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REVISED INTERNATIONAL STANDARD ISO 3010 BASES FOR DESIGN OF STRUCTURES - SEISMIC ACTIONS ON STRUCTURES

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ABSTRACT: The International Standard "ISO 3010 Bases for design of structures - Seismic actions on structures" was published in 1988 through the activity of the working group of ISO/TC98. TC98 deals with "Bases for design of structures." The aim of TC98 is to create a coherent design system of International Standards in the field of building and civil engineering works. ISO 3010 includes principles for the determination of seismic actions on structures and seismic design. The revision of ISO 3010 began in 1995, and the revised ISO 3010 was issued in December 2001. This paper introduces the activities of TC98 and the outline of the revised ISO 3010.

Key Words: international standard, design of structures, seismic actions, equivalent static analysis, structural factor, design spectrum, seismic force distribution factor

INTRODUCTION

The first edition of International Standard "ISO 3010 Bases for design of structures - Seismic actions on structures" (ISO 1988) was published in 1988 through the activity of the working group in ISO/TC98. TC98 deals with "Bases for design of structures." The aim of TC98 is to create a coherent design system of International Standards in the field of building and civil engineering works. The system forms a basis for regional and national standard bodies which prepare their standards for particular types of structures and structural materials. ISO 3010 includes principles for the determination of seismic actions on structures and seismic design. Since it does not give any specific values for factors to determine seismic loadings, it is not possible to design a structure only according to ISO 3010. Its annexes, however, give useful information to determine the values for those factors. ISO 3010 includes almost all items and factors to be considered. Therefore it is a useful document for establishing a new code or revising an old one. These features of ISO 3010 remain the same in the revision. This paper introduces the activities of TC98 and the revised ISO 3010.

ISO/TC98

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. The work of preparing International Standards is normally carried out through ISO technical committees (TC's). Each TC has several sub-committees (SC's) and each SC usually has several working groups (WG's). Currently there are approximately 200 TC's, 600 SC's and 2,000 WG's in ISO.

ISO/TC98 is one of the TC's which deals with "Bases for design of structures". The aim of TC98 is to create a coherent design system of International Standards in the field of building and civil engineering works. The system forms a basis for regional and national standard bodies that prepare their standards for particular types of structures and structural materials. Since TC98 was established in 1961, its secretariat has been in the Polish Committee for Standardization. In TC98 there are 22 participating members and 35_observers (one member or one observer from each country). TC98 has three main tasks that are shared among three SC's; (1) terminology and symbols, (2) reliability of structures, and (3) loads, forces and other actions on structures (Brandt 1998).

SC1 - Terminology and symbols

SC1 deals with the definitions and explanations of the terms used in the standards and other documents which are prepared by TC98, since very often the meanings of certain terms are different from their meanings in everyday language. The terms need to be well understood and correctly used without ambiguity. Also, similar terms have slightly different meanings in different languages. The task of establishing a coherent terminology system is essentially important. SC1 is concerned in symbols and their subscripts and superscripts as well.

SC2 - Reliability of structures

The reliability of structures is understood as a combination of their safety and serviceability. These are verified in two separate groups of limit states, i.e. (1) ultimate limit state and (2) serviceability limit state. In both limit states, all parameters such as loads, material properties, structural dimensions, etc. are considered as random variables. Because complete knowledge of statistical distributions of these parameters is lacking, the randomness is considered by a system of partial factors.

SC2 is responsible for ISO 2394:1988 "General principles on reliability of structures". ISO 2394, sometimes called the bible of TC98, introduces fundamental methods for verifying the reliability of structures and is the normative reference to ISO 3010.

SC3 - Loads, forces and other actions

SC3 elaborates the bases for various categories of loads, e.g. loads due to service loads in various types of buildings, forces caused by wind and by snow on roofs. Since 2001, SC3 has been dealing with seismic actions, which had been dealt with by WG1 which belonged directly to TC98. Recently, SC3 has started to prepare two new international standards. One is for seismic actions on geotechnical works and the other is for actions from waves and currents. The values of these actions can be given only in relatively large limits, because conditions vary considerably between countries. However, the bases for treatment of the actual data and methods of their measurement can be standardized.

