

Chapter 8 — Extracts from Eurocode 8: Design of structures for earthquake resistance

The extracts in this chapter are taken from EN 1998-1:2004, *Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings*.

EN 1998, *Eurocode 8: Design of structures for earthquake resistance*, comprises the following Parts (the items in bold are covered in this chapter).

EN 1998-1, General rules, seismic actions and rules for buildings

EN 1998-2, Bridges

EN 1998-3, Strengthening and repair of buildings

EN 1998-4, Silos, tanks and pipelines

EN 1998-5, Foundations, retaining structures and geotechnical aspects

EN 1998-6, Towers, masts and chimneys

This chapter aims to introduce the principles of seismic design to EN 1998-1 in conjunction with the other non-seismic Eurocodes such as EN 1992 and EN 1993. Therefore Sections 1 to 4, for the seismic actions and performance requirements for buildings, are extensively covered whereas Sections 5 to 9, for material-specific detailed design, are drastically summarized.

The full list of contents of EN 1998-1 follows, and is given for reference purposes. (Bold items are covered in this chapter.)

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1 General

1.1 Scope

1.1.1 Scope of EN 1998

(1) P EN 1998 applies to the design and construction of buildings and civil engineering works in seismic regions. Its purpose is to ensure that in the event of earthquakes:

- human lives are protected;
- damage is limited; and
- structures important for civil protection remain operational.

(2) P Special structures, such as nuclear power plants, offshore structures and large dams, are beyond the scope of EN 1998.

(3) P EN 1998 contains only those provisions that, in addition to the provisions of the other relevant Eurocodes, must be observed for the design of structures in seismic regions. It complements in this respect the other Eurocodes.

1.1.2 Scope of EN 1998-1

Part 1 specifies general rules, performance requirements, details of the seismic hazard and action, analysis procedures and general concepts that are applicable not only for the seismic design of buildings but also for all the other Parts of EN 1998. Part 1 also includes specific rules for the detailed design of concrete, steel, composite steel-concrete, timber, masonry and base isolated structures.

(1) EN 1998-1 applies to the design of buildings and civil engineering works in seismic regions. It is subdivided in 10 Sections, some of which are specifically devoted to the design of buildings.

(2) Section 2 of EN 1998-1 contains the basic performance requirements and compliance criteria applicable to buildings and civil engineering works in seismic regions.

(3) Section 3 of EN 1998-1 gives the rules for the representation of seismic actions and for their combination with other actions. Certain types of structures, dealt with in EN 1998-2 to EN 1998-6, need complementing rules that are given in those Parts.

(4) Section 4 of EN 1998-1 contains general design rules relevant specifically to buildings.

(5) Sections 5 to 9 of EN 1998-1 contain specific rules for various structural materials and elements, relevant specifically to buildings as follows:

Section 5: Specific rules for concrete buildings;

Section 6: Specific rules for steel buildings;

Section 7: Specific rules for composite steel-concrete buildings;

Section 8: Specific rules for timber buildings;

Section 9: Specific rules for masonry buildings.

(6) Section 10 contains the fundamental requirements and other relevant aspects of design and safety related to base isolation of structures and specifically to base isolation of buildings.

NOTE Specific rules for isolation of bridges are developed in EN 1998-2.

(7) Annex C contains additional elements related to the seismic design of slab reinforcement in steel-concrete composite beams at beam-column joints in moment resisting frames.

NOTE Informative Annex A and informative Annex B contain additional elements related to the elastic displacement response spectrum and to target displacement for pushover analysis.

The scopes of the other Parts of Eurocode 8 are summarized as follows:

Scope of EN 1998-2

Within the framework of the general requirements set forth in Part 1, this Part contains design principles, criteria and application rules applicable to the seismic design of bridges. Part 2 primarily covers the seismic design of bridges in which the horizontal seismic actions are mainly resisted at either the abutments or through bending of the piers i.e. bridges composed of vertical or near vertical pier systems supporting the traffic deck superstructure. It can also be applied to special bridges such as arch, portal or tied, and cable-stayed bridges. Suspension, moveable or extreme configuration bridges are not fully covered. Timber and floating bridges are not included. Finally, a clause on seismic isolation is included.

