Ground conditions and seismic action

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Ground conditions

Earthquake vibration at the surface is strongly influenced by the underlying ground conditions

EN 1998-1 requires that appropriate investigations (in situ or in the laboratory) must be carried out in order to identify the ground conditions, with two main objectives:

- **allow the classification of the soil profile, in view of defining the ground motion appropriate to the site (i.e. allowing the selection of the relevant spectral shape)**
- **identify the possible occurrence of soil behaviour during an earthquake detrimental to the response of the structure**

Ground conditions

Five ground types:

A - Rock

B - Very dense sand or gravel or very stiff clay

C - Dense sand or gravel or stiff clay

D - Loose to medium cohesionless soil or soft to firm cohesive soil

E - Surface alluvium layer C or D, 5 to 20 m thick, over a much stiffer material

2 special ground types S_1 and S_2 requiring special studies

Ground conditions defined by **shear wave velocities** in the **top 30 m** and also by indicative values for N_{SPT} and c_u

Ground conditions

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

Ground conditions

Table 3.1: Ground types

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
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

Ground conditions

Table 3.1: Ground types

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
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			

Seismic zonation

Competence of National Authorities

Described by a_{gR} (reference peak ground acceleration on type A ground)

Corresponds to the reference return period T_{NCR}

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

Objective for the future updating of EN1998-1:
European zonation map with **spectral values** for **different hazard levels** (e.g. 100, 500 and 2.500 years)

Seismic zonation

Seismic Hazard Analysis

Attenuation relationships

Sample law: Ambraseys et al. [1996]

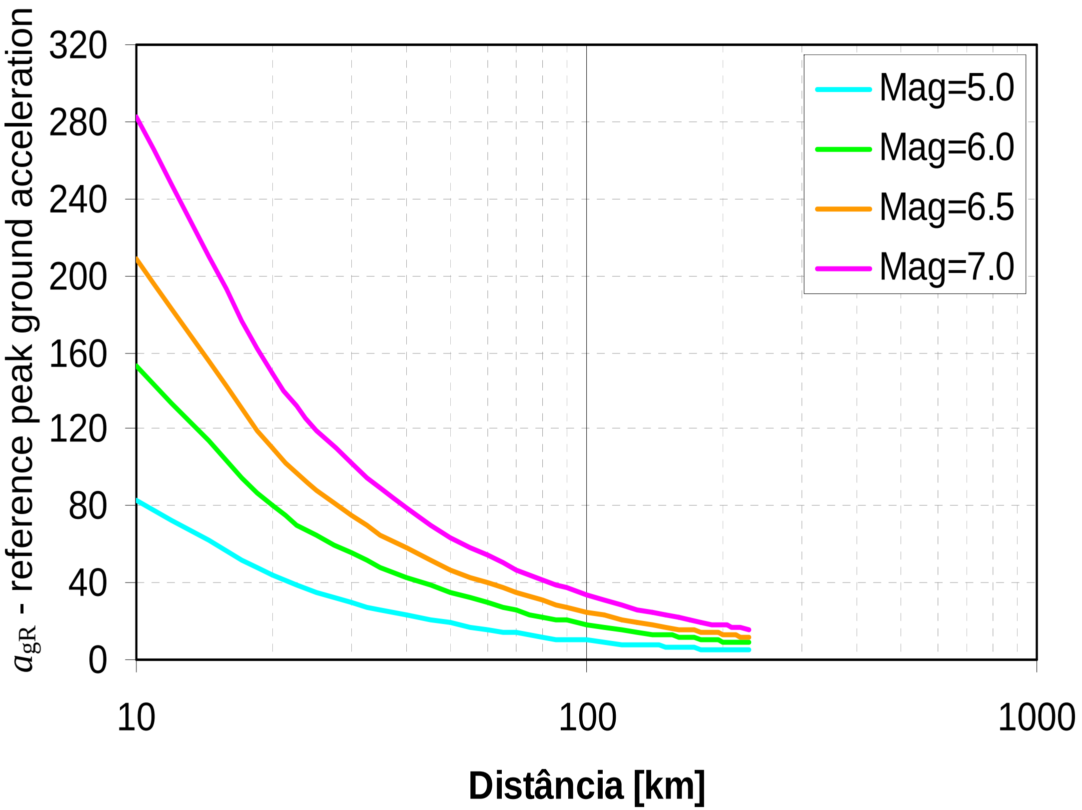
valid for:

- **Intraplate seismicity (Europe)**
- **Rock sites**
- **4.0 < M < 7.3**
- **3 km < R < 200 km**

Spectral law:

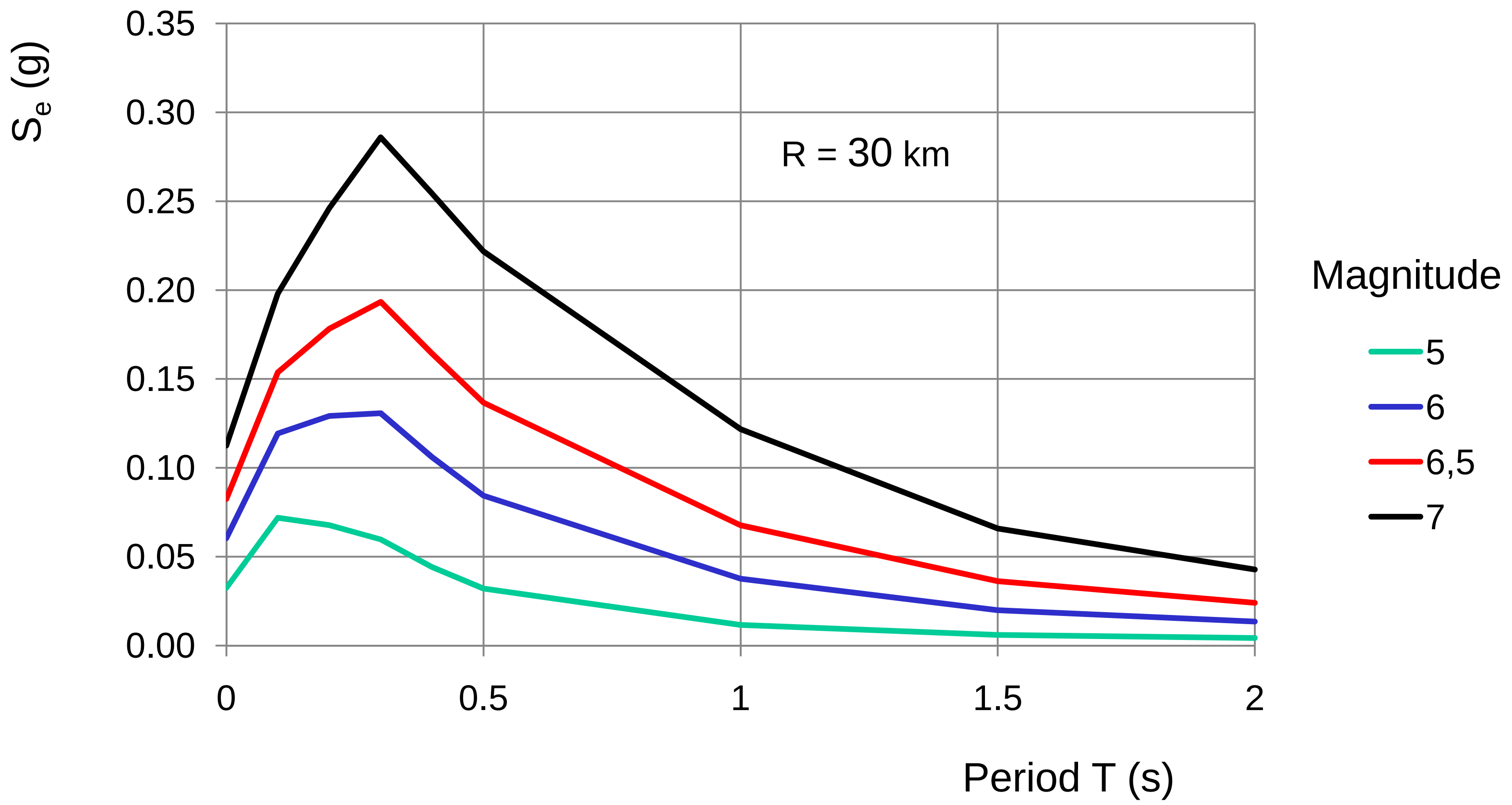
log SA [g] = c1 + c2M + c4 logR

T (s)	C'_1	C_2	C_4	h_0	σ
PGA	-1.48	0.27	-0.92	3.50	0.25
0.10	-0.84	0.22	-0.95	4.50	0.27
0.20	-1.21	0.28	-0.92	4.20	0.27
0.30	-1.55	0.34	-0.93	4.20	0.30
0.40	-1.94	0.38	-0.89	3.60	0.31
0.50	-2.25	0.42	-0.91	3.30	0.32
1.00	-3.17	0.51	-0.89	4.30	0.32
1.50	-3.61	0.52	-0.82	3.00	0.31
2.00	-3.79	0.50	-0.73	3.20	0.32