TC98 cooperates with several international organizations. Their recommendations and guidelines are systematically used as kinds of pre-standardization documents. For the last few years, the most important partner has been European Committee for Standardization (CEN), and particularly its Technical Committee 250, Structural Eurocodes. Both parties can use their documents on a reciprocal basis and develop them into ISO standards and Eurocodes, respectively (Vienna Agreement) (ISO CEN 1998). By an extensive use of common bases for design of structures, a considerable economy of time, material and money can be achieved.

REVISION OF ISO 3010

The first edition of ISO 3010 was elaborated in WG1 under TC98. The convener was the late Professor Yutaka OSAWA of the University of Tokyo, who was succeeded by Professor Yutaka MATSUSHIMA of the University of Tsukuba. Since the revision of the first edition started in 1995, the convener has been Yuji Ishiyama, one of the authors.

ISO 3010 had not been included in the Earthquake Resistant Regulations a World List, which is published by the International Association for Earthquake Engineering (IAEE) every four years when the World Conference on Earthquake Engineering (WCEE) is held. Therefore, it was not so visible to many people. However, ISO 3010 was for the first time included in the Regulations for seismic design A world list - 1996 of IAEE (IAEE 1996). This hopefully made the standard familiar to many researchers and engineers.

The standards prepared by TC98 serve as references in the field of building and civil engineering works, and are frequently called "Code for Code Writers". They are also expected to serve as guidelines for issues during construction. As for ISO 3010, it includes only principles for the determination of seismic actions and seismic design. It does not give any specific values for factors to determine design seismic forces. Therefore it is not possible to determine seismic loads or to design a structure only according to ISO 3010. The annexes of ISO 3010, however, give information to determine those values.

ISO 3010 includes almost all items and factors to be considered. Therefore it is a useful document for establishing a new code or revising an old one. These features of the standard remain the same in the revised ISO 3010. The revision of the text is rather minor, but the annexes are extensively modified to include the current knowledge on earthquake engineering. The revised ISO 3010 consists of ten clauses and ten informative annexes.

EVALUATION OF SEISMIC ACTIONS BY EQUIVALENT STATIC ANALYSIS

The evaluation of seismic actions by equivalent static analysis in Clause 8 of the revised ISO 3010 (ISO 2001) can be summarized as follows:

In the seismic analysis of structures based on a method using equivalent static loading, the variable seismic actions for the ultimate and serviceability limit states may be evaluated as follows:

Ultimate limit state (ULS)

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

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

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

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

where,

$\gamma_{\mathrm{E,u}}$ is the load factor related to the reliability of the structure for ULS;
k_{Z} is the seismic hazard zoning factor to be specified in the national code or other national documents;
$k_{\mathrm{E,u}}$ is the representative value of earthquake ground motion intensity for ULS to be specified in national codes or other national documents considering seismicity;
k_{D} is the structural factor to be specified for various structural systems according to their ductility, acceptable deformation, restoring force characteristics and overstrength;

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 and damping of the structure;
$k_{F,i}$ is the seismic force distribution factor of the *i* th level to distribute the seismic shear force at the base to each level, which characterizes the vertical distribution of seismic forces, where $k_{F,i}$ satisfies the condition $\sum k_{F,i} = 1$;
$k_{V,i}$ is the seismic shear distribution factor of the *i* th level which is the ratio of the seismic shear factor of the *i* th level to the seismic shear factor of the base, and characterizes the vertical distribution of seismic shear forces, where $k_{V,i} = 1$ at the base and usually becomes largest at the top;
$F_{G,j}$ is the gravity load at the *j* th level of the structure;
n is the number of levels above the base.