Scope of EN 1998-3

This Part covers the repair and strengthening of buildings and, where applicable, monuments, considering commonly used structural materials (concrete, steel, masonry and timber). Part 3 provides criteria for the evaluation of the seismic performance of existing individual structures, the approach in selecting necessary corrective measures and criteria for the design of the repair/strengthening measures (i.e. conception, structural analysis including intervention measures, final dimensioning of structural parts and their connections to existing structural elements).

Scope of EN 1998-4

This Part provides basic rules for the seismic design of the structural aspects of integrated facilities composed of pipeline systems and of storage tanks of different types and destinations, as well as for independent items, such as single water towers serving a specific purpose or groups of silos enclosing granular materials, etc. Part 4 may also be used as a basis for evaluating the amount of strengthening needed by existing facilities to bring them up to present standards. In applying this Part, there is no restriction on the size, structural type and other functional characteristics of these structures and for some types of tanks and silos, detailed methods of assessment and verification rules are included.

Scope of EN 1998-5

This Part establishes the requirements, criteria and rules for siting and foundation soil. Part 5 covers the design of different foundation systems, earth retaining structures and soil-structure interaction under seismic actions. As such it complements the rules of Eurocode 7, which do not cover the special requirements of seismic design. The provisions in Part 5 generally apply to buildings (Part 1), bridges (Part 2), silos, tanks and pipelines (Part 4) and towers, masts and chimneys (Part 6).

Scope of EN 1998-6

This Part establishes requirements, criteria and rules for the seismic design of tall slender structures: towers, including bell-towers and intake towers, masts, industrial chimneys and lighthouses. Different provisions apply to reinforced concrete and to steel structures. Requirements are set up for non-structural elements, such as the lining material of an industrial chimney. Part 6 is not applicable to cooling towers, offshore structures and masonry chimneys.

1.5 Terms and definitions

1.5.1 Terms common to all Eurocodes

(1) The terms and definitions given in EN 1990:2002, 1.5 apply.

1.5.2 Further terms used in EN 1998

(1) The following terms are used in EN 1998 with the following meanings:

1.5.2.1

behaviour factor

factor used for design purposes to reduce the forces obtained from a linear analysis, in order to account for the non-linear response of a structure, associated with the material, the structural system and the design procedures

1.5.2.2

capacity design method

design method in which elements of the structural system are chosen and suitably designed and detailed for energy dissipation under severe deformations while all other structural elements are provided with sufficient strength so that the chosen means of energy dissipation can be maintained

1.5.2.3

dissipative structure

structure which is able to dissipate energy by means of ductile hysteretic behaviour and/or by other mechanisms

1.5.2.4

dissipative zones

predetermined parts of a dissipative structure where the dissipative capabilities are mainly located

NOTE 1 These are also called critical regions.

1.5.2.5

dynamically independent unit

structure or part of a structure which is directly subjected to the ground motion and whose response is not affected by the response of adjacent units or structures

1.5.2.6

importance factor

factor that relates to the consequences of a structural failure

1.5.2.7

non-dissipative structure

structure designed for a particular seismic design situation without taking into account the non-linear material behaviour

1.5.2.8

non-structural element

architectural, mechanical or electrical element, system and component which, whether due to lack of strength or to the way it is connected to the structure, is not considered in the seismic design as a load carrying element

1.5.2.9

primary seismic members

members considered as part of the structural system that resists the seismic action, modelled in the analysis for the seismic design situation and fully designed and detailed for earthquake resistance in accordance with the rules of EN 1998

1.5.2.10

secondary seismic members

members which are not considered as part of the seismic action resisting system and whose strength and stiffness against seismic actions is neglected

NOTE 2 They are not required to comply with all the rules of EN 1998, but are designed and detailed to maintain support of gravity loads when subjected to the displacements caused by the seismic design situation.

