INTERNATIONAL
STANDARD

**ISO
3010**

Third edition
2017-03

Bases for design of structures — Seismic actions on structures

Bases du calcul des constructions — Actions sismiques sur les structures

Reference number
ISO 3010:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www. iso. org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

This document was prepared by ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

This third edition cancels and replaces the second edition (ISO 3010:2001), which has been technically revised.

Introduction

This document presents basic principles for the evaluation of seismic actions on structures. The seismic actions described are fundamentally compatible with ISO 2394.

It also includes principles of seismic design, since the evaluation of seismic actions on structures and the design of the structures are closely related.

Annexes A to P of this document are for information only.

NOTE 1 ISO 23469 and ISO 13033 are companion documents to this document. They provide basic design criteria for geotechnical works and for nonstructural components and systems, respectively.

NOTE 2 ISO 23469 specifies the procedure to determine the design ground motion for the dynamic analysis of geotechnical works. The procedure in ISO 23469 is applicable to the generation of design ground motion for the structures that exhibit interaction with the ground or the geotechnical works.

NOTE 3 ISO 13033 and its annexes use the same terms and definitions that are used in this document. The ground motion criteria specified in ISO 13033 are the same criteria that are used in this document. The demand on nonstructural components and systems 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 to this document.

Bases for design of structures — Seismic actions on structures

1 Scope

This document specifies principles of evaluating seismic actions for the seismic design of buildings (including both the super structure and foundation) and other structures.

This document is not applicable to certain structures, such as bridges, dams, geotechnical works and tunnels, although some of the principles can be referred to for the seismic design of those structures.

This document is not applicable to nuclear power plants, since these are dealt with separately in other International Standards.

In regions where the seismic hazard is low, methods of design for structural integrity can be used in lieu of methods based on a consideration of seismic actions.

This document is not a legally binding and enforceable code. It can be viewed as a source document that is utilized in the development of codes of practice by the competent authority responsible for issuing structural design regulations.

NOTE 1 This document has been prepared mainly for new engineered structures. The principles are, however, applicable to developing appropriate prescriptive rules for non-engineered structures (see Annex N). The principles could also be applied to evaluating seismic actions on existing structures.

NOTE 2 Other structures include self-supporting structures other than buildings that carry gravity loads and are required to resist seismic actions. These structures include seismic force-resisting systems similar to those in buildings, such as a trussed tower or a pipe rack, or systems very different from those in buildings, such as a liquid storage tank or a chimney. Additional examples include structures found at chemical plants, mines, power plants, harbours, amusement parks and civil infrastructure facilities.

NOTE 3 The level of seismic hazard that would be considered low depends not only on the seismicity of the region but also on other factors, including types of construction, traditional practices, etc. Methods of design for structural integrity include nominal design horizontal forces (such as an equivalent static loading determined from a simplified equivalent static analysis) which provide a measure of protection against seismic actions.

2 Normative references

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

ISO 13033, *Bases for design of structures — Loads, forces and other actions — Seismic actions on nonstructural components for building applications*

3 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1

base shear

design horizontal force acting at the base of the structure

3.2

complete quadratic combination method

CQC

method to evaluate the maximum response of a structure by the quadratic combination of modal response values

3.3

ductility

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

3.4

liquefaction

loss or significant reduction of shear strength and stiffness under cyclic loadings in saturated, loose, cohesionless soils

3.5

moderate earthquake ground motion

ground motion used for SLS caused by earthquakes which may be expected to occur at the site during the service life of the structure

Note 1 to entry: See Annex A.

3.6

normalized design response spectrum

spectrum to determine the base shear factor relative to the maximum ground acceleration as a function of the fundamental natural period of the structure

3.7

paraseismic influences

ground motion whose characteristics are similar to those of earthquake ground motions, but its sources are mainly due to industrial, explosive, traffic, and other human activities

3.8

P-delta effect

second-order effect which is caused by the action of gravity on the displaced mass

3.9

restoring force

force exerted by the deformed structure or structural elements which tends to move the structure or structural elements to the original position

3.10

seismic force distribution factor of the *i*th level

$k_{\mathrm{F},i}$

factor to distribute the seismic base shear to the *i*th level, which characterizes the distribution of seismic forces in elevation, where $\sum k_{\mathrm{F},i} = 1$

Note 1 to entry: See Annex C.