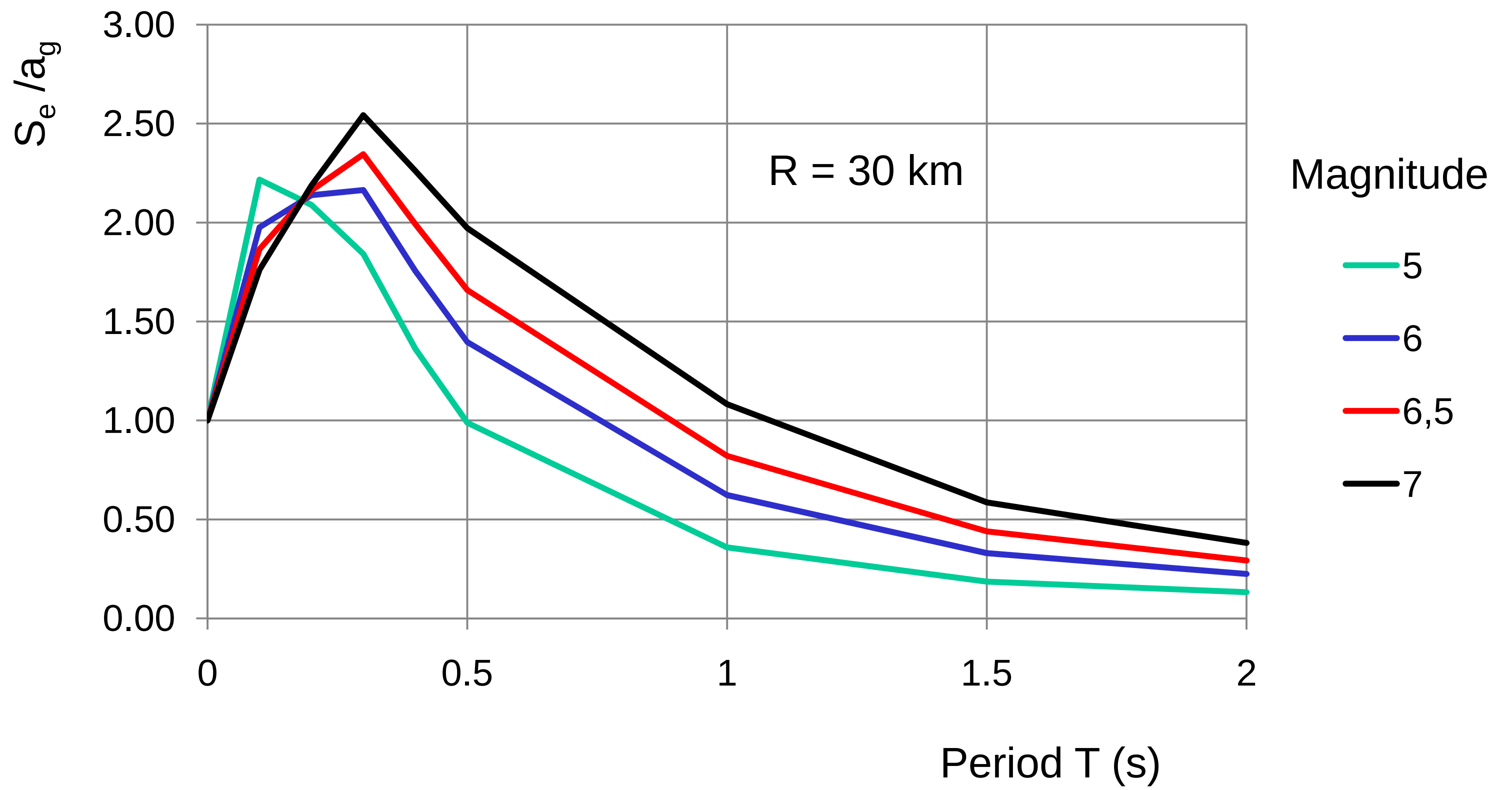
Spectral shape

Effect of Magnitude on Response Spectra (Rock, 5% damping)



