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Bases for design of structures — Seismic actions on structures

Bases du calcul des constructions — Actions sismiques sur les structures

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 3010 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Bases for design of structures — Seismic actions on structures

0 Introduction

This International Standard presents basic methods for the determination of seismic actions on structures. The seismic actions described are fundamentally compatible with ISO 2394.

1 Scope and field of application

This International Standard specifies methods of evaluating seismic actions for the earthquake-resistant design of buildings, towers, chimneys, and similar structures. Most of the principles are applicable also to structures such as bridges, dams, harbour installations, tunnels, fuel storage tanks, chemical plants, conventional power plants, etc.

The methods specified in this International Standard do not cover nuclear power plants, since they are dealt with separately in other International Standards.

2 Reference

ISO 2394, *General principles on reliability for structures.*

3 Bases of earthquake-resistant design

The basic philosophy of earthquake-resistant design of structures is, in the event of earthquakes,

a) to prevent human injury;

b) to ensure continuity of vital services;

c) 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 principles.

a) The structure should not collapse nor harm human lives by severe earthquakes which possibly could occur at the site (ultimate limit state).

b) The structure should withstand moderate earthquakes which may be expected to occur at the site during the service life of the structure without structural damage and with non-structural damage within accepted limits (serviceability limit state).

NOTE — Severe and moderate earthquakes described above may correspond respectively to accidental and variable actions — see 5.1. In addition to the earthquake-resistant design and construction of structures stated in this International Standard, adequate countermeasures should be considered against the secondary disasters such as fire, leakage of hazardous materials from industrial facilities or storage tanks, and large scale land-slides which may be triggered by the earthquake.

4 Principles of earthquake-resistant design

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

NOTE — When a structure with complex form is to be designed, an accurate dynamic analysis should be made in order to check the potential behaviour of the structure.

4.2 Structural elements to resist horizontal seismic actions should be arranged such that torsional effects become as small as possible.

NOTE — Irregular shapes in plan and eccentric distribution of loads are not desirable, since they produce torsional effects which are difficult to assess accurately and which may amplify the dynamic response of the structure.

4.3 The structural system should be clearly open to rational analysis. In computing the earthquake response of a building, the influence of not only the structural frames but also walls, floors, partitions, windows, etc., should be considered.

4.4 The structural system and its structural elements should have both adequate strength and ductility for the applied seismic actions.

NOTE — The structure should have not only adequate strength for the applied seismic actions but also have sufficient ductility to ensure sufficient energy absorption. Special attention should be given to brittle behaviour of structural elements such as, for example, buckling, bond failure, shear failure, and joint and element fracture. The deterioration of the restoring force under load reversals should be taken into account. The ultimate capacity of the structure may be higher than that assumed in the analysis. It should be considered how this would affect the structural behaviour under severe earthquake loadings. There may especially be a risk of high stress levels in the foundations.

4.5 The deformation of the structure under seismic actions should be limited, neither causing inconvenience in the use of the structure for moderate earthquakes, nor endangering public safety for severe earthquakes.

NOTE — There are two kinds of deformations to be controlled : the inter-story drift which is the lateral displacement within a story and the total lateral displacement relative to the base. The inter-story drift should be limited to restrict damage to non-structural elements such as glass panels, curtain walls, plaster walls and other partitions for moderate earthquakes and to control against fracture of structural elements and instability of the structure for severe earthquakes. The control of the total displacement is concerned with the reduction of panic or discomfort for moderate earthquakes and with sufficient separations of two adjoining structures to avoid damaging contact for severe earthquakes. In the evaluation of deformations under severe earthquakes, it is generally necessary to account for the second order effect which is caused by the additional moment due to the large deformation and the gravity load.

4.6 The characteristic of construction sites under seismic actions should be evaluated. Sites that cannot be adequately assessed or sites where the consequences of seismic actions cannot be incorporated into the design of the structure should be avoided.

The construction site in a seismic active region should be properly selected and be based on microzonation criteria (vicinity to active faults, soil profile, soil behaviour under large strain, liquefaction potential, topography, and other factors such as interactions between these).

5 Principles of evaluating seismic actions

5.1 Seismic actions shall be taken either as accidental actions or variable actions.

Structures should be designed with representative values of seismic actions for the ultimate limit state. The serviceability limit states are verified either indirectly, when the action is considered as accidental, or directly, when the action is considered as variable (see 6.1).

The representative values should be set by the national authorities, and may be determined from the viewpoint of regional seismicity, economic and social situations.