1.6 Symbols

1.6.1 General

(1) The symbols indicated in EN 1990:2002, 1.6 apply. For the material-dependent symbols, as well as for symbols not specifically related to earthquakes, the provisions of the relevant Eurocodes apply.

(2) Further symbols, used in connection with seismic actions, are defined in the text where they occur, for ease of use. However, in addition, the most frequently occurring symbols used in EN 1998-1 are listed and defined in 1.6.2 and 1.6.3.

1.6.2 Further symbols used in Sections 2 and 3 of EN 1998-1

A_{Ed}	Design value of seismic action ($= \gamma_I \cdot A_{Ek}$)
A_{Ek}	Characteristic value of the seismic action for the reference return period
E_d	Design value of action effects
N_{SPT}	Blow-count of Standard Penetration Test
P_{NCR}	Reference probability of exceedance in 50 years of the reference seismic action for the no-collapse requirement
Q	Variable action
$S_e(T)$	Elastic horizontal ground acceleration response spectrum also called "elastic response spectrum". At $T=0$, the spectral acceleration given by this spectrum equals the design ground acceleration on type A ground multiplied by the soil factor S
$S_{ve}(T)$	Elastic vertical ground acceleration response spectrum
$S_{De}(T)$	Elastic displacement response spectrum
$S_d(T)$	Design spectrum (for elastic analysis). At $T=0$, the spectral acceleration given by this spectrum equals the design ground acceleration on type A ground multiplied by the soil factor S
S	Soil factor
T	Vibration period of a linear single degree of freedom system
T_s	Duration of the stationary part of the seismic motion
T_{NCR}	Reference return period of the reference seismic action for the no-collapse requirement
a_{gR}	Reference peak ground acceleration on type A ground
a_g	Design ground acceleration on type A ground
a_{vg}	Design ground acceleration in the vertical direction
c_u	Undrained shear strength of soil
d_g	Design ground displacement
g	Acceleration of gravity
q	Behaviour factor
$v_{s,30}$	Average value of propagation velocity of S waves in the upper 30 m of the soil profile at shear strain of 10^{-5} or less
γ_I	Importance factor
η	Damping correction factor
ζ	Viscous damping ratio (in per cent)
$\psi_{2,i}$	Combination coefficient for the quasi-permanent value of a variable action i
$\psi_{E,i}$	Combination coefficient for a variable action i , to be used when determining the effects of the design seismic action

1.6.3 Further symbols used in Section 4 of EN 1998-1

E_E	Effect of the seismic action
E_{Edx}, E_{Edy}	Design values of the action effects due to the horizontal components (x and y) of the seismic action
E_{Edz}	Design value of the action effects due to the vertical component of the seismic action
F_i	Horizontal seismic force at storey i
F_a	Horizontal seismic force acting on a non-structural element (appendage)
F_b	Base shear force
H	Building height from the foundation or from the top of a rigid basement
L_{max}, L_{min}	Larger and smaller in plan dimension of the building measured in orthogonal directions
R_d	Design value of resistance
S_a	Seismic coefficient of non-structural elements

T_1	Fundamental period of vibration of a building
T_a	Fundamental period of vibration of a non-structural element (appendage)
W_a	Weight of a non-structural element (appendage)
d	Displacement
d_r	Design interstorey drift
e_a	Accidental eccentricity of the mass of one storey from its nominal location
h	Interstorey height
m_i	Mass of storey i
n	Number of storeys above the foundation or the top of a rigid basement
q_a	Behaviour factor of a non-structural element (appendage)
q_d	Displacement behaviour factor
s_i	Displacement of mass m_i in the fundamental mode shape of a building
z_i	Height of mass m_i above the level of application of the seismic action
α	Ratio of the design ground acceleration to the acceleration of gravity
γ_a	Importance factor of a non-structural element (appendage)
γ_d	Overstrength factor for diaphragms
θ	Interstorey drift sensitivity coefficient

Further terms and symbols for Sections 5 to 9 are defined in the text where they occur, for ease of use.

