2C09
Design for seismic and climate change

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European Erasmus Mundus Master Course
Sustainable Constructions
under Natural Hazards and Catastrophic Events
520121-1-2011-1-CZ-ERA MUNDUS-EMMC

List of Lectures

1. Earthquake-Resistant Design of Structures I
2. Earthquake-Resistant Design of Structures II
3. Seismic Design of Steel Structures

Earthquake-Resistant Design of Structures II

1. Eurocode 8
2. General rules
3. Seismic actions
4. Design of buildings

Earthquake-Resistant Design of Structures II

1. Eurocode 8
2. General rules
3. Seismic actions
4. Design of buildings

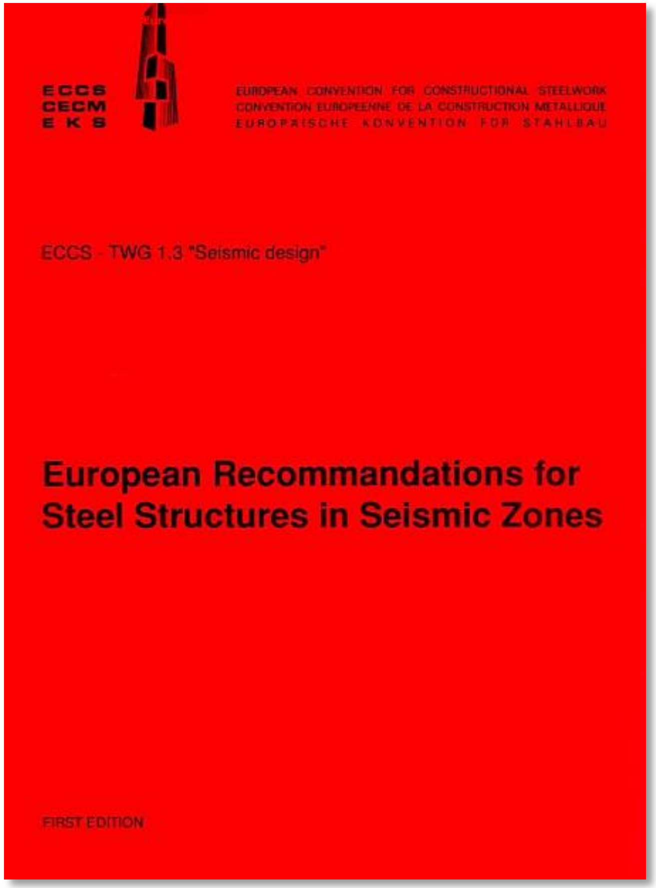
Eurocode 8

Genesis of EU seismic codes

The development of seismic design provisions for steel structures is ongoing for over thirty years in the framework of ECCS.

- First activities started in 1980’s

- First EU seismic code:
  ECCS code 1991
  European for Recommendations
  for Steel Structures in Seismic Zones.



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EUROCODES
BUILDING THE FUTURE

Eurocode 8

Design of structures for earthquake resistance.

Part 1. General rules, seismic actions and rules for buildings

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1998-1

December 2004

ICS 91.120.25

Supersedes ENV 1998-1-1:1994, ENV 1998-1-2:1994, ENV 1998-1-3:1995

English version

Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

Eurocode 8: Calcul des structures pour leur résistance aux séismes - Partie 1: Règles générales, actions sismiques et règles pour les bâtiments

Eurocode 8: Auslegung von Bauwerken gegen Erdbeben - Teil 1: Grundlagen, Erdbebeneinwirkungen und Regeln für Hochbauten

This European Standard was approved by CEN on 23 April 2004.

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1. GENERAL

1.1 SCOPE

THE **main goals** in the **DESIGN OF SEISMIC RESISTANT STRUCTURES**

In the event of earthquakes:

- Human lives are protected
- Damage is limited
- Structures important for civil protection remain operational

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1. GENERAL

1.2 NORMATIVE REFERENCES

EN 1990 - Eurocode 0 - Basis of structural design

EN 1992-1-1 Eurocode 2 – Design of concrete structures
Part 1-1: General –Common rules for building and civil engineering structures

EN 1993-1-1 Eurocode 3 – Design of steel structures
Part 1-1: General – General Rules

EN 1994-1-1 Eurocode 4 – Design of composite steel and concrete structures
Part 1-1: General – Common rules and rules for buildings

EN 1995-1-1 Eurocode 5 – Design of timber structures
Part 1-1: General – Common rules and rules for buildings

EN 1996-1-1 Eurocode 6 – Design of masonry structures
Part 1-1: General –Rules for reinforced and unreinforced masonry

EN 1997-1 Eurocode 7 - Geotechnical design
Part 1: General rules

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1. GENERAL

1.3 ASSUMPTIONS

1.4 DISTINCTION BETWEEN PRINCIPLES AND APPLICATION RULES

1.5 TERMS AND DEFINITIONS

1.6 SYMBOLS

1.7 S.I. UNITS

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LIMIT STATES

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.1 FUNDAMENTAL REQUIREMENTS

Two different limit states are defined for the achievement of fundamental requirements

Damage Limitation Requirement	No Collapse Requirement
Damage Limitation State (DLS)	**Ultimate Limit State (ULS)**
• For ordinary structures this requirement should be met for a seismic action with 10 % probability of exceedance in 10 years • Return Period= 95 years • Performance level required: • Withstand the design seismic action without damage • Avoid limitations of use and high repair costs	• For ordinary structures this requirement should be met for a reference seismic action with 10 % probability of exceedance in 50 years Return Period= 475 years • Performance level required: • Withstand the design seismic action without local or global collapse • Retain structural integrity and residual load bearing capacity after the event

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Ultimate Limit State (ULS)

It shall be verified the resistance and energy dissipation capacity.

In operational terms the balance between resistance and energy-dissipation capacity is characterised by the values of the behaviour factor q and the associated ductility classification.

As a limiting case, for the design of structures classified as low-dissipative, no account is taken of any hysteretic energy dissipation and the behaviour factor may not be taken greater than the value of 1,5 considered to account for overstrengths.

For steel or composite steel concrete buildings, this limiting value of the q factor may be taken as being between 1,5 and 2.

For dissipative structures the behaviour factor is taken as being greater than these limiting values accounting for the hysteretic energy dissipation that mainly occurs in specifically designed zones, called dissipative zones or critical regions.

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Ultimate Limit State (ULS)

The structure as a whole shall be checked to ensure that it is stable under the design seismic action. Both overturning and sliding stability shall be taken into account.

It shall be verified that both the foundation elements and the foundation soil are able to resist the action effects resulting from the response of the superstructure without substantial permanent deformations.

In the analysis the possible influence of second order effects on the values of the action effects shall be taken into account.

It shall be verified that under the design seismic action the behaviour of nonstructural elements does not present risks to persons and does not have a detrimental effect on the response of the structural elements.

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Damage Limitation State (DLS)

An adequate degree of reliability against unacceptable damage shall be ensured by satisfying the deformation limits or other relevant limits defined in the relevant Parts of EN 1998.

In structures important for civil protection the structural system shall be verified to ensure that it has sufficient resistance and stiffness to maintain the function of the vital services in the facilities for a seismic event associated with an appropriate return period.