Serviceability limit state (SLS)

The design lateral seismic force at the *i* th level of a structure for SLS $F_{E,s,i}$ may be determined by:

$$F_{E,s,i} = \gamma_{E,s}\ k_Z\ k_{E,s}\ k_R\ k_{F,i} \sum_{j=1}^{n} F_{G,j} \tag{3}$$

or the design lateral seismic shear force of the *i* th level for SLS $V_{E,s,i}$ can be used instead of the above seismic force,

$$V_{E,s,i} = \gamma_{E,s}\ k_Z\ k_{E,s}\ k_R\ k_{V,i} \sum_{j=i}^{n} F_{G,j} \tag{4}$$

where,
$\gamma_{E,s}$ is the load factor related to the reliability of the structure for SLS;
$k_{E,s}$ is the representative value of earthquake ground motion intensity for SLS to be specified in national codes or other national documents considering seismicity.
$k_{E,u}$ and $k_{E,s}$ may be replaced by a unique representative value k_E as specified in ISO 2394 (ISO 1998) in the verification procedure, by which the reliability of the structure and the consequences of failure, including the significance of the type of failure, are taken into account to specify the load factors $\gamma_{E,u}$ and $\gamma_{E,s}$.

Specific values for these factors are not given in the text. The annexes, however, describe informatively the factors as follows (Equation, table and figure numbers are not the same as in the revised ISO 3010) :

Structural factor

The structural factor k_D is to reduce design seismic forces and shear forces, taking into account the ductility, acceptable deformation, restoring force characteristics and overstrength (or overcapacity) of the structure. The factor can be divided into two factors, namely $k_{D\mu}$ and k_{Ds} and expressed as the product of them, where $k_{D\mu}$ is related to ductility, acceptable deformation and restoring force characteristics, whereas k_{Ds} is related to overstrength.

Recent studies indicate that $k_{D\mu}$ also depends on the natural period of vibration of the structure and the possible reduction in strength remains minimal for structures having a shorter fundamental natural period. k_{Ds} is a function of the difference between the actual strength and calculated strength and varies according to the method of strength calculation. Quantification of these factors is a matter of debate, and one generic term k_D has been adopted in most codes.

The structural factor k_D 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 values of k_D are under continuing investigation and may take other values in some circumstances.

Load factors and representative values

$\boldsymbol{\gamma}_{E,u}$ and $\boldsymbol{\gamma}_{E,s}$ are, for example, listed in Tables 1 and 2 for a region of relatively high seismic hazard, along with the representative values of earthquake ground motion intensity $k_{E,u}$ and $k_{E,s}$. An example using the unity load factor for a normal degree of importance is shown in Table 1, while a common representative value k_E is used in Table 2.

Table 1 – Example 1 for load factors $\gamma_{E,u}$ and $\gamma_{E,s}$
and representative values $k_{E,u}$ and $k_{E,s}$ (where $k_{E,u} \neq k_{E,s}$)

Limit state	Degree of importance	$\gamma_{E,u}$ or $\gamma_{E,s}$	$k_{E,u}$ or $k_{E,s}$	Return period for $k_{E,u}$ or $k_{E,s}$
Ultimate	a) High	1.5 – 2.0	0.4	500 years
	b) Normal	1.0		
	c) Low	0.4 – 0.8		
Serviceability	a) High	1.5 – 3.0	0.08	20 years
	b) Normal	1.0		
	c) Low	0.4 – 0.8		

Table 2 – Example 2 for load factors $\gamma_{E,u}$ and $\gamma_{E,s}$
and representative value k_E

Limit state	Degree of importance	$\gamma_{E,u}$ or $\gamma_{E,s}$	$k_E = k_{E,u} = k_{E,s}$	Return period for k_E
Ultimate	a) High	3.0 – 4.0	0.2	100 years
	b) Normal	2.0		
	c) Low	0.8 – 1.6		
Serviceability	a) High	0.6 – 1.2		
	b) Normal	0.4		
	c) Low	0.16 – 0.32		

Normalized design response spectrum

The normalized design response spectrum can be interpreted as an acceleration spectrum normalized by the maximum ground acceleration for design purpose. It may be of the form as illustrated in Figure 1. In the figure, k_R is the ordinate of the normalized design response spectrum, and k_{Ro} is a factor dependent on the soil profile and the characteristics of the structure, e.g. the damping of the structure. For a structure with a damping ratio of 0.05 resting on average quality soil, k_{Ro} may be taken as 2 to 3. T is the fundamental natural period of the structure, T_c and T'_c are the corner periods related to the soil condition, and η is an exponent that can vary from 1/3 to 1. T'_c may be taken as 1/5 to 1/2 of T_c .

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.