2 Performance requirements and compliance criteria

2.1 Fundamental requirements

(1) P Structures in seismic regions shall be designed and constructed in such a way, that the following requirements are met, each with an adequate degree of reliability.

- No-collapse requirement.

The structure shall be designed and constructed to withstand the design seismic action defined in Section 3 without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after the seismic events. The design seismic action is expressed in terms of: a) the reference seismic action associated with a reference probability of exceedance, P_{NCR} , in 50 years or a reference return period, T_{NCR} , and b) the importance factor γ_I (see EN 1990:2002 and (2) P and (3) P of this clause) to take into account reliability differentiation.

NOTE 1 The values to be ascribed to P_{NCR} or to T_{NCR} for use in a country may be found in its National Annex of this document. The recommended values are $P_{NCR} = 10\%$ and $T_{NCR} = 475$ years.

- Damage limitation requirement.

The structure shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself. The seismic action to be taken into account for the damage limitation requirement has a probability of exceedance, P_{DLR} , in 10 years and a return period, T_{DLR} . In the absence of more precise information, the reduction factor applied on the design seismic action in accordance with 4.4.3.2 may be used to obtain the seismic action for the verification of the damage limitation requirement.

NOTE 3 The values to be ascribed to P_{DLR} or to T_{DLR} for use in a country may be found in its National Annex of this document. The recommended values are $P_{DLR} = 10\%$ and $T_{DLR} = 95$ years.

(2) P Target reliabilities for the no-collapse requirement and for the damage limitation requirement are established by the National Authorities for different types of buildings or civil engineering works on the basis of the consequences of failure.

The following text has been adapted from 2.1(3)P and 2.1(4) respectively.

(3) P Reliability differentiation is implemented by classifying structures into different importance classes. To each importance class an importance factor γ_I is assigned.

(4) The different levels of reliability are obtained by multiplying the reference seismic action or, when using linear analysis, the corresponding action effects by this importance factor.

2.2 Compliance criteria

2.2.1 General

(1) P In order to satisfy the fundamental requirements in 2.1 the following limit states shall be checked (see 2.2.2 and 2.2.3):

- ultimate limit states;
- damage limitation states;

Ultimate limit states are those associated with collapse or with other forms of structural failure which might endanger the safety of people.

Damage limitation states are those associated with damage occurrence, corresponding to states beyond which specified service requirements are no longer met.

EN 1998 adopts a one-level design philosophy in which only the ultimate limit states are required to be satisfied explicitly. The damage limitation states are achieved by limiting the overall deformations of the structure.

(2) P In order to limit the uncertainties and to promote a good behaviour of structures under seismic actions more severe than the design seismic action, a number of pertinent specific measures shall also be taken (see 2.2.4).

(3) For well defined categories of structures in cases of low seismicity (see 3.2.1(4)), the fundamental requirements may be satisfied through the application of rules simpler than those given in the relevant parts of EN 1998.

(4) In cases of very low seismicity, the provisions of EN 1998 need not be observed (see 3.2.1(5) and the notes therein for the definition of cases of very low seismicity).

2.2.2 Ultimate limit state

(1) P It shall be verified that the structural system has the resistance and energy-dissipation capacity specified in the relevant Parts of EN 1998.

The following text has been adapted from 2.2.2(2):

(2) The resistance and energy-dissipation capacity to be assigned to the structure are related to the extent to which its non-linear response is to be exploited. In operational terms such balance between resistance and energy-dissipation capacity is characterized by the values of the behaviour factor q and the associated ductility classification, which are given in the relevant Parts of EN 1998. 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, in general, as being greater than the value of 1,5 considered to account for overstrengths. For steel or composite steel-concrete buildings, the 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.