Limit States: PBD

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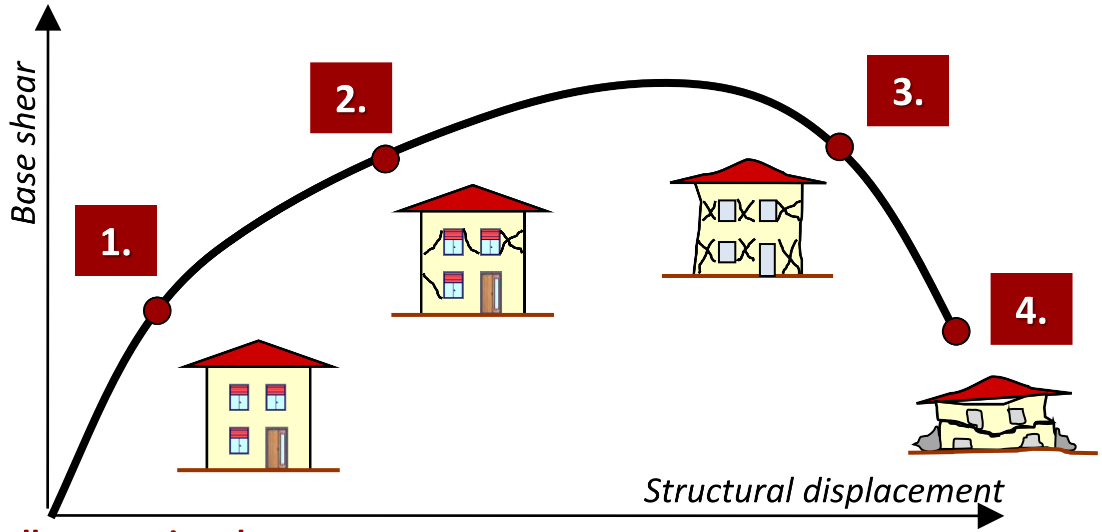
Performance Based Design



1. Fully operational:
Continuous service. Negligible structural and nonstructural damage.

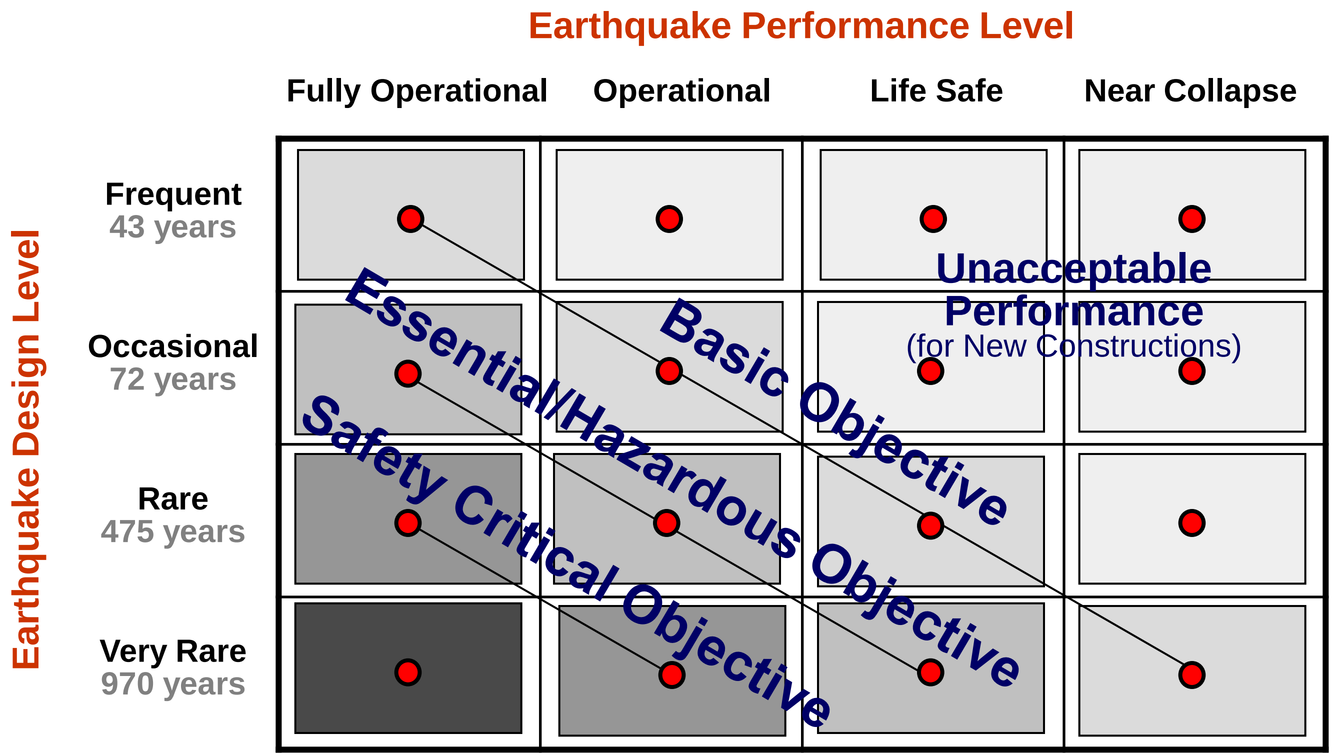
2. Operational:
Most operations and functions can resume immediately. Structure safe for occupancy. Essential operations protected, non-essential operations disrupted. Repair required to restore some non-essential services. Damage is light.

3. Life Safety:
Damage is moderate, but structure remains stable. Selected building systems, features, or contents may be protected from damage. Life safety is generally protected. Building may be evacuated following earthquake. Repair possible, but may be economically impractical.

4. Near Collapse:
Damage severe, but structural collapse prevented. Nonstructural elements may fall. Repair generally not possible

Limit States: PBD

Performance Based Design



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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Design Principles

• Structures should have **simple** and **regular** shapes both in plan and elevation. If necessary, the structure can be subdivided by joints into dynamically independent units;

• In order to ensure an **overall dissipative and ductile behaviour**, brittle failure or the premature formation of unstable mechanisms shall be avoided. The capacity design procedure shall be applied, to obtain the hierarchy of resistance and plastic mechanism;

•The **detailing of critical regions** or elements shall be such as to maintain the capacity to transmit the forces and to dissipate energy;

• The analysis shall be based on an **adequate structural model**, which, when necessary, shall take into account the influence of soil deformability and of nonstructural elements and other aspects, such as the presence of adjacent structures.

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Foundations

- The **stiffness of the foundations** shall be adequate for transmitting the actions received from the superstructure to the ground as uniformly as possible;

- With the exception of bridges, only one **foundation type** should in general be used for the same structure, unless the latter consists of dynamically independent units.

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2. PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.2 COMPLIANCE CRITERIA

Quality system plan

• The design documents shall indicate the sizes, the details and the characteristics of the **materials** of the structural elements. If appropriate, the design documents shall also include the characteristics of **special devices** to be used and the distances between structural and non-structural elements;

• **Elements of special structural importance** requiring special checking during construction shall be identified on the design drawings. In this case the checking methods to be used shall also be specified;

• In regions of **high seismicity** and in structures of **special importance**, formal quality system plans, covering design, construction, and use, additional to the control procedures prescribed in the other relevant Eurocodes, should be used.

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EN1998-1 to be applied in combination with other Eurocodes

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3.1 GROUND CONDITIONS

- Appropriate investigations shall be carried out in order to identify the **ground types**;

- The construction site and the nature of the supporting ground should normally be free from risks of ground rupture, slope instability and permanent settlements caused by l**iquefaction or densification** in the event of an earthquake;

- Depending on the importance class of the structure and the particular conditions of the project, ground investigations and/or geological studies should be performed to determine the seismic action;

- The conditions under which ground investigations additional to those necessary for design for non-seismic actions may be omitted and default ground classification may be used may be specified in the National Annex.

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3. GROUND CONDITIONS AND SEISMIC ACTION

3.1 GROUND CONDITIONS

Identification of ground types

Ground types A, B, C, D, and E, described by the stratigraphic profiles, may be used to account for the influence of local ground conditions on the seismic action.

This may also be done by additionally taking into account the influence of deep geology on the seismic action.

The ground classification scheme accounting for deep geology for use in a country may be specified in its National Annex, including the values of the parameters S, TB, TC and TD defining the horizontal and vertical elastic response spectra.

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3.1 GROUND CONDITIONS

Identification of ground types

Ground type	Description of stratigraphic profile
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.