Spectral shape

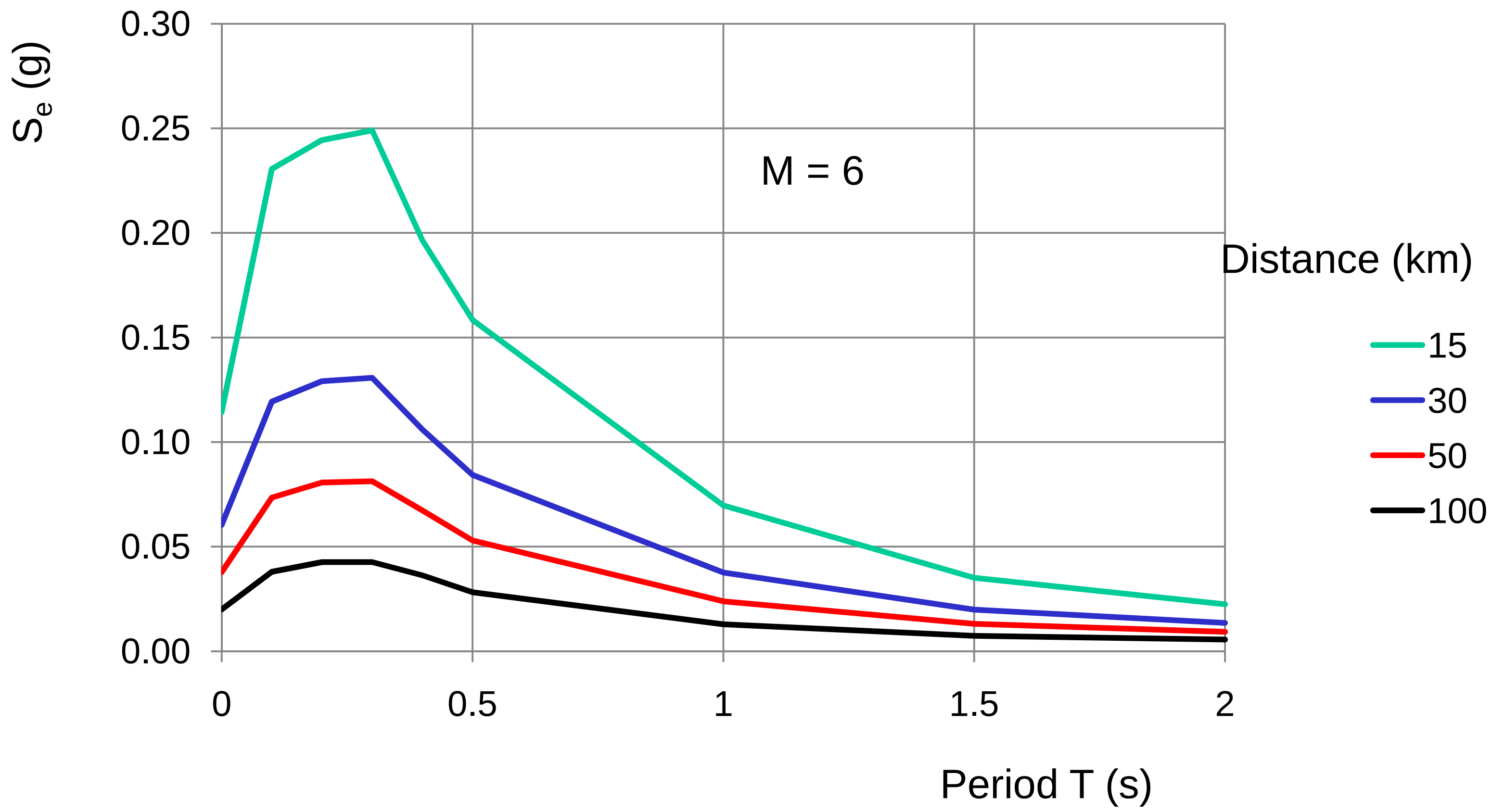
Effect of Magnitude on normalised shape (Rock, 5% damping)



