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Basis for design of structures — Seismic actions on structures

Bases du calcul des constructions — Actions sismiques sur les structures

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 3010 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

This second edition cancels and replaces the first edition (ISO 3010:1988), which has been technically revised.

Annexes A, B, C, D, E, F, G, H, I and J of this International Standard are for information only.

Introduction

This International Standard 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.

Basis for design of structures — Seismic actions on structures

1 Scope

This International Standard specifies principles of evaluating seismic actions for the seismic design of buildings, towers, chimneys and similar structures. Some of the principles can be referred to for the seismic design of structures such as bridges, dams, harbour installations, tunnels, fuel storage tanks, chemical plants and conventional power plants.

The principles specified in this International Standard do not cover 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 may be used in lieu of methods based on a consideration of seismic actions.

This International Standard 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 International Standard has been prepared mainly for engineered structures. The principles are, however, applicable to non-engineered structures.

NOTE 2 The qualification of the level of seismic hazard that would be considered low depends on not only the seismicity of the region but other factors, including types of construction, traditional practices, etc. Methods of design for structural integrity include regional design horizontal forces which provide a measure of protection against seismic actions.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2394, *General principles on reliability for structures*

3 Terms and definitions

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

3.1
complete quadratic combination method
method to evaluate the maximum response of a structure by the quadratic combination of modal response values

3.2
ductility
ability to deform beyond the elastic limit under cyclic loadings without serious reduction in strength or energy absorption capacity

3.3
liquefaction
loss of shear strength and degradation of stiffness under cyclic loadings in saturated, loose, cohesionless soils

3.4
moderate earthquake ground motion
moderate ground motion caused by earthquakes which may be expected to occur at the site during the service life of the structure

3.5
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

3.6
paraseismic influences
ground motion whose characteristics are similar to those of natural earthquake ground motions, but its sources are mainly due to human activities

3.7
P-delta effect
second-order effect which is caused by the additional moment due to the large displacement and the gravity load

3.8
restoring force
force exerted from the deformed structure or structural elements which tends to move the structure or structural elements to the original position

3.9
seismic force distribution factor of the ith level
$k_{\mathrm{F},i}$

factor to distribute the seismic shear force of the base to the ith level, which characterizes the distribution of seismic forces in elevation, where

$$\sum k_{\mathrm{F},i} = 1$$

3.10
seismic hazard zoning factor
k_{Z}
factor to express the relative seismic hazard of the region

NOTE This is usually unity at the region of the highest seismic hazard.

3.11
seismic shear distribution factor of the ith level
$k_{\mathrm{v},i}$
ratio of the seismic shear factor of the ith level to the seismic shear factor of the base, which characterizes the distribution of seismic shear forces in elevation

NOTE $k_{\mathrm{v},i} = 1$ at the base and usually becomes largest at the top.

3.12
severe earthquake ground motion
severe ground motion caused by an earthquake that could occur at the site

3.13
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

3.14
structural factor
k_D
factor to reduce design seismic forces or shear forces taking into account ductility, acceptable deformation, restoring force characteristics and overstrength (or overcapacity) of the structure

4 Symbols and abbreviated terms

CQC Complete quadratic combination

$F_{E,s,i}$ Design lateral seismic force of the ith level of a structure for SLS

$F_{E,u,i}$ Design lateral seismic force of the ith level of a structure for ULS

$F_{G,i}$ Gravity load at the ith level of the structure

k_D Structural factor

$k_{E,s}$ Representative value of earthquake ground motion intensity for SLS

$k_{E,u}$ Representative value of earthquake ground motion intensity for ULS

$k_{F,i}$ Seismic force distribution factor of the ith level

k_R Ordinate of the normalized design response spectrum

$k_{V,i}$ Seismic shear distribution factor of the ith level

k_Z Seismic hazard zoning factor

n Number of levels above the base

SLS Serviceability limit state

SRSS Square root of sum of squares

ULS Ultimate limit state

$V_{E,s,i}$ Design lateral seismic shear force of the ith level of a structure for SLS

$V_{E,u,i}$ Design lateral seismic shear force of the ith level of a structure for ULS

$\gamma_{E,s}$ Load factor as related to reliability of the structure for SLS

$\gamma_{E,u}$ 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 minimize damage to property.

It is recognized that to give complete protection against all earthquakes is not economically feasible for most types of structures. This International Standard 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).

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).

In order to ensure safety and vital services, elements controlling services to buildings, such as cables, pipe lines, air-conditioning, fire-fighting system, elevator system and other similar systems, should be protected against seismic actions.

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

NOTE 2 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 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 Construction site

Characteristics of construction sites 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).

6.2 Structural configuration

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

a) **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).

b) **Vertical irregularities**

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

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 non-structural elements

The building, including non-structural as well as structural elements, should be clearly defined as a lateral load-resisting system which can be analysed. In computing the earthquake response of a building, the influence of not only the structural frames but also walls, floors, partitions, stairs, windows, etc., should be considered.