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3.2 SEISMIC ACTION

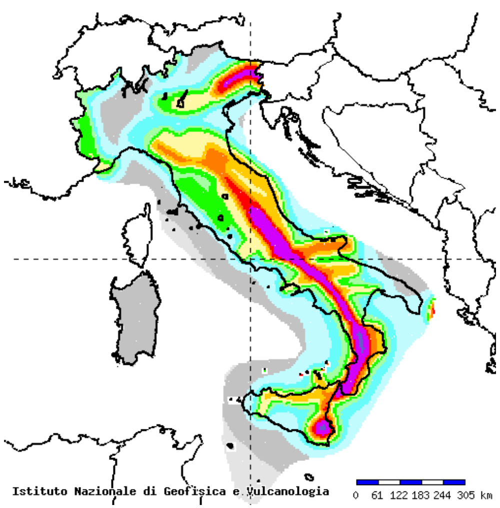
Seismic zones

National territories shall be subdivided by the National Authorities into **seismic zones**, depending on the local hazard.

• The hazard is described by **a_{gR} ,** the value of the reference peak ground acceleration on type A, derived from zonation maps in National Annex;

• The parameter **a_{gR}** corresponds to the reference return period **T_{NCR}** of the seismic action for the no-collapse requirement;

• The parameter **a_{gR}** is modified by the **Importance Factor γ_I** to become the design ground acceleration (on type A ground) $a_g = a_{gR} \cdot \gamma_I$



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3. GROUND CONDITIONS AND SEISMIC ACTION

3.2 SEISMIC ACTION

Importance factors

Target **reliability of requirement** depending on consequences of failure:

- Classify the structures into importance classes
- Assign a higher or lower return periodto the design seismic action

In operational terms multiply the reference seismic action by the importance factor γ_I

Importance class	Buildings	γ_I
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0,8
II	Ordinary buildings, not belonging in the other categories.	1,0
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.	1,2
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1,4

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3.2 SEISMIC ACTION

Basic representation of the seismic action

The earthquake motion at a given point on the surface is represented by an **elastic ground acceleration response spectrum**, called "ELASTIC RESPONSE SPECTRUM".

- Common shape for the ULS and DLS verifications
- Two orthogonal independent horizontal components
- Vertical spectrum shape different from the horizontal spectrum (common for all ground types)
- Possible use of more than one spectral shape (to model different seismo-genetic mechanisms)

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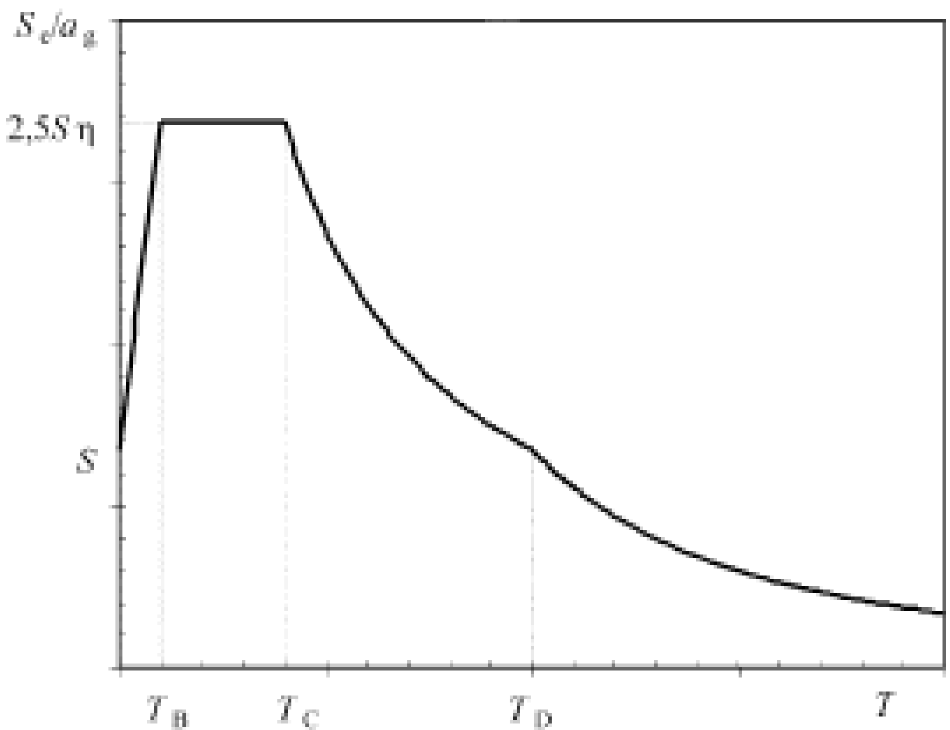
ELASTIC RESPONSE SPECTRUM



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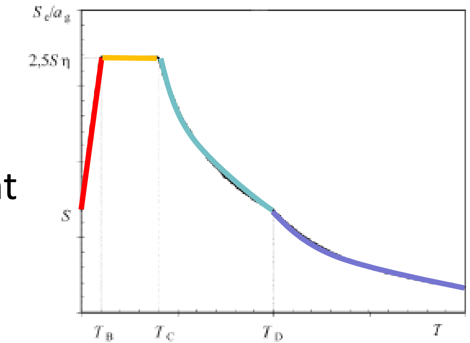

The **ELASTIC RESPONSE SPECTRUM** is divided in 4 different branches defined by the following expressions:

- $0 \leq T \leq T_B$ $\quad S_e(T) = a_g \,.\, S \,.\, (1+T/T_B \,.\, (\eta \,.\, 2{,}5 - 1))$
- $T_B \leq T \leq T_C$ $\quad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5$
- $T_C \leq T \leq T_D$ $\quad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5\,(T_C/T)$
- $T_D \leq T \leq 4\text{ s}$ $\quad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5\,(T_C \,.\, T_D/T^2)$

$S_e(T)$	**elastic** response spectrum
a_g	**design ground acceleration** on type A ground
T_B T_C T_D	**corner periods** in the spectrum (NDPs)
S	**soil factor** (NDP)
η	**damping** correction factor (η = 1 for 5% damping)

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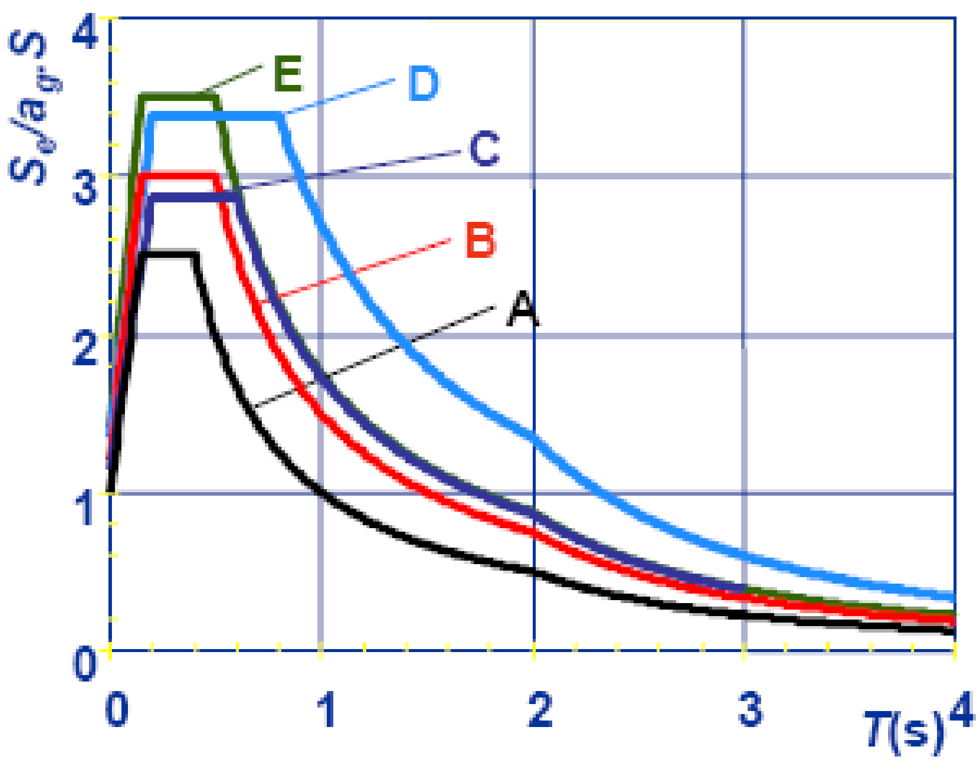
The **ELASTIC RESPONSE SPECTRUM** is different for the different grounds types:



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VERTICAL **ELASTIC RESPONSE SPECTRUM**

The vertical component of the seismic action shall be represented by an elastic response spectrum, Sve(T), derived using expressions :

$$0 \le T \le T_B : S_{ve}(T) = a_{vg} \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 3{,}0 - 1)\right]$$

$$T_B \le T \le T_C : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3{,}0$$

$$T_C \le T \le T_D : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3{,}0 \left[\frac{T_C}{T}\right]$$

$$T_D \le T \le 4\mathrm{s} : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3{,}0 \left[\frac{T_C . T_D}{T^2}\right]$$

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3.2 SEISMIC ACTION

DESIGN RESPONSE SPECTRUM

The capacity of structural systems to resist seismic actions in the non-linear range generally permits their design for resistance to seismic forces smaller than those corresponding to a linear elastic response.

The capacity of the structure to dissipate energy is taken into account by performing an elastic analysis based on a reduced response spectrum, called ''**DESIGN SPECTRUM**''

This reduction is accomplished by introducing the **behaviour factor "q".**

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BEHAVIOUR FACTOR "q"

The **behaviour factor q** is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure.

The **values** of the behaviour factor q, which also account for the influence of the viscous damping being different from 5%, are given for various **materials** and **structural systems** according to the relevant **ductility classes**.

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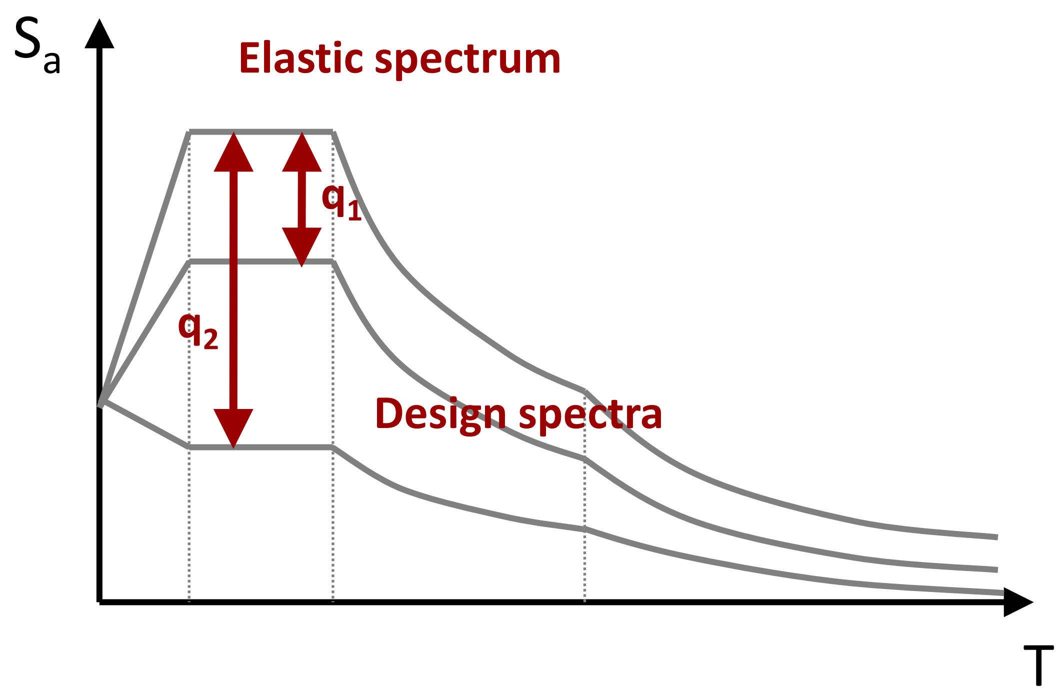
BEHAVIOUR FACTOR “q”

The behaviour factor takes into account the dissipative capacity of the structural systems. Hence, it varies with the structural typology.



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3. GROUND CONDITIONS AND SEISMIC ACTION

3.2 SEISMIC ACTION

COMBINATIONS OF SEISMIC ACTIONS WITH OTHER ACTIONS

The design value *Ed* of the effects of actions in the seismic design situation shall be determined in accordance with EN 1990:2002

$$E_d = E\left\{G_{k,j} \, ; P \, ; A_{Ed} \, ; \psi_{2,i} Q_{k,i}\right\} \quad j \geq 1 \, ; i \geq 1$$

The inertial effects of the design seismic action shall be evaluated by taking into account the presence of the masses associated with all gravity loads appearing in the following combination of actions:

$$\Sigma G_{k,j} \text{ "+" } \Sigma \psi_{E,i} \cdot Q_{k,i}$$

$\Psi_{E,i}$ is the combination coefficient for variable action *i*, it takes into account the likelihood of the loads $Q_{k,i}$ not being present over the entire structure during the earthquake. These coefficients may also account for a reduced participation of masses in the motion of the structure due to the non-rigid connection between them.

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3.2 SEISMIC ACTION

COMBINATIONS OF SEISMIC ACTIONS WITH OTHER ACTIONS

The combination coefficients ΨEi for the calculation of the effects of the seismic actions shall be computed from the following expression:

$$\psi_{Ei} = \varphi \cdot \psi_{2i}$$

Table 4.2: Values of φ for calculating ψ_{Ei}

Type of variable action	Storey	φ
Categories A-C*	Roof	1,0
	Storeys with correlated occupancies	0,8
	Independently occupied storeys	0,5
Categories D-F* and Archives		1,0

* Categories as defined in EN 1991-1-1:2002.

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4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

BASIC PRINCIPLES OF CONCEPTUAL DESIGN

In seismic regions the aspect of seismic hazard shall be taken into account in the early stages of the **conceptual design** of the building.
The guiding principles governing this conceptual design are:

- structural simplicity;
- uniformity, symmetry and redundancy;
- bi-directional resistance and stiffness;
- torsional resistance and stiffness;
- diaphragmatic behaviour at storey level;
- adequate foundation.

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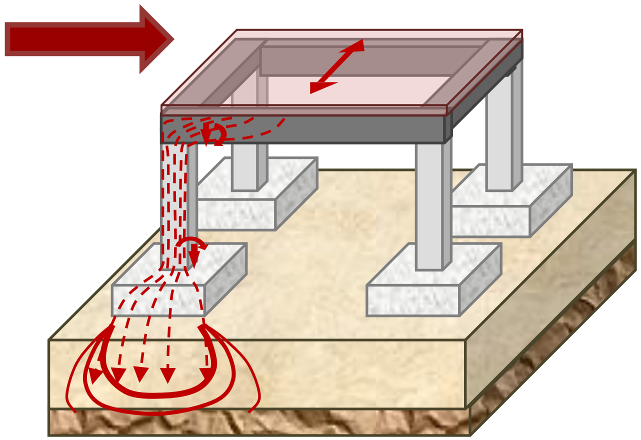
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Structural simplicity

Structural simplicity, characterised by the existence of **clear and direct paths for the transmission of the seismic forces**, is an important objective to be pursued, since the modelling, analysis, dimensioning, detailing and construction of simple structures are subject to much less uncertainty and thus the prediction of its seismic behaviour is much more reliable.