For structures with a fundamental natural period shorter than T'_c , it is recommended to use $k_R = k_{Ro}$ as indicated by the dotted line in Figure 1, because of the uncertainties in ground motion characteristics and the unconservative estimation of structural factor k_D in this range. For determining forces at longer periods, it is recommended that a lower limit be considered as indicated by the dashed line in Figure 1. The value of this level may be taken as 1/3 to 1/5 of k_{Ro}.

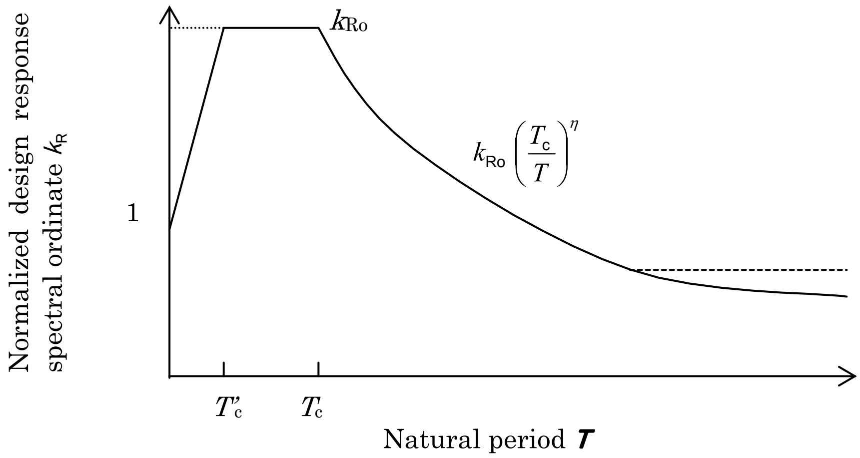


Figure 1 - Normalized design response spectrum

Seismic force distribution factor

The seismic force distribution factor $k_{F,i}$, which is identical to the coefficient of seismic force distribution $\phi_{,i}$ described in the original ISO 3010, can be determined by

$$k_{F,i} = \frac{F_{G,i}\ h_i^{\nu}}{\sum_{j=1}^{n} F_{G,j}\ h_j^{\nu}} \qquad (5)$$

where,
$F_{G,i}$ is the gravity load of the structure at the i th level,
h_i is the height above the base to the i th level,
n is the number of levels above the base.

The exponent ν may be taken as follows:

- $\nu = 0$ for very low buildings (up to two-story buildings), or structures for which $T \leq 0.2$ s,
- $\nu = 0$ to 1 for low-rise buildings (three to five-story buildings), or structures for which 0.2 s < $T \leq 0.5$ s,
- $\nu = 1$ to 2 for intermediate buildings, or structures for which 0.5 s < $T \leq 1.5$ s,
- $\nu = 2$ for high-rise buildings (higher than 50 meters or more than fifteen-story buildings), or structures for which $T > 1.5$ s.

Seismic force distribution factor for high-rise buildings

Since Equation (5) does not give an appropriate seismic force distribution for high-rise buildings, even if the exponent ν becomes 2 (compare dash-dotted curves and dotted curves in Figure 2a-c). A modified seismic distribution factor was introduced in the revised ISO 3010.

The seismic force distribution factor $k_{F,i}$ for high-rise buildings can be determined by

$$k_{F,n} = \rho \qquad (6)$$

$$k_{F,i} = (1-\rho)\frac{F_{G,i}\ h_i}{\sum_{j=1}^{n} F_{G,j}\ h_j} \tag{7}$$

where, ρ is the factor to give a concentrated force at the top and is approximately equal to 0.1.

The seismic force distribution factor $k_{F,i}$ given by Equation (5) is shown in Figure 2a), as the solid line for $\nu = 0$, as the dashed curve for $\nu = 1$, and as the dash-dotted curve for $\nu = 2$. Seismic shear distribution factor $k_{V,i}$ and seismic shear $V_{E,i}$ normalized by the base shear, calculated from $k_{F,i}$, are shown in Figure 2b) and Figure 2c), respectively. The dotted curves in Figure 2a-c) show the distribution for the shear type structure subjected to white noise excitation given by Equation (8) where k_1 =0 and k_2=1.