3.11

seismic hazard zoning factor

k_{Z}

factor to express the relative seismic hazard of the region

3.12

seismic shear factor

factor to give seismic shear of one level, that is defined as the seismic shear of the level divided by the weight of the structure above the level

3.13

seismic shear distribution factor of the *i*th level

$k_{V,i}$

ratio of the seismic shear factor of the *i*th level to the seismic shear factor of the base, which characterizes the distribution of seismic shears in elevation where $k_{V,i} = 1$ at the base and usually becomes largest at the top

Note 1 to entry: See Annex C.

3.14

severe earthquake ground motion

ground motion used for ULS caused by an earthquake that could occur at the site

Note 1 to entry: See Annex A.

3.15

soil-structure interaction

effect by which structure and surrounding soil mutually affect their overall response

3.16

square root of sum of squares method

method to evaluate the maximum response of a structure by the square root of the sum of the squares of modal response values

3.17

structural design factor

k_D

factor to reduce seismic forces or shears to levels to be used for design, taking into account ductility, acceptable deformation, restoring force characteristics, and overstrength of the structure

4 Symbols and abbreviated terms

$F_{E,s,i}$	design lateral seismic force of the *i*th level of a structure for SLS
$F_{E,u,i}$	design lateral seismic force of the *i*th level of a structure for ULS
$F_{G,i}$	gravity load at the *i*th level of the structure
$k_{E,s}$	representative value of earthquake ground motion intensity for SLS
$k_{E,u}$	representative value of earthquake ground motion intensity for ULS
k_R	ordinate of the normalized design response spectrum
k_S	soil factor
n	number of levels above the base
SLS	serviceability limit state
SRSS	square root of sum of squares
SSI	soil-structure interaction
ULS	ultimate limit state

$V_{\mathrm{E,s},i}$	design lateral seismic shear of the *i*th level of a structure for SLS
$V_{\mathrm{E,u},i}$	design lateral seismic shear of the *i*th level of a structure for ULS
$\gamma_{\mathrm{E,s}}$	load factor as related to reliability of the structure for SLS
$\gamma_{\mathrm{E,u}}$	load factor as related to reliability of the structure for ULS

5 Bases of seismic design

The basic philosophy of seismic design of structures is, in the event of earthquakes

- to prevent human casualties,
- to ensure continuity of vital services, and
- to reduce damage to property.

In addition to these, societal goals for the environment should be considered.

It is recognized that to give complete protection against all earthquakes is not economically feasible for most types of structures. This document states the following basic principles.

a) The structure should not collapse nor experience other similar forms of structural failure due to severe earthquake ground motions that could occur at the site [ultimate limit state (ULS)]. Higher reliability for this limit state should be provided for structures with high consequence of failure.

b) The structure should withstand moderate earthquake ground motions which may be expected to occur at the site during the service life of the structure with damage within accepted limits [serviceability limit state (SLS)].

Structural integrity should also be examined by considering the behaviour of the structure after exceeding each of the limit states (SLS and ULS). If it is essential that services (e.g. mechanical and electrical equipment including their distribution systems) retain their functions after severe or moderate earthquake ground motions, then the seismic actions should be evaluated in accordance with the requirements of ISO 13033. The structure itself should also be verified that essential functions remain operational under the same level of the motions.

NOTE 1 In addition to the seismic design and construction of structures stated in this document, it is important to consider adequate countermeasures against subsequent disasters (such as fire, leakage of hazardous materials from industrial facilities or storage tanks, large-scale landslides and tsunami) which may be triggered by the earthquake.

NOTE 2 Following an earthquake, earthquake-damaged structures might need to be evaluated for safe occupation during a period of time when aftershocks occur. This document, however, does not address actions that can be expected due to aftershocks. In this case, a model of the damaged structure is required to evaluate seismic actions.

6 Principles of seismic design

6.1 Site conditions

Conditions of the site under seismic actions should be evaluated, taking into account microzonation criteria (vicinity to active faults, soil profile, soil behaviour under large strain, liquefaction potential, topography, subsurface irregularity, and other factors such as interactions between these).

In the case of liquefaction prone sites, appropriate foundations and/or ground improvement should be introduced to accommodate or control such phenomena (see ISO 23469).

In areas prone to tsunami hazard, certain important structures (vertical evacuation refuges, hospitals, emergency communication facilities, etc.) are required to resist tsunami actions (see Annex O).