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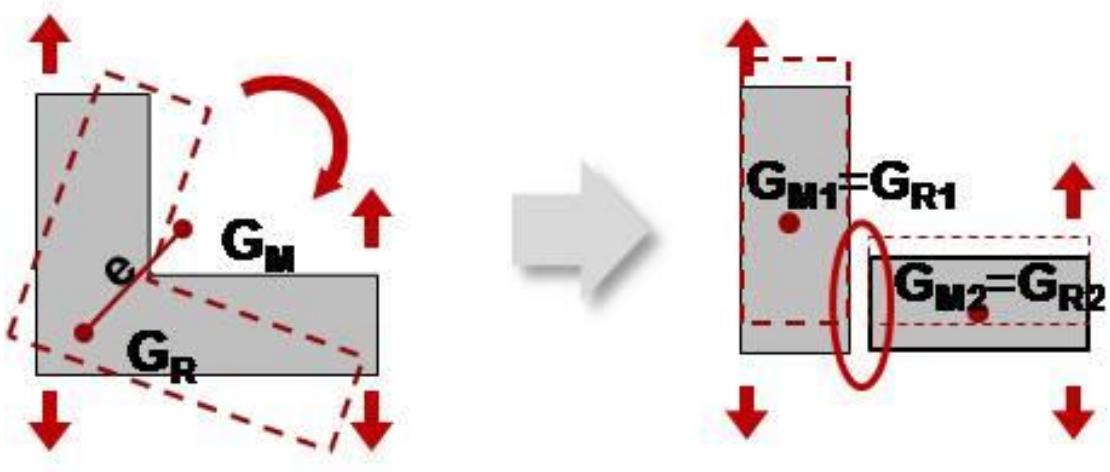
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Uniformity

Uniformity **in plan** is characterized by an even distribution of the structural elements which allows **short and direct transmission of the inertia forces** created in the distributed masses of the building.

If necessary, uniformity may be realized by subdividing the entire building by seismic joints into dynamically independent units provided that these joints are designed against pounding of the individual units.



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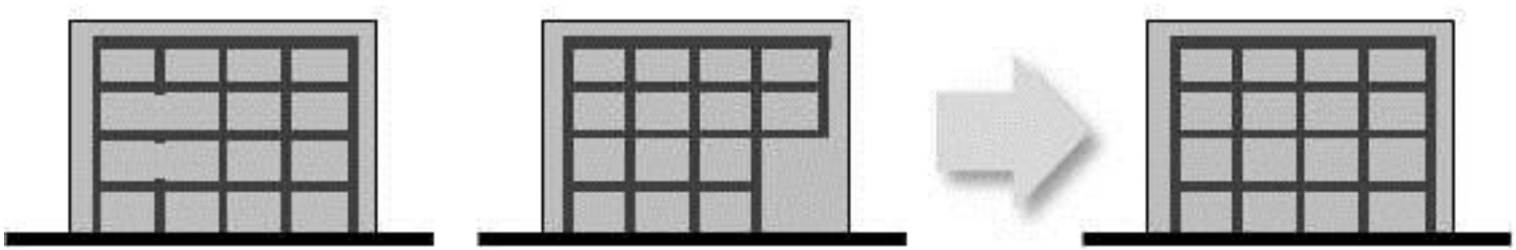
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Uniformity

Uniformity in the development of the structure **along the height** of the building is also important, since it tends to eliminate the occurrence of sensitive zones where **concentrations of stress** or large ductility demands might prematurely cause collapse.



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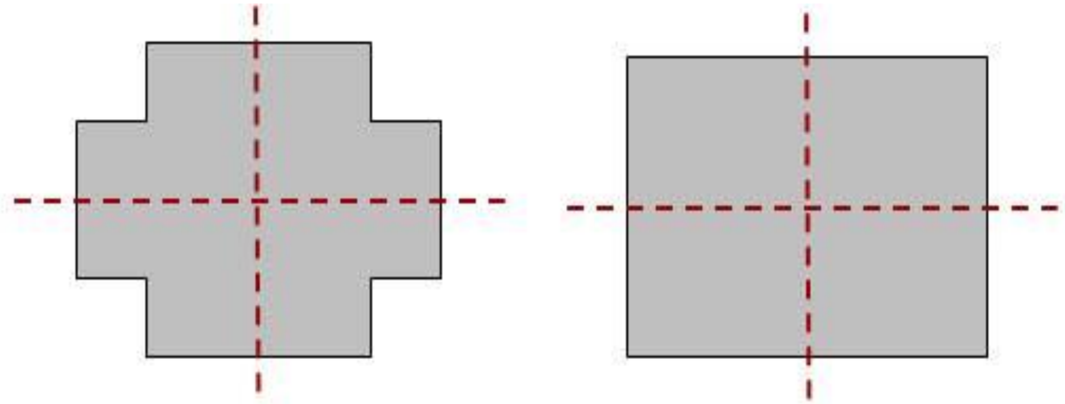
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Symmetry

If the building configuration is symmetrical or quasi-symmetrical, a symmetrical layout of structural elements, which should be well-distributed in-plan, is appropriate for the achievement of uniformity.

A close relationship between the distribution of masses and the distribution of resistance and stiffness eliminates large eccentricities between mass and stiffness.



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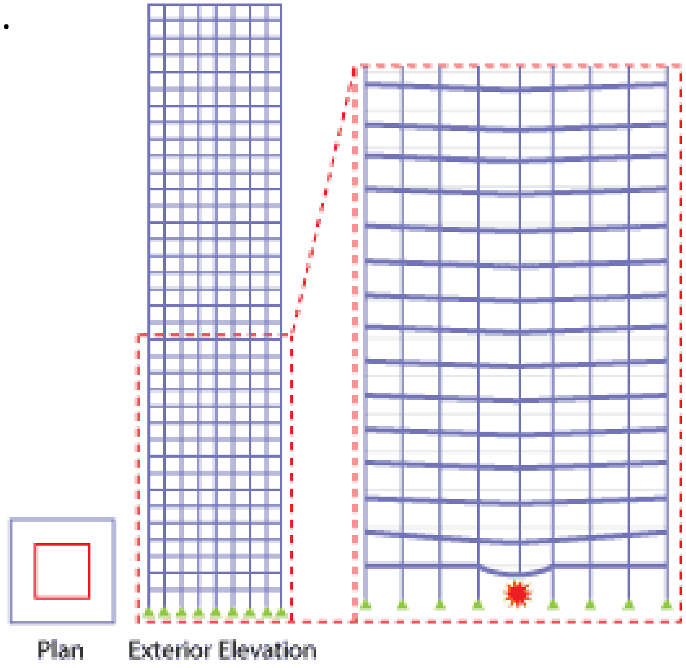
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Redundancy

The use of evenly distributed structural elements increases **redundancy** and allows a more favourable **redistribution of action effects** and widespread energy dissipation across the entire structure.



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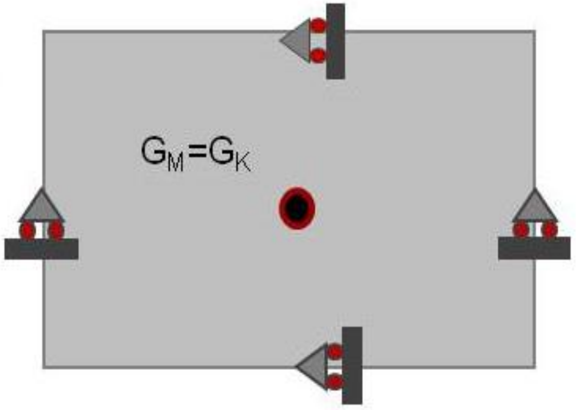
4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Bi-directional resistance and stiffness

Building structures shall be able to resist horizontal actions in any direction, so the structural elements should be arranged in an orthogonal inplan structural pattern, ensuring **similar resistance and stiffness characteristics in both main directions**.

