{R,p,i,rigid}$ = 1,0, see Annex D).

G.2.3 Building-specific floor response spectrum – horizontal motion

When the building dynamic characteristics are known,

$$A_{flexible} = A_{D,I} \cdot k_{R,p,i,flexible} \quad \text{(G.4)}$$

$$A_{rigid} = A_{D,I} \cdot k_{R,p,i,rigid} \quad \text{(G.5)}$$

where

$A_{D,i}$ is the acceleration at level *i* obtained from a dynamic analysis procedure (including torsional response) that utilizes an elastic ground motion response spectrum or time-history analysis.

G.3 Additional considerations

The mass of the NSCS should always be included in the building model and it is always permissible to include the NSCS explictly in the building model. When the weight of a flexible NSCS (i.e. having a frequency less than f_2) exceeds 20 % of the total seismic weight of the supporting floor level including the weight of the component, it is recommended that interaction effects between the structure and the NSCS be considered in the development of floor response spectra.

Annex H
(informative)

Methods for verifying NSCS by design analysis

H.1 Methods of evaluation

Methods of evaluating NSCS response to seismic demand include analysis, qualification testing, experience data, or a combination thereof. The selection of the appropriate method, including type of analysis, type of qualification tests, or type and scope of experience data, depends on the nature, complexity and performance objective of the NSCS.

H.2 Evaluation by analysis

The seismic actions and effects of NSCS in buildings shall be determined either by dynamic analysis or by equivalent static analysis. In both cases the dynamic properties of the supporting structure and the interaction effects between the dynamic responses of the supporting structures and the NSCS shall be taken into consideration.

Appropriate nonlinear post-elastic behaviour and the behaviour sequence of the supporting building structure for a NSCS during severe earthquakes shall be considered in determining the seismic force and imposed deformation or relative displacement demands on the NSCS.

For NSCS that provide essential services (e.g. mechanical and electrical equipment and piping) required to remain functional during and after severe or moderate earthquake ground motions, it may be adequate to perform equivalent static analysis using enhanced force levels. For some special cases, the design of NSCS can require a more rigorous analysis to demonstrate acceptable performance.

H.2.1 Modelling

The type of modelling suitable for a NSCS as a secondary system in relation to the primary building structure system depends on the properties and characteristics of the NSCS, including its mass, stiffness (or flexibility), ductility, and boundary conditions.

NOTE A secondary system is an NSCS that does not influence the building response.

For a rigid NSCS, the analysis for the seismic demand can be performed using rigid body mechanics. For some standardized NSCS, such as some electrical or mechanical equipment, no modelling of the NSCS is necessary and the ability of the NSCS to withstand the seismic demand can be assessed by prescriptive methods, by use of experience data, or by testing (force, relative displacement or shake table testing).

NSCS that are flexible should be modelled as secondary systems to assess the effect of the seismic action on the component. For slender, tall, or other flexible NSCS that possess unique vibration characteristics and behaviour, the modelling of the secondary NSCS should include any interaction effects between the primary building and secondary system, including modification to the response of either system due to the interaction and torsional sensitivity where significant. The complexity, value and importance of the NSCS versus cost of modelling should be considered in selecting the level of modelling detail and analysis approach. It may be preferable to make conservative assumptions to facilitate a more simplified and practical design approach.

H.2.2 Equivalent static analysis

For the case of a NSCS with mass that is small relative to the supporting building, the seismic force demand may be determined by the equivalent static load method using conventional linear elastic analysis. Where the local supporting members are flexible, their mass and stiffness properties should be included in the determination of the equivalent static load.

H.2.3 Dynamic analysis

To more accurately determine the interaction effects between the supporting building structure and an attached or supported NSCS, dynamic analysis of the NSCS subjected to the floor response motion at attachment points may be performed. The dynamic analysis of the NSCS can be carried out by floor response spectrum analysis or time-history analysis of a complete structural model of the building structure with the attached or supported NSCS included in the model. For example, in the case of heavy mechanical or electrical equipment where the dynamic response can impart a significant seismic force feedback to the supporting structure or a sensitive NSCS, a dynamic analysis of the complete building and NSCS combined system is recommended.

For non-massive NSCS secondary systems, dynamic analysis by the floor response spectrum method with appropriate modal combination procedures is recommended. Conventional floor response spectrum methods derived from the vibration of the building structure alone neglect the dynamic interaction between the building and NSCS, and do not account for modification to the responses of the combined primary-secondary system due to interaction.

NOTE In some cases, inelastic behaviour of the building structure can result in an additional amplification of maximum NSCS acceleration demands. This is particularly important for NSCS that are located at the bottom floors of the building structure (except at ground level) with periods that are close to the higher modal periods of the building.

H.2.4 Seismicity and soil conditions

The determination of seismicity and soil conditions should be in accordance with ISO 3010.

H.2.5 Dynamic properties of the building structure

Where a dynamic model of the building is used to determine the seismic demands for NSCS, that model should be in accordance with ISO 3010.

H.2.6 Dynamic interaction between the secondary and primary systems

NSCS attached to a building respond to base excitation from the floor acceleration of the structure at the point where the component is attached. If the component is rigid and rigidly attached to the structure, it will undergo acceleration of the same magnitude as that of the structure at the attachment point. Flexible components and/or components with flexible attachment to the structure will undergo different response because of the modification, amplification or filtering effects associated with the dynamic response of the supporting structures, and of the attachment devices and the components. In general, the ground acceleration levels are amplified in the building response to the earthquake ground motion, and the level of vibration increases with height within the building with highest accelerations occurring at the roof level.

As some NSCS are sensitive to damage from higher mode effects from the supporting building, these should be considered especially when the natural frequencies of the NSCS are close to vibration periods of the building structure.

H.2.7 Boundary condition of NSCS

The flexibility, strength and reserve capacity of the attachment or supporting devices of NSCS to the building structure, including isolation devices, should be considered in the determination of the magnitude and characteristics of the seismic load demands for the seismic design and performance evaluation of the NSCS. For examples of attachment geometry, see Annex D.

H.2.8 Imposed relative displacements or deformations

For NSCS attached to the supporting building at multiple support points that undergo spatially varying out-of-phase support motion, an additional pseudo-static deformation demand is imposed on the NSCS. The NSCS should be designed to have the strength, flexibility or ductility capacity to accommodate the imposed relative displacement or deformation demands. For example, a glass panel on the exterior building façade with attachment points on separate structural members of the building frame should be designed to accommodate the relative movement of the support points in addition to the dynamic load effects.