6.2 Structural configuration

For better seismic resistance, it is recommended that structures have regular forms in both plan and elevation.

6.2.1 Plan irregularities

Structural elements to resist horizontal seismic actions should be arranged such that torsional effects become as small as possible. Irregular shapes in plan causing eccentric distribution of forces are not desirable, since they produce torsional effects which are difficult to assess accurately and which may amplify the dynamic response of the structure (see Annex F).

6.2.2 Vertical irregularities

Changes in mass, stiffness, and capacity along the height of the structure should be minimized to avoid damage concentration (see Annex C).

When a structure with complex form is to be designed, an appropriate dynamic analysis is recommended in order to check the potential behaviour of the structure.

6.3 Influence of nonstructural elements

The structure, including nonstructural as well as structural elements, should be clearly defined as a seismic force-resisting system which can be analysed. In computing the earthquake response of a structure, the influence of not only the structural system elements but also nonstructural walls, partitions, stairs, windows, etc. should be considered when they are significant to the structural response.

NOTE Nonstructural elements are often neglected in seismic analysis. In many cases, the nonstructural elements can provide additional strength and stiffness to the structure, which may result in favourable behaviour during earthquakes which justifies their being neglected. However, in some cases, the nonstructural elements can cause unfavourable behaviour. Examples are: spandrel walls that reduce clear height of reinforced concrete columns and cause the brittle shear failure to the columns, and unsymmetrical arrangement of partition walls (which are considered to be nonstructural elements) that causes large torsional moments to the structure. Therefore, it is important to consider all elements as they behave during earthquakes. If neglecting the stiffness and strength of nonstructural elements does not cause any unfavourable behaviour, they need not be included in seismic analysis. ISO 13033 provides additional criteria regarding when nonstructural components should be included in the building seismic analysis model.

6.4 Strength and ductility

The structural system and its structural elements (both members and connections) should have both adequate strength and ductility for the applied seismic actions. Adequate post-elastic performance should be provided by appropriate choice of the structural system and/or ductile detailing. The structure should have adequate strength for the applied seismic actions and sufficient ductility to ensure adequate energy absorption (see Annex D). Special attention should be given to suppressing the low ductile behaviour of structural elements, such as buckling, bond failure, shear failure, and brittle fracture. The deterioration of the restoring force under cyclic loadings should be taken into account.

Local capacities of the structure may be higher than that assumed in the analysis. Such overcapacities should be taken into account in evaluating the behaviour of the structure, including the failure mode of structural elements, failure mechanism of the structure, and the behaviour of the foundations due to severe earthquake ground motions.

6.5 Deformation of the structure

The deformation of the structure under seismic actions should be limited, in order to restrict damage for moderate earthquake ground motions and to avoid collapse or other similar forms of structural failure for severe earthquake ground motions.

For long period structures such as high-rise buildings and seismically isolated buildings, effects of repeated large displacement response should be evaluated for severe ground motions with long period and long duration and limited to be within the deformation capacity.

NOTE There are two kinds of deformation to control: (1) inter-storey drift to restrict damage to nonstructural elements and (2) total lateral displacement to avoid damaging contact with adjoining structures (see Annex L).

6.6 Response control systems

Response control systems for structures, e.g. seismic isolation or energy dissipating devices, can be used to ensure continuous use of the structure for moderate and, in some cases, severe earthquake ground motions and also to prevent collapse during severe earthquake ground motions (see Annex M).

6.7 Foundations

The type of foundation should be selected carefully in accordance with the type of structure and local soil conditions, e.g. soil profile, subsurface irregularity, groundwater level. Both forces and deformations transferred through the foundations should be evaluated properly considering the strains induced to soils during earthquake ground motions as well as kinematic and inertial interactions between soils and foundations.

7 Principles of evaluating seismic actions

7.1 Variable and accidental actions

Seismic actions should be taken either as variable actions or accidental actions.

Structures should be verified against design values of seismic actions for ULS and SLS.

Accidental seismic actions can be considered for structures in regions where seismic activity is low to ensure structural integrity.

NOTE The verification for the SLS can be omitted provided that it is satisfied through the verification for the ULS. The verification of the SLS can also be omitted in low seismicity regions, where the SLS actions are low, and for stiff structures (e.g. shear wall buildings) which are designed to remain nearly elastic under ULS actions.

7.2 Dynamic and equivalent static analyses

The seismic analysis of structures should be performed either by dynamic analysis or by equivalent static analysis. In both cases, the dynamic properties of the structure should be taken into consideration.