The choice of the stiffness characteristics of the structure, while attempting to minimize the effects of the seismic action (taking into account its specific features at the site) should also limit the development of excessive displacements that might lead to either instabilities due to second order effects or excessive damages.



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4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Torsional resistance and stiffness

Besides lateral resistance and stiffness, building structures should possess adequate **torsional resistance** and stiffness in order to limit the development of torsional motions which tend to stress the different structural elements in a non-uniform way .

In this respect, arrangements in which the main elements resisting the seismic action are distributed close to the periphery of the building present clear advantages.

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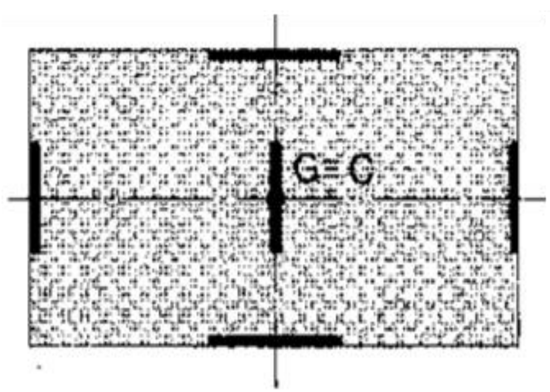

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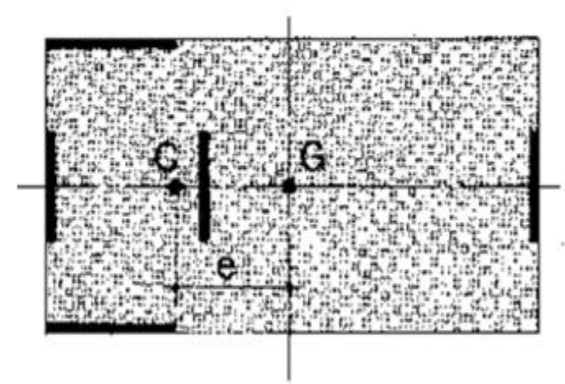

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4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Diaphragmatic behaviour at storey level

Floors act as **horizontal diaphragms** that collect and transmit the inertia forces to the vertical structural systems and ensure that those systems act together in resisting the horizontal seismic action.

Floor systems should be provided with **in-plane stiffness** and **resistance** and with effective connection to the vertical structural systems. Particular care should be taken in cases of non-compact or very elongated in-plan shapes and in cases of large floor openings, especially if the latter are located in the vicinity of the main vertical structural elements.

Diaphragms should have sufficient in-plane stiffness for the distribution of horizontal inertia forces to the vertical structural systems in accordance with the assumptions of the analysis, particularly when there are significant changes in stiffness or offsets of vertical elements above and below the diaphragm.

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4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Adequate foundation

With regard to the seismic action, the design and construction of the foundations and of the connection to the superstructure shall ensure that the whole building is subjected to a uniform seismic excitation.

For structures composed of a discrete number of structural walls, likely to differ in width and stiffness, a rigid, box-type or cellular foundation, containing a foundation slab and a cover slab should generally be chosen.

For buildings with individual foundation elements (footings or piles), the use of a foundation slab or tie-beams between these elements in both main directions is recommended, subject to the criteria and rules of EN 1998-5:2004, 5.4.1.2.

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4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Secondary seismic members

A certain number of structural members may be designated as "**secondary**" seismic members, not forming part of the seismic action resisting system of the building. The strength and stiffness of these elements against seismic actions shall be neglected.

Nonetheless these members and their connections shall be designed and detailed to maintain support of gravity loading when subjected to the displacements caused by the most unfavourable seismic design condition. Due allowance of 2nd order effects (P-Δ effects) should be made in the design of these members.

The total contribution to lateral stiffness of all secondary seismic members should not exceed 15% of that of all primary seismic members.

The designation of some structural elements as secondary seismic members is not allowed to change the classification of the structure from non-regular to regular.

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4. DESIGN OF BUILDINGS

4.2 CHARACTERISTICS OF EARTHQUAKE RESISTANT BUILDINGS

Primary seismic members

All structural members not designated as being secondary seismic members are taken as being **primary** seismic members.

These elements are taken as being part of the lateral force resisting system, should be modeled in the structural analysis in accordance with 4.3.1 and designed and detailed for earthquake resistance in accordance with the rules of Sections 5 to 9.

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4. DESIGN OF BUILDINGS

4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

General

For the purpose of seismic design, building structures are categorized into being **regular** or **non-regular.**

This distinction has implications for the following aspects of the seismic design:

• the structural model, which can be either a simplified planar model or a spatial model ;

• the method of analysis, which can be either a simplified response spectrum analysis (lateral force procedure) or a modal one;

• the value of the behaviour factor q, which shall be decreased for buildings non-regular in elevation.

Separate consideration is given to the regularity characteristics of the building in plan and in elevation.

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4. DESIGN OF BUILDINGS

4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

General

Table 4.1: Consequences of structural regularity on seismic analysis and design

Regularity		Allowed Simplification		Behaviour factor
Plan	Elevation	Model	Linear-elastic Analysis	(for linear analysis)
Yes	Yes	Planar	Lateral force[a]	Reference value
Yes	No	Planar	Modal	Decreased value
No	Yes	Spatial[b]	Lateral force[a]	Reference value
No	No	Spatial	Modal	Decreased value

[a] If the condition of **4.3.3.2.1(2)**a) is also met.
[b] Under the specific conditions given in **4.3.3.1(8)** a separate planar model may be used in each horizontal direction, in accordance with **4.3.3.1(8)**.

For non-regular in elevation buildings the decreased values of the behaviour factor are given by the reference values multiplied by 0,8.

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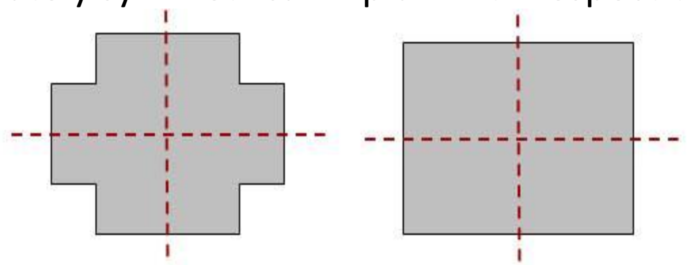
4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

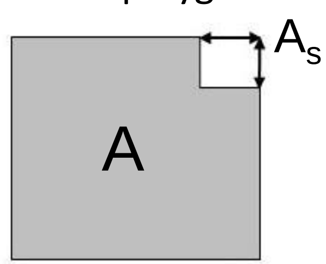
Criteria for regularity in plan

• With respect to the lateral stiffness and mass distribution, the building structure shall be approximately symmetrical in plan with respect to two orthogonal axes.



• The plan configuration shall be compact: each floor shall be delimited by a polygonal convex line.

If in plan set-backs (re-entrant corners or edge recesses) exist, the area between the outline of the floor and a convex polygonal line enveloping the floor does not exceed 5 % of the floor area.



$$A_s \leq 0.05\,A$$

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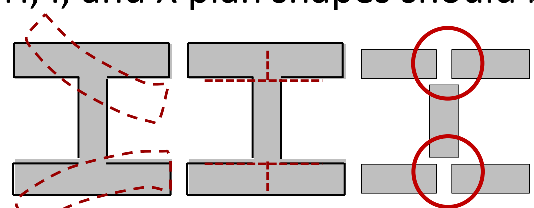
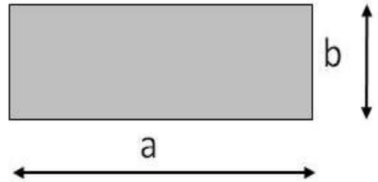
4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

Criteria for regularity in plan

• The in-plan stiffness of the floors shall be sufficiently large in comparison with the lateral stiffness of the vertical structural elements, so that the deformation of the floor shall have a small effect on the distribution of the forces among the vertical structural elements.
In this respect, the L, C, H, I, and X plan shapes should be carefully examined.