Spectral shape

Effect of Epicentral Distance on Response Spectra

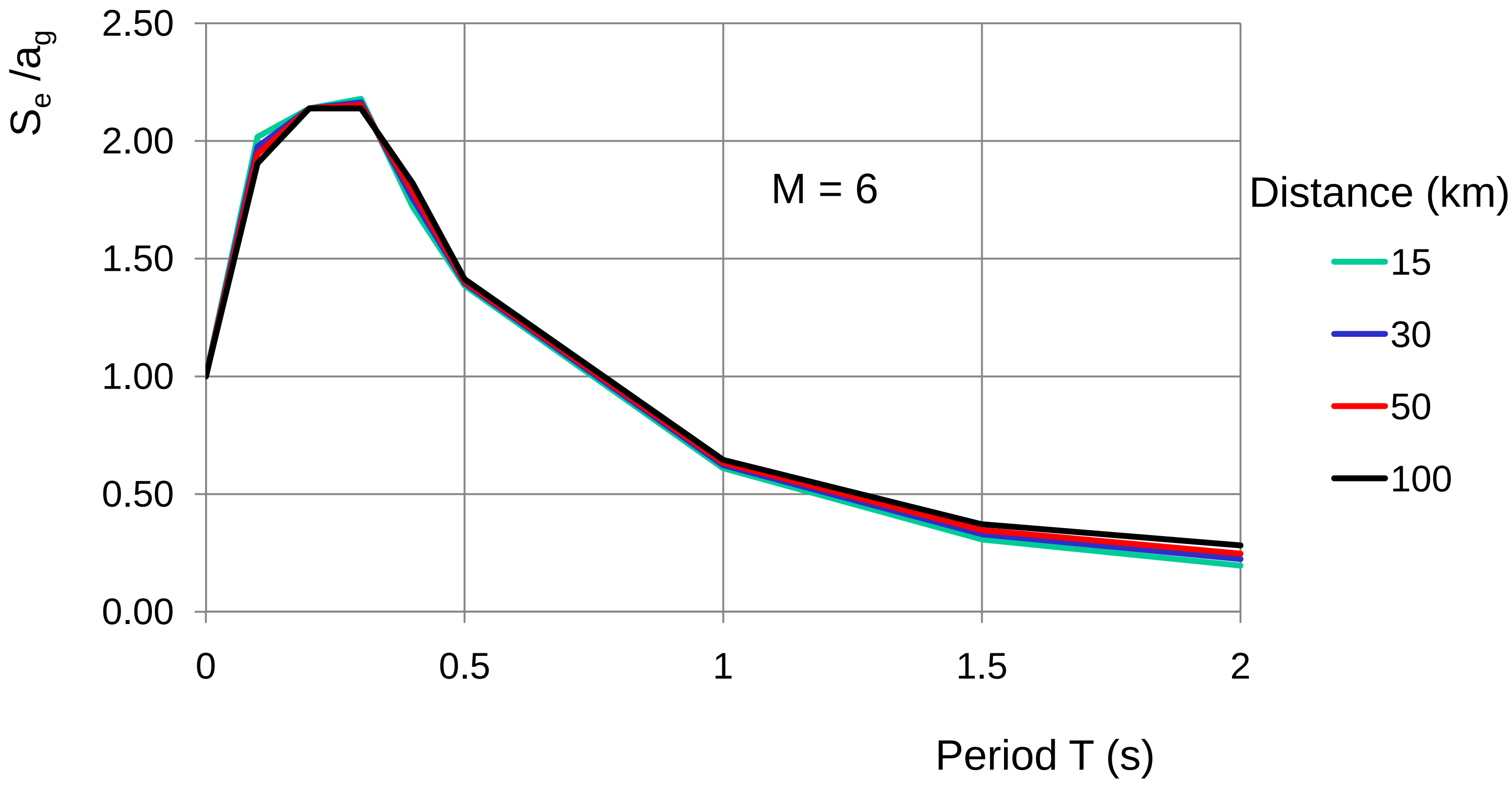
(Rock, 5% damping)