When performing nonlinear analysis, the sequence of nonlinear behaviours of the structure, including the formation of the collapse mechanism, should be determined when nonlinear behaviour is anticipated for severe earthquake ground motions.

NOTE Nonlinear static analysis can be used to determine collapse mechanisms (see Annex H and Annex I).

7.2.1 Equivalent static analysis

Ordinary and regular structures may be designed by the equivalent static method using conventional linear elastic analysis.

7.2.2 Dynamic analysis

A dynamic analysis should be performed for structures whose seismic response may not be predicted accurately by an equivalent static analysis. Examples include those structures with irregularities of geometry, mass distribution or stiffness distribution, or very tall structures at sites with high seismic hazard (see Annex K). A dynamic analysis is also recommended for structures with innovative structural systems [e.g. response control systems (see 6.6)], structures made of new materials, structures built on special soil conditions, and structures of special importance. Dynamic analysis is classified as either a) the response spectrum analysis, b) linear response history analysis or c) nonlinear response history analysis (see Annex H).

7.2.3 Nonlinear static analysis

Structures where nonlinear sequence of behaviour is difficult to predict should utilize nonlinear static analysis to determine the sequence (see Annex I).

7.3 Criteria for determination of seismic actions

The design seismic actions should be determined based on the following considerations.

7.3.1 Seismicity of the region

The seismicity of the region where a structure is to be constructed is usually indicated by mapping a seismic zoning parameter [peak ground motion value(s) or design ground motion spectral response value(s)], which should be based on either the seismic history or on seismological data of the region (including active faults), or on a combination of historical and seismological data. In addition, the expected values of the maximum intensity of the earthquake ground motion in the region in a given future period of time should be determined on the basis of the regional seismicity.

NOTE There exist many kinds of parameters which can be used to characterize the intensity of earthquake ground motion. These are seismic intensity scales, peak ground acceleration and velocity, “effective” peak ground acceleration and velocity, spectral response parameters that are related to smoothed response spectra, input energy, etc. Often, these parameters are determined by a probabilistic seismic hazard analysis to give uniform hazard for a range of natural periods of vibration. In some cases, the hazard analysis is extended to encompass the variation in hazard level with probability level and to integrate that variation with structural fragility to reach a consistent reliability against collapse.

7.3.2 Site conditions

Dynamic properties of the supporting soil layers of the structure should be investigated and the effect on the ground motion at the site should be considered. Geographical and geological conditions and influence of deep subsurface structure (basin effects) should also be taken into consideration.

The ground motion at a particular site during earthquakes has a predominant period of vibration which, in general, is shorter on firm ground and longer on soft ground. Attention should be paid to the possibility of local amplifications of earthquake ground motions, which may occur (*inter alia*) in the presence of soft soils and near the edge of alluvial basins. The possibility of liquefaction should also be considered, particularly in saturated, loose, cohesionless soils.

NOTE The properties of earthquake ground motions including intensity, frequency content and duration of motion are important features as far as the destructiveness of earthquakes is concerned. Furthermore, structures constructed on soft ground often suffer damage due to uneven or large settlements during earthquakes if not constructed on deep foundations.

7.3.3 Dynamic properties of the structure

Dynamic properties, such as periods and modes of vibration and damping, should be considered for the overall soil-structure system. The dynamic properties depend on the shape of the structure, mass distribution, stiffness distribution, soil properties, and the type of construction. Nonlinear behaviour of the structural elements should also be taken into account (see 8.1.1). A larger value of the seismic design force should be considered for a structure having less ductility capacity or for a structure where a structural element failure may lead to complete structural collapse.

7.3.4 Consequence of failure of the structure

Consequence of possible failures as well as expense and effort required to reduce the risk of those failures should be taken into account. By considering them and minimizing risk, design with a higher reliability level is appropriate for buildings where large numbers of people assemble, or structures which are essential for public well-being during and after the earthquakes, such as hospitals, power stations, fire stations, broadcasting stations, and water supply facilities (see Annex A). For high-rise buildings, also see Annex K. For national and political economic reasons, a higher level of reliability may be required in urban areas with a high damage potential and a high concentration of capital investment.

NOTE The load factors as related to reliability of the structure $\gamma_{\mathrm{E,u}}$ and $\gamma_{\mathrm{E,s}}$ (see 8.1) are generally increased when consequence class is high (see Annex A). For response history analysis, the input ground motions are either amplified or more stringent acceptance criteria are used, consistent with the increase of the desired reliability.