• The slenderness λ = Lmax/Lmin of the building in plan shall be not higher than 4, where Lmax and Lmin are respectively the larger and smaller in plan dimension of t the building, measured in orthogonal directions.



$$\frac{a}{b} \leq 4$$

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4. DESIGN OF BUILDINGS

4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

Criteria for regularity in plan

• At each level and for each direction of analysis, the structural eccentricity e_o and the torsional radius *r* shall be (for the y direction of analysis):

$$e_{ox} \leq 0{,}30 \cdot r_x \qquad\qquad r_x \geq l_s$$

e_{xo} is the distance between the centre of stiffness and the centre of mass, measured along the x direction, which is normal to the direction of analysis considered;
r_x is the torsional radius, square root of the ratio of the torsional stiffness to the lateral stiffness in the y direction;
l_s is the radius of gyration of the floor mass in plan (square root of the ratio of the polar moment of inertia of the floor mass in plan with respect to the centre of mass of the floor to the floor mass).

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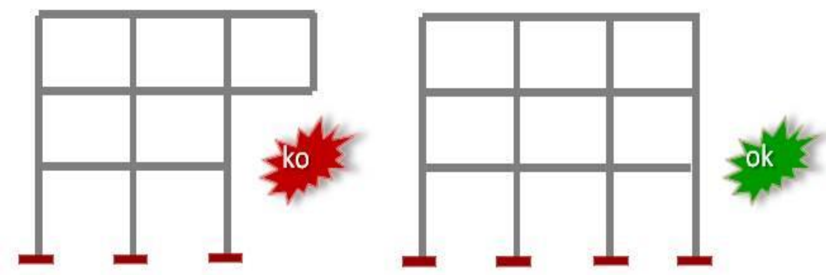
Criteria for regularity in elevation

• All lateral load resisting systems, such as cores, structural walls, or frames, shall run without interruption from their foundations to the top of the building or, if setbacks at different heights are present, to the top of the relevant zone of the building.



• Both the lateral stiffness and the mass of the individual storeys shall remain constant or reduce gradually, without abrupt changes, from the base to the top of a particular building.

•In framed buildings the ratio of the actual storey resistance to the resistance required by the analysis should not vary disproportionately between adjacent storeys.

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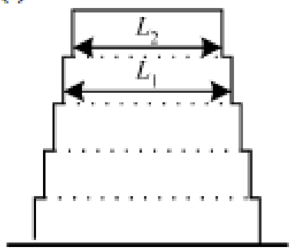
4. DESIGN OF BUILDINGS

4.2.3 CRITERIA FOR STRUCTURAL REGULARITY

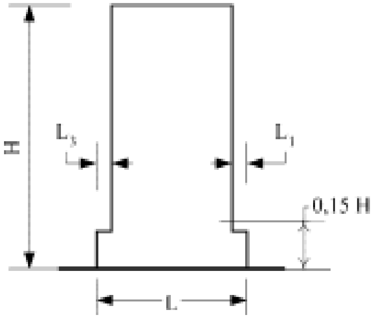
Criteria for regularity in elevation

(a)

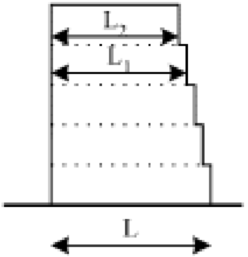


• When setbacks are present, the following additional conditions apply:

a) for gradual setbacks preserving axial symmetry, the setback at any floor shall be not greater than 20 % of the previous plan dimension in the direction of the setback ;



b) for a single setback within the lower 15 % of the total height of the main structural system, the setback shall be not greater than 50 % of the previous plan dimension.



c) if the setbacks do not preserve symmetry, in each face the sum of the setbacks at all storeys shall be not greater than 30 % of the plan dimension at the ground floor above the foundation or above the top of a rigid basement, and the individual setbacks shall be not greater than 10 % of the previous plan dimension

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4. DESIGN OF BUILDINGS

4.3 STRUCTURAL ANALYSIS

Modeling

• The model of the building shall adequately represent the distribution of stiffness and mass in it so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. In the case of non-linear analysis, the model shall also adequately represent the distribution of strength.

• The model should also account for the contribution of joint regions to the deformability of the building (the end zones in beams or columns of frame type structures). Non-structural elements, which may influence the response of the primary seismic structure, should also be accounted for.

4. DESIGN OF BUILDINGS

4.3 STRUCTURAL ANALYSIS

Modeling

• In general the structure may be considered to consist of a number of vertical and lateral load resisting systems, connected by horizontal diaphragms.

• When the floor diaphragms of the building may be taken as being rigid in their planes, the masses and the moments of inertia of each floor may be lumped at the centre of gravity.

• For buildings conforming to the criteria for regularity in plan the analysis may be performed using two planar models, one for each main direction.

4. DESIGN OF BUILDINGS

4.3 STRUCTURAL ANALYSIS

Modeling

• In concrete buildings, in composite steel-concrete buildings and in masonry buildings the stiffness of the load bearing elements should, in general, be evaluated taking into account the effect of cracking. Such stiffness should correspond to the initiation of yielding of the reinforcement.

• Unless a more accurate analysis of the cracked elements is performed, the elastic flexural and shear stiffness properties of concrete and masonry elements may be taken to be equal to one-half of the corresponding stiffness of the uncracked elements.

• Infill walls which contribute significantly to the lateral stiffness and resistance of the building should be taken into account.

• The deformability of the foundation shall be taken into account in the model, whenever it may have an adverse overall influence on the structural response.

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4.3 STRUCTURAL ANALYSIS

Accidental torsional effects

In order to account for uncertainties in the location of masses and in the spatial variation of the seismic motion, the calculated centre of mass at each floor *i* shall be considered as being displaced from its nominal location in each direction by an accidental eccentricity

$$e_{\mathrm{ai}} = \pm 0{,}05 \cdot L_{\mathrm{i}}$$

e_{ai} is the accidental eccentricity of storey mass i from its nominal location, applied in the same direction at all floors;

L_i is the floor-dimension perpendicular to the direction of the seismic action.

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4.3 STRUCTURAL ANALYSIS

Methods of analysis

The effects of the actions included in the seismic design situation may be determined on the basis of the **linear-elastic behaviour of the structure**.

The reference method for determining the seismic effects shall be the **modal response spectrum analysis**, using a **linear-elastic model of the structure** and the **design spectrum.** Depending on the structural characteristics of the building one of the following two types of linear-elastic analysis may be used:

a) the "lateral force method of analysis" for buildings meeting the criteria for regularity

b) the "modal response spectrum analysis", which is applicable to all types of buildings

As an alternative to a linear method, a non-linear method may also be used, such as:

c) non-linear static (pushover) analysis

d) non-linear time history (dynamic) analysis

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Resistance condition

The following relation shall be satisfied for all structural elements including connections and the relevant non-structural elements:

$$E_{\mathrm{d}} \leq R_{\mathrm{d}}$$

Ed is the design value of the action effect, due to the seismic design situation;
Rd is the corresponding design resistance of the element, calculated in accordance with the rules specific to the material used.

Second-order effects (P-Δ effects) need not be taken into account if the following condition is fulfilled in all storeys:

$$\theta = \frac{P_{\mathrm{tot}} \cdot d_{\mathrm{r}}}{V_{\mathrm{tot}} \cdot h} \leq 0{,}10$$

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Global and local ductility condition

It shall be verified that both the structural elements and the structure as a whole possess adequate ductility, taking into account the expected exploitation of ductility, which depends on the selected system and the behaviour factor.

In frame buildings with two or more storeys, the following condition should be satisfied at all joints of primary or secondary seismic beams with primary seismic columns:

$$\sum M_{\mathrm{Rc}} \geq 1{,}3 \sum M_{\mathrm{Rb}}$$

M_{Rc} is the design value of the moments of resistance of the columns framing the joint.