(3) P 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. Specific rules for checking the overturning of structures are given in the relevant Parts of EN 1998.

The following text has been adapted from 2.2.2(4):

(4) P 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.

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

(6) P It shall be verified that under the design seismic action the behaviour of non-structural elements does not present risks to persons and does not have a detrimental effect on the response of the structural elements. For buildings, specific rules are given in 4.3.5 and 4.3.6.

2.2.3 Damage limitation state

(1) P 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.

(2) P 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 seismic events associated with an appropriate return period.

2.2.4 Specific measures

2.2.4.1 Design

(1) To the extent possible, structures should have simple and regular forms both in plan and elevation, (see 4.2.3). If necessary this may be realised by subdividing the structure by joints into dynamically independent units.

(2) P In order to ensure an overall dissipative and ductile behaviour, brittle failure or the premature formation of unstable mechanisms shall be avoided. To this end, where required in the relevant Parts of EN 1998, resort shall be made to the capacity design procedure, which is used to obtain the hierarchy of resistance of the various structural components and failure modes necessary for ensuring a suitable plastic mechanism and for avoiding brittle failure modes.

(3) P Since the seismic performance of a structure is largely dependent on the behaviour of its critical regions or elements, the detailing of the structure in general and of these regions or elements in particular, shall be such as to maintain the capacity to transmit the necessary forces and to dissipate energy under cyclic conditions. To this end, the detailing of connections between structural elements and of regions where non-linear behaviour is foreseeable should receive special care in design.

(4) P The analysis shall be based on an adequate structural model, which, when necessary, shall take into account the influence of soil deformability and of non-structural elements and other aspects, such as the presence of adjacent structures.

2.2.4.2 Foundations

(1) P The stiffness of the foundations shall be adequate for transmitting the actions received from the superstructure to the ground as uniformly as possible.

(2) 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.

3 Ground conditions and seismic action

3.1 Ground conditions

3.1.1 General

(1)P Appropriate investigations shall be carried out in order to identify the ground conditions in accordance with the types given in 3.1.2.

3.1.2 Identification of ground types

(1) Ground types A, B, C, D, and E, described by the stratigraphic profiles and parameters given in Table 3.1 and described hereafter, may be used to account for the influence of local ground conditions on the seismic action. This may also be done by additionally considering the influence of deep geology on the seismic action.

NOTE: 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 , T_B , T_C and T_D defining the horizontal and vertical elastic response spectra in accordance with 3.2.2.2 and 3.2.2.3.

Table 3.1 – Ground types

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	–	–
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.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 – 50	70 – 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
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.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index ($PI > 40$) and high water content	< 100 (indicative)	–	10 – 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

(2) The site shall be classified according to the value of the average shear wave velocity, $v_{s,30}$, if this is available. Otherwise the value of N_{SPT} shall be used.

3.2 Seismic action

3.2.1 Seismic zones

(1) P For the purpose of EN 1998, national territories shall be subdivided by the National Authorities into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant.

(2) For most of the applications of EN 1998, the hazard is described in terms of a single parameter, i.e. the value of the reference peak ground acceleration on type A ground, a_{gR} . Additional parameters required for specific types of structures are given in the relevant Parts of EN 1998.

NOTE The reference peak ground acceleration on type A ground, a_{gR} , for use in a country or parts of a country, may be derived from zonation maps found in its National Annex.

(3) The reference peak ground acceleration, chosen by the National Authorities for each seismic zone, corresponds to the reference return period T_{NCR} of the seismic action for the no-collapse requirement (or equivalently the reference probability of exceedance in 50 years, P_{NCR}) chosen by the National Authorities (see 2.1(1) P). An importance factor γ_I equal to 1,0 is assigned to this reference return period. For return periods other than the reference (see importance classes in 2.1(3) P and (4)), the design ground acceleration on type A ground a_g is equal to a_{gR} times the importance factor γ_I ($a_g = \gamma_I \cdot a_{gR}$). (See Note to 2.1(4)).