5.2 The seismic analysis of structures shall take the dynamic properties of the structure into consideration either by dynamic analysis or by equivalent static analysis. A dynamic analysis is highly recommended for specific structures such as slender high-rise buildings and structures with irregularities of geometry or mass distribution or rigidity distribution.

Ordinary structures may be designed by the equivalent static method using conventional linear elastic analysis. Appropriate post-elastic performance shall be provided by adequate choice of structural system and ductile detailing. Non-linear methods of analysis should be employed to verify the sequence of inelastic behaviour and formation of collapse mechanism.

NOTE — If it is essential that services, e.g. mechanical and electrical equipment and pipings, retain their functions during and after a severe earthquake, 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.

5.3 The design seismic actions shall be determined after consideration of the following points.

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 in the region in a given future period of time should be determined on the basis of the local seismicity.

NOTE — In addition to the consideration of the historical records of earthquakes, investigation of actual earthquake faults in the region will provide valuable guidance for estimating the future occurrence of earthquakes.

There exist many kinds of parameters which can be used to characterize the intensity of ground shaking. They are seismic intensity scale, peak ground acceleration and velocity, "effective" peak ground acceleration and velocity which are related to smoothed response spectra, etc. 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 considered. It is generally recognized that the motion of the ground 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 also be paid to the problem of soil amplification.

NOTE — The dynamic properties of ground motions such as predominant periods of vibration and duration of motion are important features as far as destructiveness of earthquakes is concerned. Furthermore, it should be recognized that structures constructed on soft ground often suffer damage due to irregular or large settlements during earthquakes. In addition, attention should be paid to soil liquefaction which tends to occur in soft, saturated and cohesionless sandy soils.

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, distribution of masses, distribution of rigidities, soil properties, and the type of construction. Inelastic behaviour of the structural elements should also be taken into account. A larger value of the seismic force should be considered for a structure having less ductile properties or for a structure where a component failure may lead to complete structural collapse.

d) Importance of the structure as related 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, water supply facilities, etc.

NOTE — From the point of view of national and political economics, the importance factor of the structure (see 6.1) should generally be increased in urban areas with a high damage potential and a high concentration of capital investment.

6 Evaluation of seismic actions in equivalent static analyses

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

a) Ultimate limit state

The design lateral seismic force of the ith level of a structure subjected to accidental seismic actions, $F_{i,\,a}$, may be determined by

$$F_{i,\,a} = \alpha \beta \gamma_a \delta \varrho \phi_i G$$

where

α is the importance factor as related to the use of structure (see clause A.1);

β is the seismic hazard zoning coefficient to be specified in the national code;

γ_a is the standard base shear coefficient for the accidental seismic action to be specified in the national code;

δ is the structural coefficient to be specified for various structural systems according to their ductility (see clause A.2);

ϱ is the dynamic coefficient as related to the response spectrum, considering the effect of soil conditions (see clause A.3) and damping property of structure (see clause A.8);

ϕ_i is the coefficient which characterizes the distribution of seismic forces in elevation, where ϕ_i satisfies the condition $\Sigma\phi_i = 1$ (see clause A.4);

G is the gravity load of the structure.

b) Serviceability limit state

The design lateral seismic force of the ith level of a structure subjected to variable seismic actions, $F_{i,\,v}$, may be determined by

$$F_{i,\,v} = \alpha \beta \gamma_v \varrho \phi_i G$$

where γ_v is the standard base shear coefficient for variable seismic action to be specified in the national code.

NOTE — The factor α may be deleted if a coefficient such as γ_n specified in ISO 2394 is adopted in the verification procedure, by which the importance of the structure and the consequences of failure, including the significance of the type of failure, are taken into account.

The values of gravity load should be equal to the total permanent load plus a probable variable imposed load. In special areas, a probable snow load is also to be considered.

Depending on the definition of the seismic actions as accidental or variable, the values for the combination of seismic actions and other actions may be different. For the combination of actions, see ISO 2394.

6.2 The three displacement components of the ground motion and their spatial variation, leading to torsional excitation of structures, have to be considered (see clause A.5).

NOTE — The fact that the seismic actions in any direction do not always attain their maxima at the same time should be borne in mind.

The vertical component of the ground motion is usually less intense than the horizontal components and is characterized by higher frequencies. In the vicinity of the epicentre, however, the vertical peak acceleration may be higher than the horizontal peak acceleration.

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 should be taken into account.

6.3 The torsional effects of seismic actions should, in general, be taken into account with due regard to the following quantities: eccentricity between centres of mass and rigidity, the dynamic magnification caused mainly by the coupling between translational and torsional vibrations, effects of eccentricities in other stories, inaccuracy of computed eccentricity, and rotational components of ground shaking (see clause A.6).