Seismic shear distribution factor

In the case of more complicated buildings such as buildings with uneven weight distribution, Equations (6) and (7) do not always give an appropriate seismic force distribution factor. For example, a concentrated force at the top is not practical for buildings with setbacks. Therefore, the revised ISO 3010 introduced the new concept of the seismic shear distribution factor $k_{V,i}$ in addition to the conventional seismic force distribution factor $k_{F,i}$. The factor $k_{V,i}$ is interpreted as the shear factor of the i th level normalized by the base shear factor.

The seismic shear distribution factor $k_{V,i}$ can be determined by

$$k_{V,i} = 1 + k_1(1-\alpha_i) + k_2\left(\frac{1}{\sqrt{\alpha_i}} - 1\right) \tag{8}$$

where, k_1 and k_2 are factors from 0 to 1 and determined mainly by the height or the fundamental natural period of the structure, and α_i is the normalized weight which is given by

$$\alpha_i = \frac{\sum_{j=i}^{n} F_{G,j}}{\sum_{j=1}^{n} F_{G,j}} \tag{9}$$

The normalized weight is used instead of the height of levels above the base, because the normalized weight is more convenient and rational to express the distribution of seismic force parameters. The ordinate in Figure 2a-c) is the normalized weight.

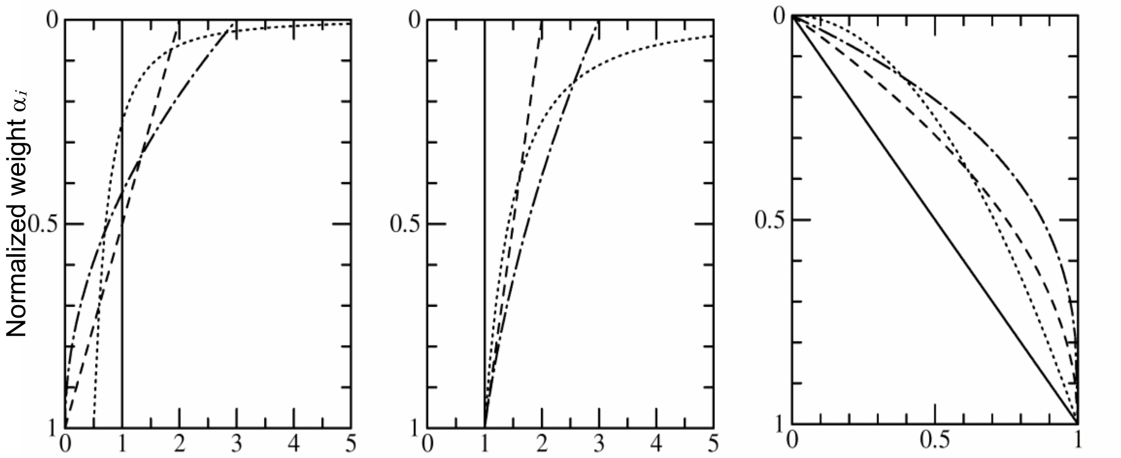
The seismic shear distribution factor $k_{V,i}$ given by Equation (8) is shown as the solid line in Figure 2b) for $k_1 = 0$ and $k_2 = 0$ (uniform distribution of seismic forces), as the dashed curve for $k_1 = 1$ and $k_2 = 0$ (inverted triangular distribution of seismic forces), and as the dotted curve for $k_1 = 0$ and $k_2 = 1$ (seismic force distribution for shear type structures subjected to white noise excitation). Seismic force parameters $k_{F,i}$ and $V_{E,i}$ calculated from $k_{V,i}$ are shown in Figure 2a) and Figure 2c), respectively. The dash-dotted curves in Figure 2a-c) correspond to the distribution given by Equation(5) with parameter $\nu = 2$.

The advantage of this seismic shear distribution factor $k_{V,i}$ is that, with appropriate k_1 and k_2, this equation can provide more appropriate seismic shear distribution for a wide variety of structures from very low to high-rise buildings.