(4) In cases of low seismicity, reduced or simplified seismic design procedures for certain types or categories of structures may be used.

NOTE The selection of the categories of structures, ground types and seismic zones in a country for which the provisions of low seismicity apply may be found in its National Annex. It is recommended to consider as low seismicity cases either those in which the design ground acceleration on type A ground, a_g , is not greater than 0,08 g (0,78 m/s²), or those where the product $a_g \cdot S$ is not greater than 0,1 g (0,98 m/s²). The selection of whether the value of a_g , or that of the product $a_g \cdot S$ will be used in a country to define the threshold for low seismicity cases, may be found in its National Annex.

(5) P In cases of very low seismicity, the provisions of EN 1998 need not be observed.

NOTE The selection of the categories of structures, ground types and seismic zones in a country for which the EN 1998 provisions need not be observed (cases of very low seismicity) may be found in its National Annex. It is recommended to consider as very low seismicity cases either those in which the design ground acceleration on type A ground, a_g , is not greater than 0,04 g (0,39 m/s²), or those where the product $a_g \cdot S$ is not greater than 0,05 g (0,49 m/s²). The selection of whether the value of a_g , or that of the product $a_g \cdot S$ will be used in a country to define the threshold for very low seismicity cases, can be found in its National Annex.

3.2.2 Basic representation of the seismic action

3.2.2.1 General

(1) P Within the scope of EN 1998 the earthquake motion at a given point on the surface is represented by an elastic ground acceleration response spectrum, henceforth called an "elastic response spectrum".

(2) The shape of the elastic response spectrum is taken as being the same for the two levels of seismic action introduced in 2.1(1) P and 2.2.1(1) P for the no-collapse requirement (ultimate limit state – design seismic action) and for the damage limitation requirement.

(3) P The horizontal seismic action is described by two orthogonal components considered as being independent and represented by the same response spectrum.

(4) For the three components of the seismic action, one or more alternative shapes of response spectra may be adopted, depending on the seismic sources and the earthquake magnitudes generated from them.

NOTE The selection of the shape of the elastic response spectrum to be used in a country or part of a country may be found in its National Annex.

Recommended shapes are described in the Note of 3.2.2.2 (2) P.

3.2.2.2 Horizontal elastic response spectrum

(1) P For the horizontal components of the seismic action, the elastic response spectrum $S_e(T)$ is defined by the following expressions (see Figure 3.1):

$$0 \leq T \leq T_B : S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2,5 - 1) \right] \quad (3.2)$$

$$T_B \leq T \leq T_C : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \quad (3.3)$$

$$T_C \leq T \leq T_D : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \left[\frac{T_C}{T} \right] \quad (3.4)$$

$$T_D \leq T \leq 4s : S_e(T) = a_g \cdot S \cdot \eta \cdot 2,5 \left[\frac{T_C T_D}{T^2} \right] \quad (3.5)$$

where

- $S_e(T)$ is the elastic response spectrum;
- T is the vibration period of a linear single-degree-of-freedom system;
- a_g is the design ground acceleration on type A ground ($a_g = \gamma_I \cdot a_{gR}$);
- T_B is the lower limit of the period of the constant spectral acceleration branch;
- T_C is the upper limit of the period of the constant spectral acceleration branch;
- T_D is the value defining the beginning of the constant displacement response range of the spectrum;
- S is the soil factor;
- η is the damping correction factor with a reference value of $\eta = 1$ for 5 % viscous damping, see (3) of this clause.