7.3.5 Spatial variation of earthquake ground motion

Usually, the relative motion between different points of the ground may be disregarded. However, in the case of long-span or widely spread structures, this action and the effect of a travelling wave which can come with phase delay should be taken into account. Spatial variation of wave due to the differences of the ground condition and subsurface geological structure should also be considered.

8 Evaluation of seismic actions by equivalent static analysis

8.1 Equivalent static loadings

In the seismic analysis of structures based on a method using equivalent static loadings, the variable seismic actions for ULS and for SLS may be evaluated as follows.

8.1.1 ULS

The design lateral seismic force of the ith level of a structure for ULS, $F_{\mathrm{E,u},i}$, may be determined by

$$F_{\mathrm{E,u},i} = \gamma_{\mathrm{E,u}}\ k_{\mathrm{Z}}\ k_{\mathrm{E,u}}\ k_{\mathrm{S}}\ k_{\mathrm{D}}\ k_{\mathrm{R}}\ k_{\mathrm{F},i} \sum_{j=1}^{n} F_{\mathrm{G},j} \tag{1}$$

or the design lateral seismic shear for ULS, $V_{\mathrm{E,u},i}$, may be used instead of the above seismic force:

$$V_{\mathrm{E,u},i} = \gamma_{\mathrm{E,u}}\ k_{\mathrm{Z}}\ k_{\mathrm{E,u}}\ k_{\mathrm{S}}\ k_{\mathrm{D}}\ k_{\mathrm{R}}\ k_{\mathrm{V},i} \sum_{j=i}^{n} F_{\mathrm{G},j} \tag{2}$$

where

$\gamma_{\mathrm{E,u}}$ is the load factor as related to reliability of the structure for ULS (see Annex A);

k_{Z} is the seismic hazard zoning factor to be specified in the national code or other national documents (see Annex A);

$k_{\mathrm{E,u}}$ is the representative value of earthquake ground motion intensity for ULS to be specified in the national code or other national documents by considering the seismicity (see Annex A);

k_{S} is the ratio of the earthquake ground motion intensity considering the effect of soil conditions to the earthquake ground motion intensity for the reference site condition (see Annex A);

k_{D} is the structural design factor to be specified for various structural systems according to their ductility, acceptable deformation, restoring force characteristics, and overstrength (see Annex D);

k_{R} is the ordinate of the normalized design response spectrum, as a function of the fundamental natural period of the structure considering the effect of soil conditions (see Annex B) and damping property of the structure (see Annex G);

$k_{\mathrm{F},i}$ is the seismic force distribution factor of the ith level to distribute the seismic base shear to each level, which characterizes the distribution of seismic forces in elevation, where $k_{\mathrm{F},i}$ satisfies the condition $\sum k_{\mathrm{F},i} = 1$ (see Annex C);

$k_{\mathrm{V},i}$ is the seismic shear distribution factor of the ith level which is the ratio of the seismic shear factor of the ith level to the seismic shear factor of the base, and characterizes the distribution of seismic shears in elevation, where $k_{\mathrm{V},i} = 1$ at the base and usually becomes largest at the top (see Annex C);

$F_{\mathrm{G},j}$ is the gravity load at the jth level of the structure;

n is the number of levels above the base.

8.1.2 SLS

The design lateral seismic force of the ith level of a structure for SLS, $F_{\mathrm{E,s},i}$, may be determined by

$$F_{\mathrm{E,s},i} = \gamma_{\mathrm{E,s}}\ k_{\mathrm{Z}}\ k_{\mathrm{E,s}}\ k_{\mathrm{S}}\ k_{\mathrm{R}}\ k_{\mathrm{F},i} \sum_{j=1}^{n} F_{\mathrm{G},j} \qquad (3)$$

or the design lateral seismic shear for SLS, $V_{\mathrm{E,s},i}$, may be used instead of the above seismic force:

$$V_{\mathrm{E,s},i} = \gamma_{\mathrm{E,s}}\ k_{\mathrm{Z}}\ k_{\mathrm{E,s}}\ k_{\mathrm{S}}\ k_{\mathrm{R}}\ k_{\mathrm{V},i} \sum_{j=i}^{n} F_{\mathrm{G},j} \qquad (4)$$