NOTE Non-structural elements neglected in seismic analysis can provide additional strength and stiffness to the structure, which may result in favourable behaviour during earthquakes. The non-structural elements, however, may cause unfavourable behaviour, e.g. spandrel walls may reduce clear height of reinforced concrete columns and cause the brittle shear failure to the columns, or unsymmetrical allocation of partition walls (which are considered to be non-structural elements) may cause large torsional moments to the structure. Therefore, all elements should be considered as they behave during earthquakes. If neglecting the non-structural elements does not cause any unfavourable behaviour, they need not be included in seismic analysis.

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.

The structure should have adequate strength for the applied seismic actions and sufficient ductility to ensure adequate energy absorption (see annex B). Special attention should be given to suppressing the brittle 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, neither causing malfunction of the structure for moderate earthquake ground motions, nor causing collapse or other similar forms of structural failure for severe earthquake ground motions.

NOTE There are two kinds of deformations to be controlled: the interstorey drift which is the lateral displacement within a storey and the total lateral displacement at some level relative to the base. The interstorey drift should be limited to restrict damage to non-structural elements such as glass panels, curtain walls, plaster walls and other partitions for moderate earthquake ground motions and to control failure of structural elements and the instability of the structure in the case of severe earthquake ground motions. The control of the total displacement is concerned with sufficient separations of two adjoining structures to avoid damaging contact for severe earthquake ground motions. The control of the total displacement may also decrease the amplitude of vibration of the structure and reduce panic or discomfort for moderate earthquake ground motions. In the evaluation of deformations under severe earthquake ground motions, it is generally necessary to account for the second order effect (P-delta effect) of additional moments due to gravity plus vertical seismic forces acting on the displaced structure which occurs as a result of severe earthquake ground motions.

6.6 Response control systems

Response control systems for structures, e.g. seismic isolation, can be used to ensure continuous use of the structure for moderate earthquake ground motions and to prevent collapse during severe earthquake ground motions (see annex J).

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 shall be taken either as variable actions or accidental actions.

Structures should be verified against design values of seismic actions for ULS and SLS. The verification for the SLSs may be omitted provided that it is satisfied through the verification for the ULSs (see 8.1).

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

NOTE Verification of the SLS may be omitted in low seisimicity 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 shall be performed either by dynamic analysis or by equivalent static analysis. In both cases the dynamic properties of the structure shall be taken into consideration.

Appropriate post-elastic performance shall be provided by adequate choice of the structural system and ductile detailing. The sequence of behaviour of the structure, including the formation of the collapse mechanism, should be established.

NOTE 1 Usually the sequence of behaviour can be verified through non-linear static analysis under lateral loads.

a) **Dynamic analysis**

A dynamic analysis is highly recommended for specific structures such as slender high-rise buildings and structures with irregularities of geometry, mass distribution or stiffness distribution. 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.

b) **Equivalent static analysis**

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

NOTE 2 If it is essential that services (e.g. mechanical and electrical equipment and pipings) retain their functions during and after severe or moderate earthquake ground motions, then the design of these services should preferably be done by dynamic analysis procedures based on the earthquake response of the structure which supports them.

7.3 Criteria for determination of seismic actions

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

a) **Seismicity of the region**

The seismicity of the region where a structure is to be constructed is usually indicated by a seismic zoning map, which may be based on either the seismic history or on seismotectonic data of the region, or on a combination of historical and seismotectonic 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 1 In addition to the consideration of the historical records of earthquakes, investigation of actual earthquake faults in the region could provide valuable guidance for estimating the future occurrence of earthquakes.

NOTE 2 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 which is related to smoothed response spectra, input energy, etc. Recently a method has been proposed to determine the parameters from a probabilistic seismic hazard analysis to give uniform hazard for structures of different periods of vibration. The selection of the type of parameter depends mainly on available data and the type of structure.

b) **Soil conditions**

Dynamic properties of the supporting soil layers of the structure should be investigated and considered.

NOTE 3 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 4 The properties of earthquake ground motions such as predominant periods of vibration and duration of motion are also important features as far as the destructiveness of earthquakes is concerned. Furthermore, it should be recognized that structures constructed on soft ground often suffer damage due to uneven or large settlements during earthquakes.

c) **Dynamic properties of the structure**

Dynamic properties, such as periods and modes of vibration and damping properties, 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. Non-linear behaviour of the structural elements should also be taken into account (see 8.1a). 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.

d) **Importance of the structure in relation to its use**

A higher level of reliability is required 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).

NOTE 5 From the point of view of national and political economics, the load factors as related to reliability of the structure $\gamma_{\mathrm{E,u}}$ and $\gamma_{\mathrm{E,s}}$ (see 8.1) should generally be increased in urban areas with a high damage potential and a high concentration of capital investment.

e) **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.

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.

a) **ULS**

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

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

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

$$V_{\mathrm{E,u},i} = \gamma_{\mathrm{E,u}}\, k_{\mathrm{Z}}\, k_{\mathrm{E,u}}\, k_{\mathrm{D}}\, k_{\mathrm{R}}\, k_{\mathrm{V},i} \sum_{j=1}^{n} F_{\mathrm{G},j} \qquad (2)$$

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);