M_{Rb} is the design value of the moments of resistance of the beams framing the joint.

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Equilibrium condition

• The building structure shall be stable in the seismic design situation , including overturning or sliding.

• In special cases, the equilibrium may be verified by means of energy balance methods, or by geometrically non-linear methods with the seismic action.

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Resistance of horizontal diaphragms

• Diaphragms and bracings in horizontal planes shall be able to transmit, with sufficient overstrength, the effects of the design seismic action to the lateral load-resisting systems to which they are connected.

• This requirement is considered to be satisfied if for the relevant resistance verifications the seismic action effects in the diaphragm obtained from the analysis are multiplied by an overstrength factor γ_d greater than 1,0.

• The values to be ascribed to γ_d for use in a country may be found in its National Annex. The recommended value for brittle failure modes, such as in shear in concrete diaphragms is 1.3, and for ductile failure modes is 1,1.

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Resistance of foundations

• The action effects for the foundation elements shall be derived on the basis of capacity design considerations accounting for the development of possible overstrength, but they need not exceed the action effects corresponding to the response of the structure under the seismic design situation inherent to the assumption of an elastic behaviour (q = 1,0).

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Resistance of foundations

- For foundations of individual vertical elements (walls or columns), the design values of the action effects E_{Fd} on the foundations are derived as follows:

$$E_{\mathrm{Fd}} = E_{\mathrm{F,G}} + \gamma_{\mathrm{Rd}} \Omega E_{\mathrm{F,E}}$$

γ_{Rd} is the overstrength factor, taken as being equal to 1,0 for $q \leq 3$, or as being equal to 1,2 otherwise;

$E_{F,G}$ is the action effect due to the non-seismic actions in the seismic combination;

$E_{F,E}$ is the action effect from the analysis of the design seismic action;

Ω is the value of $(R_{di}/E_{di}) \leq q$ of the dissipative zone or element i of the structure which has the highest influence on the effect E_F under consideration;

R_{di} is the design resistance of the zone or element i;

E_{di} is the design value of the action effect in the seismic design situation.

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4.4 SAFETY VERIFICATIONS

Ultimate limit state

Seismic joint condition

Buildings shall be protected from earthquake-induced pounding from adjacent structures or between structurally independent units of the same building:

• for structurally independent units, that do not belong to the same property, if the distance from the property line to the potential points of impact is not less than the maximum horizontal displacement of the building at the corresponding level,

• for structurally independent units, belonging to the same property, if the distance between them is not less than the SRSS of the maximum horizontal displacements of the two buildings or units at the corresponding level.

If the floor elevations of the building or independent unit under design are the same as those of the adjacent building or unit, the above referred minimum distance may be reduced by a factor of 0,7.

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4.4 SAFETY VERIFICATIONS

Damage limitation

Limitation of interstorey drift

The following limits shall be observed:

a) for buildings having non-structural elements of brittle materials attached to the structure:

$$d_r \nu \leq 0{,}005\, h\,;$$

b) for buildings having ductile non-structural elements:

$$d_r \nu \leq 0{,}0075\, h\,;$$

c) for buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements:

$$d_r \nu \leq 0{,}010\, h$$

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Future of EU seismic codes

European Convention for Constructional Steelwork

Technical Committee n.13 "Seismic Design" - TC13

TC13 MISSION

TC13 is devoted to the topic of seismic design with the mission to promote the use of steel in seismic regions.

TC13 CHAIRMAN

Raffaele Landolfo

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TC 13 OBJECTIVES

Short term objectives

• to provide a comprehensive state-of-the-art on the ongoing research activities in the field of seismic design of steel structures
• to analyze the current status of European and worldwide codification
• to identify further research priorities and critical issues in the technical specifications
• to explore, in cooperation with TMB, the possibility to participate in European R&D projects dealing with the use of steel structures in seismic areas as partner devoted to the result dissemination

Long term objectives

• to prepare background documents for the new generation of Eurocodes, namely EC8
• to develop specific tools for designers and constructors

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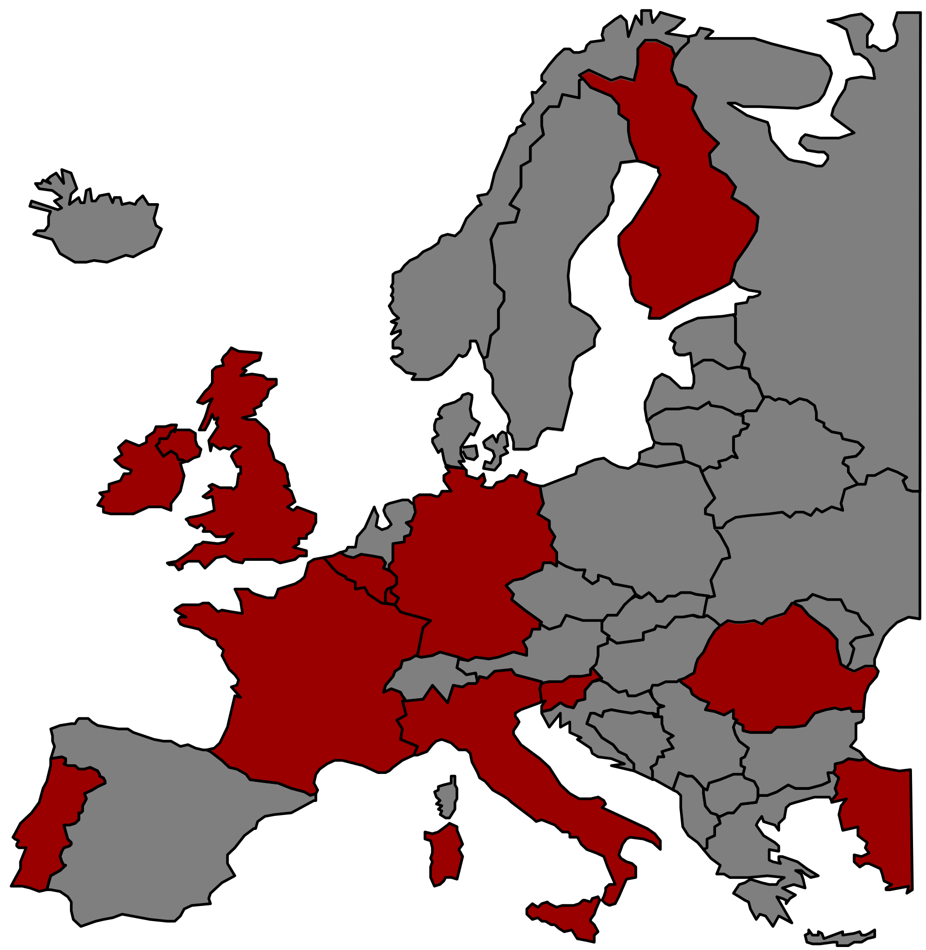
TC 13 MEMBERSHIP

EUROPEAN MEMBERS	
BELGIUM	2 F.M.
FINLAND	1 C.M.
FRANCE	2 F.M.+1 C.M.
GERMANY	1 F.M.+1 C.M.
ITALY	4 F.M.
LUXEMBOURG	1 F.M. + 1 C.M.
PORTUGAL	2 FM + 1C.M.
ROMANIA	3 F.M.+1C.M.
SLOVENIA	1 C.M.
TURKEY	2 F.M. + 1 C.M.
UNITED KINGDOM	2 F.M.
EXTRA EUROPEAN MEMBERS	
USA	1 F.M.+ 1 C.M.
JAPAN	1 F.M.



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TC13 PUBLICATIONS

Issues in EN 1998-1: 2004 needing clarifications and/or developments

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ECCS EUROCODE DESIGN MANUAL EC8-1

DESIGN OF STEEL STRUCTURES FOR BUILDINGS IN SEISMIC AREAS

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