The factors k_1 and k_2 for Equation (8) may be taken as follows:

- $k_1 \cong 0$ and $k_2 \cong 0$ for very low buildings,
- $k_1 \cong 1$ and $k_2 \cong 0$ for low-rise buildings,

- $k_1 \cong 0.5$ and $k_2 \cong 0.5$ for intermediate buildings,
- $k_1 \cong 0$ and $k_2 \cong 1$ for high-rise buildings.



a) Seismic force distribution factor $k_{F,i}$ b) Seismic shear distribution factor $k_{V,i}$ c) Normalized seismic shear force $V_{E,i}$

Figure 2 - Distribution of seismic force parameters

Figure 2c) shows the normalized distribution of seismic shear $V_{E,i}$ corresponding to the seismic force distribution factor $k_{F,i}$ in Figure 2a) and the seismic shear distribution factor $k_{V,i}$ in Figure 2b). The line types are the same in all figures. The relationship among seismic force parameters $k_{F,i}$, $k_{V,i}$ and $V_{E,i}$ can be well understood by comparing these four line types. This comparison becomes possible because of the introduction of the normalized weight in Equation (9).

It is of interest that $k_{F,i}$ and $k_{V,i}$ for structures subjected to white noise excitation (dotted curves) become infinitely large at α_i=0. However, $V_{E,i}$ is zero at this level and gradually increases as α_i increases. Because of this feature of Equation (8), it is no longer necessary to apply a concentrated force at the top as provided by Equation (6) for high-rise buildings.

Since the deformation caused by the earthquake ground motions concentrates at the level which has less stiffness. For buildings with structural irregularities, however, $k_{F,i}$ and $k_{V,i}$ should be adjusted to take such behavior into account.

Other amendments

The revised ISO 3010 has two new annexes. The outline of various response control systems including seismic isolation (base isolation) are described in Annex I. Since the effectiveness of the response control system depends on the type of structure, soil and ground motion characteristics and the system itself. Appropriate dynamic analysis is required to evaluate the usefulness of the control system installed.

"Para-seismic" influences to the structure are described in Annex J. Some of these influences can be estimated by using equations described in clause 8 with appropriate variables.

CONCLUSIONS

The second edition of "ISO 3010 Bases for design of structures - Seismic actions on structures" was published in December 2001. The basic concept of the standard remains the same as the first edition. However, it incorporates some new information to evaluate seismic actions more accurately for high-rise buildings and buildings with structural irregularities. Also some detailed information for the determination of seismic actions was incorporated. The differences of the structure of these two versions are summarized in Table 3. The revised ISO 3010 is expected to be used as a raw material for new national regulations or as a guideline for revising existing national regulations. ISO standards are subject to periodic review, usually every five years. ISO 3010 is to be reviewed in 2006.

Table 3 – Comparision of structure of ISO 3010

Clauses	First edition (1988)		Second edition (2001)	
Scope	1		1	In low seismic hazard region, structural integrity design may be used.
Normative reference	2	ISO 2394	2	ISO 2394
Terms and definitions	-		3	New clause
Symbols and abbreviations	-		4	New clause
Bases for design	3	Earthquake-resistant design	5	*Seismic* design
Principles of design	4		6	"Response control system" and "Foundations" are amended in 6.6 and 6.7.
Principles of evaluating seismic actions	5		7	"Spatial variation of earthquake ground motions" is amended in 7.3.e.
Equivalent static analysis	6		8	"Lateral seismic shear force" $V_{E,s,i}$ and $V_{E,u,i}$ are introduced.
Dynamic analysis	7	7.2 a) the response spectrum analyses. 7.2 b) the time history	9	9.2 a) the response spectrum analysis *for linear or equivalent linear system; or* 9.2 b) the time history analyses *for linear*
Para-seismic	-		10	New clause
Annex	A.1 Importance factor A.2 Parameters on ductility A.3 Dynamic coefficient A.4 Seismic force distribution A.5 Seismic action components A.6 Torsional moments A.7 Dynamic response A.8 Damping ratio		A.1 Load factors related to the reliability of the structure A.2 Seismic hazard zoning factor A.3 Representative values of earthquake ground motion intensity B. Structural factor C. Normalized design response spectrum D. Seismic force and seismic shear distribution E. Components of seismic action F. Torsional moments G. Dynamic response H. Damping ratio I. Response control system J. Para-seismic influences	

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