NOTE — In a number of structural forms the magnitude of structural response from torsional vibration may be comparable to or greater than that from translational vibration. For highly irregular structures, two- or three-dimensional dynamic analyses are recommended, and it is desirable that the non-linear behaviour of structural elements be taken into account.

6.4 Larger seismic actions than those given in 6.1 should be considered for the design of parts or portions of structures such as cantilever parapets, structures projecting from the roof, ornamentations and appendages. In addition, curtain walls, infill panels and partitions adjacent to exit ways or facing streets should be designed for safety using the appropriate values of seismic actions.

NOTE — In the case of parapets, curtain walls, etc., the seismic actions should be assumed to take place in the direction normal to their surface. Vertical forces should also be considered for connections of such appendages.

7 Evaluation of seismic actions in dynamic analyses

7.1 When performing a dynamic analysis, it is important to consider the following items.

a) A proper physical model should be set up, which can represent the dynamic properties of the real structure such as the natural periods and modes of vibration, damping properties, and restoring force characteristics;

b) Appropriate earthquake ground motions should be determined, taking into account the seismicity and local soil conditions.

7.2 The usual dynamic analysis procedures may be classified as :

a) the response spectrum analysis;

b) the time history analysis.

7.3 In the response spectrum analysis, the maximum dynamic response is usually obtained by the superposition method of "square root of sum of squares", taking the predominant vibration modes (often the first three modes) into consideration (see clause A.7).

NOTE — Attention should be given to the fact that the method of "square root of sum of squares" does not always lead to conservative values, particularly for two or more natural modes the frequencies of which are closely spaced. This condition often arises in the vibration of buildings having large set backs and in the torsional vibration (6.3).

7.4 The time history analysis may require several earthquake records to ensure adequate coverage of the problem. Simulated earthquake ground motions may be used as an alternative. It should be noted that the earthquake motion can be considered as a stochastic process. The time history analysis can be applied to both elastic and inelastic systems.

7.5 When actual earthquakes are considered in a dynamic analysis, the following records may be referred to :

a) strong earthquake motions recorded at or near the site;

b) strong earthquake motions recorded at other sites with similar geological, topographic and seismotectonic characteristics.

Usually these earthquake records have to be scaled according to specific characteristics of the site.

7.6 Since it is impossible to predict exactly the earthquake motions expected at a site in the future, it may be appropriate to use simulated ground motions in dynamic analyses. Synthetic accelerograms should be based on probabilistic methods.

7.7 When setting up a physical model representing the dynamic properties of the real structure, reference should be made to examples of realistic models with which the validity of the dynamic analysis has been demonstrated. Consideration should be given to :

a) coupling effects of the structure with its foundation and supporting ground;

b) damping in fundamental and higher modes of vibration (see clause A.8);

c) restoring the force-distortion relationship of the structural elements in elastic and inelastic ranges;

d) effects of non-structural elements on the rigidity of the structure;

e) torsional effects on earthquake response.

Annex

Parameters on structural characteristics

(This annex does not form part of the Standard.)

A.1 Coefficient of importance of structure

The coefficient of the importance of the structure, α, may be

— 1,2 to 2 for structures of special importance,

— 1 for structures of medium importance,

— 0,4 to 0,8 for structures of little importance.

A.2 Parameter on ductility

The parameter concerning the ductility of structural systems, δ, may be, for example,

— 1/5 to 1/3 for systems with excellent ductility,

— 1/3 to 1/2 for systems with medium ductility,

— 1/2 to 1 for systems with poor ductility.

These ranges of δ are under continuing investigation and may take other values in some circumstances.

The ductility is defined as the ability to deform beyond the elastic limit under load reversals without serious reduction in strength or energy dissipation capacity.

The typical examples of structural systems given below with different ductility are only examples. It should be noted that detailing of members and joints to get appropriate ductility is important.

The structural system with excellent ductility is a structural system where the lateral resistance is provided by steel or reinforced concrete moment resisting frames with adequate connection details and member ductility.

The structural system with medium ductility is a structural system where the lateral resistance is provided by steel-braced frames or reinforced concrete shear walls.

The structural system with poor ductility is a structural system where the lateral resistance is provided by unreinforced or partially reinforced masonry shear walls.

A.3 Dynamic coefficient

The dynamic coefficient, ϱ, may be of the form

$$\varrho = \varrho_0 \quad \text{for } T \leqslant T_c$$

$$\varrho = \varrho_0 \left(\frac{T_c}{T} \right)^{\eta} \quad \text{for } T > T_c$$

where

ϱ_0 is a coefficient dependent on the soil amplification and the damping of the structure. For a structure with a damping ratio of 0,05 resting on the average quality soil, ϱ_0 may be taken as 1;

T is the fundamental natural period of the structure;

T_c is the critical period as related to the soil condition, as illustrated in the figure;

η is an exponent that can vary between 1/3 and 1.