Spectral shape

Effect of Epicentral Distance on normalised shape

(Rock, 5% damping)



Elastic response spectrum

Common shape for the ULS and DLS verifications

2 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)

Account of **topographical effects** (EN 1998-5) and **spatial variation** of motion (EN1998-2) required in some special cases

Definition of the horizontal elastic response spectrum

Four branches

$0 \leq T \leq T_B \qquad S_e(T) = a_g \,.\, S \,.\, (1+T/T_B \,.\, (\eta \,.\, 2{,}5 -1))$

$T_B \leq T \leq T_C \qquad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5$

$T_C \leq T \leq T_D \qquad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5\,(T_C\,/T)$

$T_D \leq T \leq 4\text{ s} \qquad S_e(T) = a_g \,.\, S \,.\, \eta \,.\, 2{,}5\,(T_C \,.\, T_D\,/T^{2})$

$S_e(T)$	**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)

Additional **information** for $T > 4$ s in Informative Annex

Normalised elastic response spectrum

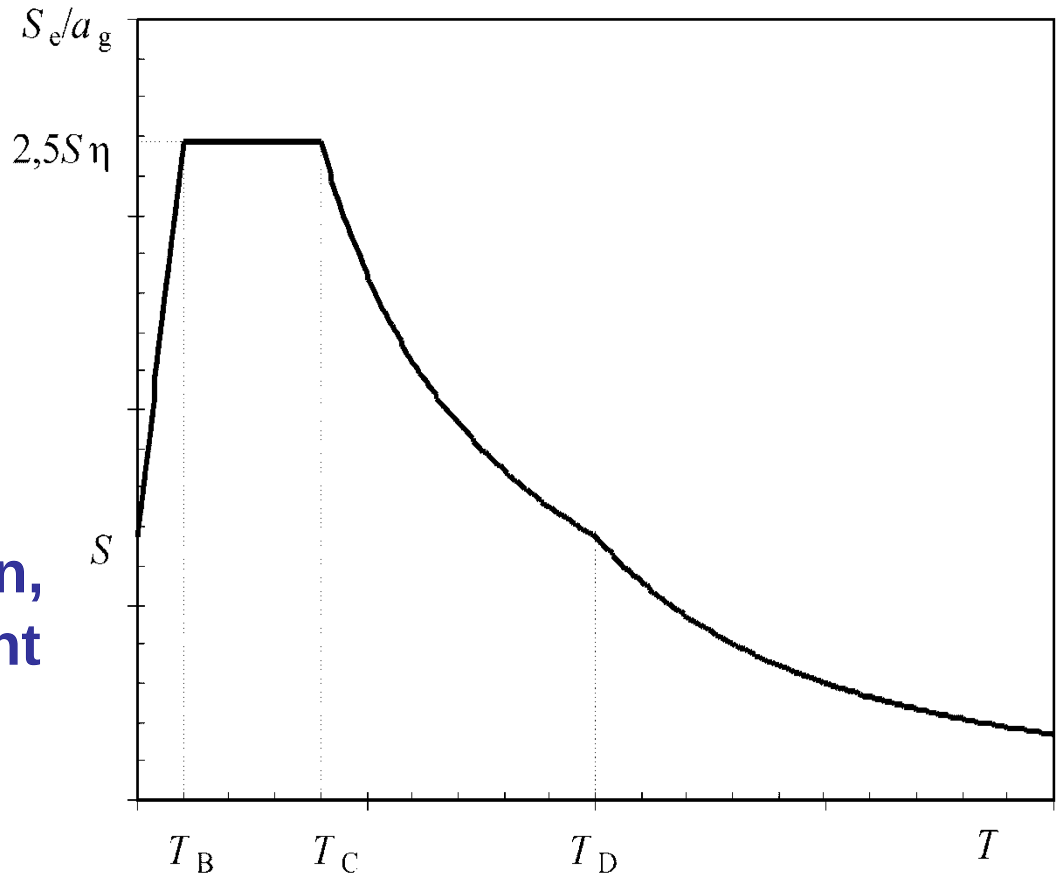
Standard shape

Control variables

- S, T_B, T_C, T_D (NDPs)
- η ($\geq$ 0,55) damping correction for $\xi \neq 5$ %

Fixed variables

- Constant acceleration, velocity & displacement spectral branches
- acceleration spectral amplification: 2,5