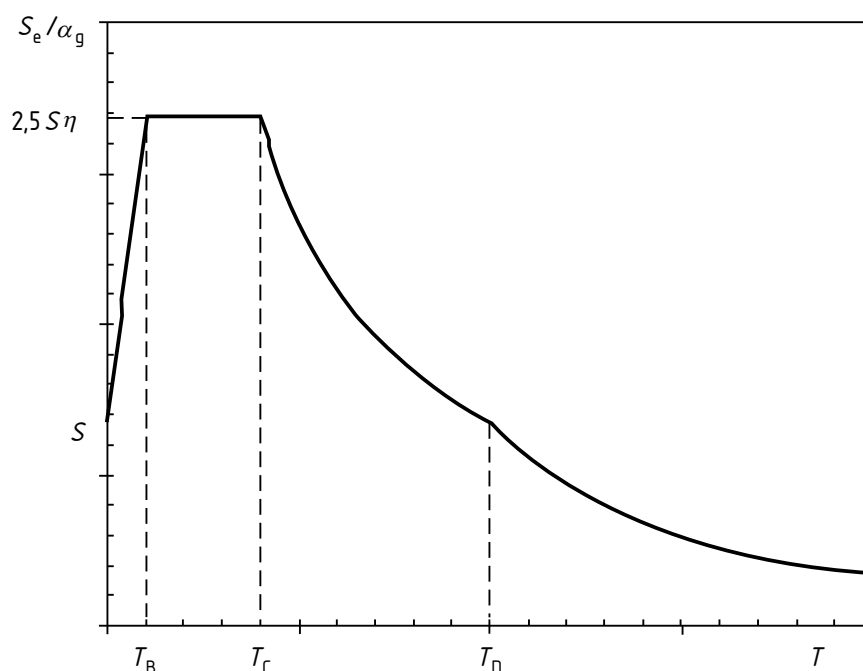


Figure 3.1 — Shape of the elastic response spectrum

(2) P The values of the periods T_B , T_C and T_D and of the soil factor S describing the shape of the elastic response spectrum depend on the ground type.

NOTE The values to be ascribed to T_B , T_C , T_D and S for each ground type and type (shape) of spectrum to be used in a country may be found in its National Annex. If deep geology is not accounted for (see 3.1.2(1)), the recommended choice is the use of two types of spectra: Type 1 and Type 2. If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, M_s , not greater than 5,5, it is recommended that the Type 2 spectrum is adopted. For the five ground types A, B, C, D and E the recommended values of the parameters S , T_B , T_C and T_D are given in Table 3.2 for the Type 1 spectrum and in Table 3.3 for the Type 2 spectrum.

Table 3.2 – Values of the parameters describing the Type 1 elastic response spectrum

Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

Table 3.3 – Values of the parameters describing the recommended Type 2 elastic response spectrum

Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,05	0,25	1,2
B	1,35	0,05	0,25	1,2
C	1,5	0,10	0,25	1,2
D	1,8	0,10	0,30	1,2
E	1,6	0,05	0,25	1,2

(3) The value of the damping correction factor η may be determined by the expression:

$$\eta = \sqrt{10 / (5 + \xi)} \geq 0,55 \quad (3.6)$$

where

ξ is the viscous damping ratio of the structure, expressed as a percentage.

3.2.2.3 Vertical elastic response spectrum

(1) P The vertical component of the seismic action shall be represented by an elastic response spectrum, $S_{ve}(T)$, derived using expressions (3.8)-(3.11).

$$0 \leq T \leq T_B : S_{ve}(T) = a_{vg} \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 3,0 - 1) \right] \quad (3.8)$$

$$T_B \leq T \leq T_C : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \quad (3.9)$$

$$T_C \leq T \leq T_D : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left[\frac{T_C}{T} \right] \quad (3.10)$$

$$T_D \leq T \leq 4s : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left[\frac{T_C \cdot T_D}{T^2} \right] \quad (3.11)$$

NOTE The values to be ascribed to T_B , T_C , T_D and a_{vg} for each type (shape) of vertical spectrum to be used in a country may be found in its National Annex. The recommended choice is the use of two types of vertical spectra: Type 1 and Type 2. As for the spectra defining the horizontal components of the seismic action, if the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, M_s , not greater than 5,5, it is recommended that the Type 2 spectrum is adopted. For the five ground types A, B, C, D and E the recommended values of the parameters describing the vertical spectra are given in Table 3.4. These recommended values do not apply for special ground types S_1 and S_2 .