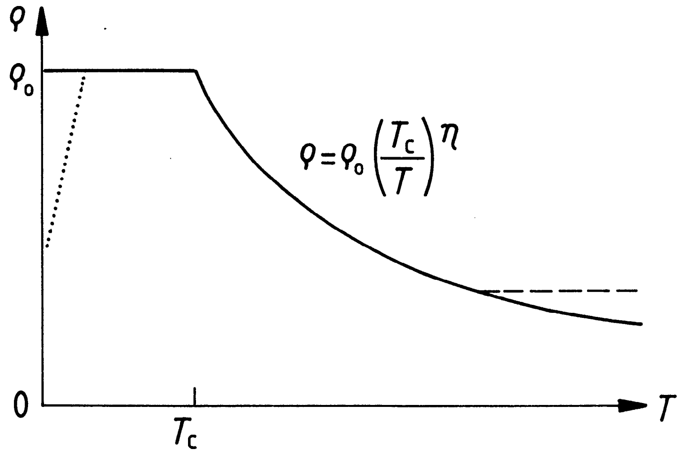

Figure — Dynamic coefficient ϱ

For example, T_c can be taken as

- 0,3 to 0,5 s for stiff and hard soil conditions,
- 0,5 to 0,8 s for intermediate soil conditions,
- 0,8 to 1,2 s for loose and soft soil conditions.

The fundamental natural period, T, may be calculated from calibrated empirical formulae, from Rayleigh's approximation, or from an eigenvalue formulation. For analytical determinations of T, member stiffness of concrete structures should correspond to cracked sections.

In some codes and proposals, ϱ is decreased linearly down to 1/2 to 1/3 for very stiff structures having T less than say (1/3) T_c, as indicated by the dotted line in the figure. It is recommended, however, not to lower ϱ like this because of uncertainty of ground motion characteristics in this range. Strong motion accelerometers have low sensitivity in the range of shorter periods and therefore there is a possibility of a higher value of ϱ than the apparent one. In addition, it is recommended to provide the lower limit as indicated by a broken line in order to cover the uncertainty of ground motions in the range of longer periods. The value of this level may be taken as 1/3 to 1/5.

A.4 Coefficient of seismic force distribution

The seismic force distribution coefficient, ϕ_i, may be determined by

$$\phi_i = \frac{G_i h_i^{\mu}}{\sum_{j=1}^{n} G_j h_j^{\mu}}$$

where

G_i is the gravity load of the structure at the ith level;

h_i is the height above of the base to the point of the ith level;

n is the number of levels.

The exponent μ can be taken as

- 0 for very low buildings, or structures $T < 0,2$ s,
- 0 to 1 for low-rise buildings, or structures 0,2 s $< T <$ 0,5 s,
- 1 to 2 for intermediate buildings, or structures 0,5 s $< T <$ 1,5 s,
- 2 for high-rise buildings, or structures $T >$ 1,5 s.

Very low, low-rise, intermediate and high-rise buildings may be classified as follows :

- very low building : up to two-story building,
- low-rise building : three- to five-story building,
- high-rise building : higher than 50 metres or more than fifteen-story building,
- intermediate building : others.

A.5 Seismic action components

The two horizontal components of the seismic action are designated as E_x and E_y according to the orthogonal axes x-y, the directions of which follow the layout of the structures. The total design seismic action, E, to be considered usually consists of the following two combinations of E_x and E_y:

$$E = E_x + \lambda E_y$$

$$E = \lambda E_x + E_y$$

The value of λ will be specified in the national code. For example, this value may be taken as around 0,3. For corner columns of buildings, the value may be higher.

The structural system is usually verified for both combinations, when it should be considered that each component of the seismic action can become effective with both forms.

The vertical component E_z is usually not considered explicitly. It is, however, taken into account with its most unfavourable value, for example in the following cases:

a) prestressed structures;

b) horizontal structural members with clear spans of more than 20 m;

c) constructions with high arching forces;

d) cantilever members;

e) concrete columns and shear walls subjected to high shear forces, especially at construction interfaces.

A.6 Seismic action torsional moments

The torsional moment of the ith level of the structure, M_i, may be determined by

$$M_i = Q_i e_i$$

where

Q_i is the seismic shear force of the ith level:

$$Q_i = \sum_{j=i}^{n} F_j$$

in which n is the number of levels;