Table 3.4 – Recommended values of parameters describing the vertical elastic response spectrum

Spectrum	a_{vg}/a_g	T_B (s)	T_C (s)	T_D (s)
Type 1	0,90	0,05	0,15	1,0
Type 2	0,45	0,05	0,15	1,0

3.2.2.4 Design ground displacement

(1) Unless special studies based on the available information indicate otherwise, the value of the design ground displacement d_g may be estimated by means of the following expression:

$$d_g = 0,025 \cdot a_g \cdot S \cdot T_C \cdot T_D \quad (3.12)$$

with a_g , S , T_C and T_D as defined in 3.2.2.2.

3.2.2.5 Design spectrum for elastic analysis

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

(2) To avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and/or other mechanisms, is taken into account by performing an elastic analysis based on a response spectrum reduced with respect to the elastic one, henceforth called a "design spectrum". This reduction is accomplished by introducing the behaviour factor q .

(3)P 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 value 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 in the various Parts of EN 1998. The value of the behaviour factor q may be different in different horizontal directions of the structure, although the ductility classification shall be the same in all directions.

(4) P For the horizontal components of the seismic action the design spectrum, $S_d(T)$, shall be defined by the following expressions:

$$0 \leq T \leq T_B : S_d(T) = a_g \cdot S \cdot \left[\frac{2}{3} + \frac{T}{T_B} \cdot \left(\frac{2,5}{q} - \frac{2}{3} \right) \right] \quad (3.13)$$

$$T_B \leq T \leq T_C: S_d(T) = a_g \cdot S \cdot \frac{2,5}{q} \quad (3.14)$$

$$T_C \leq T \leq T_D: S_d(T) \begin{cases} = a_g \cdot S \cdot \frac{2,5}{q} \cdot \left[\frac{T_C}{T} \right] \\ \geq \beta \cdot a_g \end{cases} \quad (3.15)$$

$$T_D \leq T: S_d(T) \begin{cases} = a_g \cdot S \cdot \frac{2,5}{q} \cdot \left[\frac{T_C T_D}{T^2} \right] \\ \geq \beta \cdot a_g \end{cases} \quad (3.16)$$

where

a_g , S , T_C and T_D are as defined in 3.2.2.2;
 $S_d(T)$ is the design spectrum;
 q is the behaviour factor;
 β is the lower bound factor for the horizontal design spectrum.

NOTE The value to be ascribed to β for use in a country can be found in its National Annex. The recommended value for β is 0,2.

5) For the vertical component of the seismic action the design spectrum is given by expressions (3.13) to (3.16), with the design ground acceleration in the vertical direction, a_{vg} replacing a_g , S taken as being equal to 1,0 and the other parameters as defined in 3.2.2.3.

(6) For the vertical component of the seismic action a behaviour factor q equal to 1,5 should generally be adopted for all materials and structural systems.

(7) The adoption of values for q greater than 1,5 in the vertical direction shall be justified through an appropriate analysis.

(8) P The design spectrum as defined above is not sufficient for the design of structures with base-isolation or energy-dissipation systems.

3.2.4 Combinations of the seismic action with other actions

(1) P The design value E_d of the effects of actions in the seismic design situation shall be determined in accordance with EN 1990:2002, 6.4.3.4.

(2) P 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:

$$\Sigma G_{k,j} "+" \Sigma \psi_{E,i} \cdot Q_{k,i} \quad (3.17)$$

where

$\psi_{E,i}$ is the combination coefficient for variable action i (see 4.2.4).

(3) The combination coefficients $\psi_{E,i}$ take 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.