Normalised elastic response spectrum

Correction for damping

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

To be applied only to elastic spectra

Elastic response spectrum

Two types of (recommended) spectral shapes

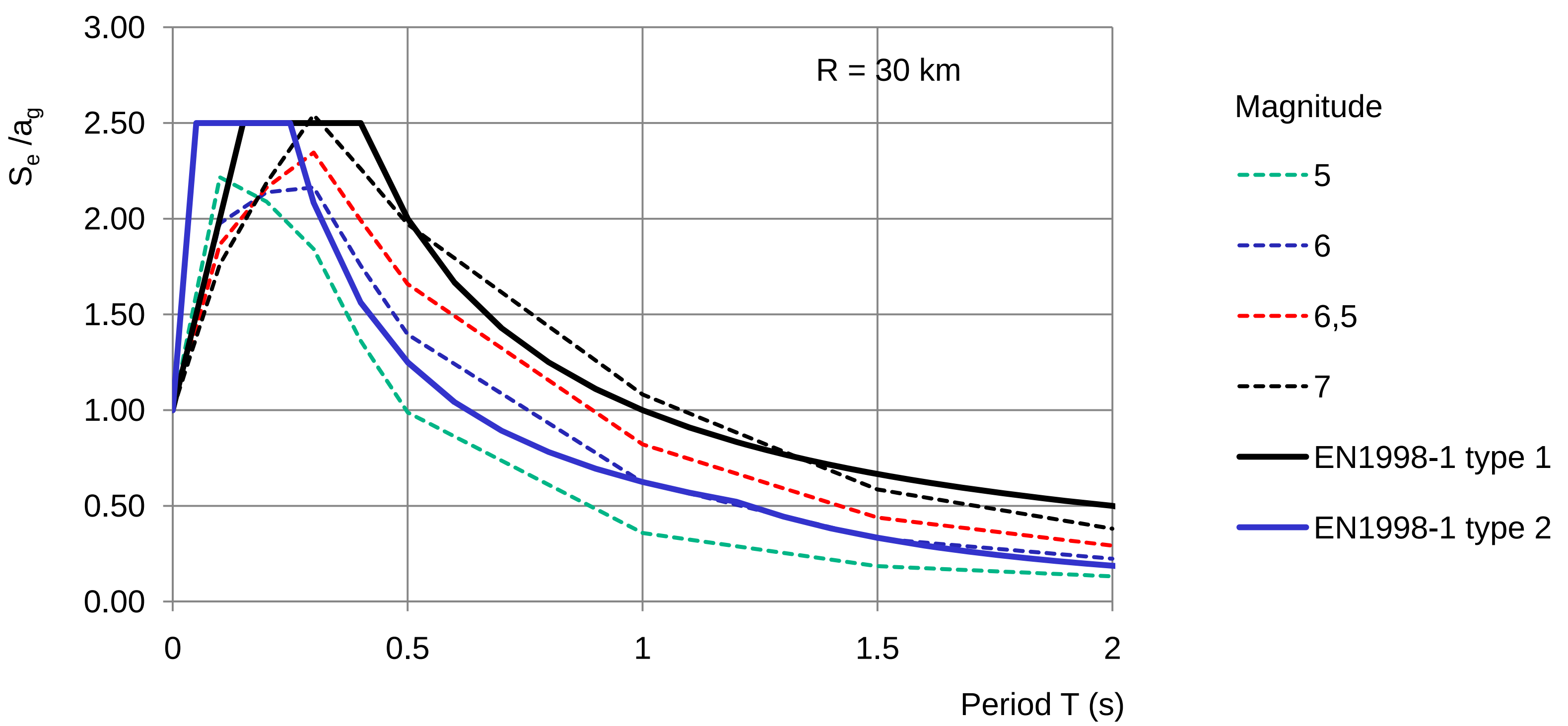
Depending on the characteristics of the most significant earthquake contributing to the local hazard:

- **Type 1 - High and moderate seismicity regions ($M_s > 5{,}5$)**
- **Type 2 - Low seismicity regions ($M_s \leq 5{,}5$); near field earthquakes**

Optional account of **deep geology effects** (NDP) for the definition of the seismic action

Recommended elastic response spectra

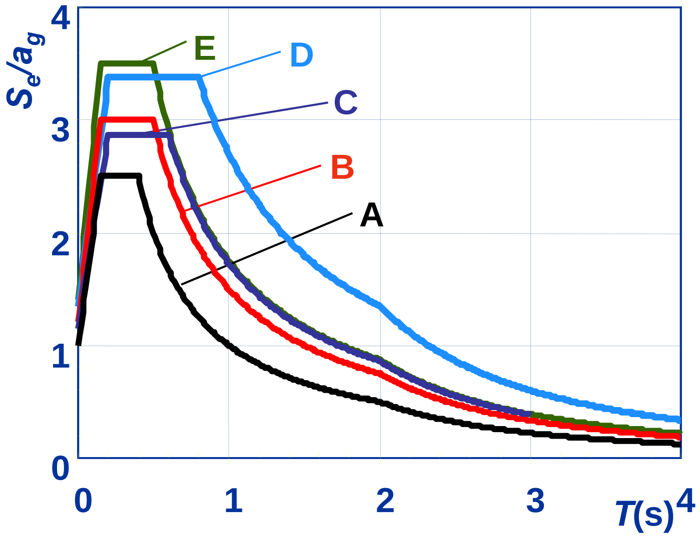
Normalised shape for Type 1 and Type 2 seismic action (rock)

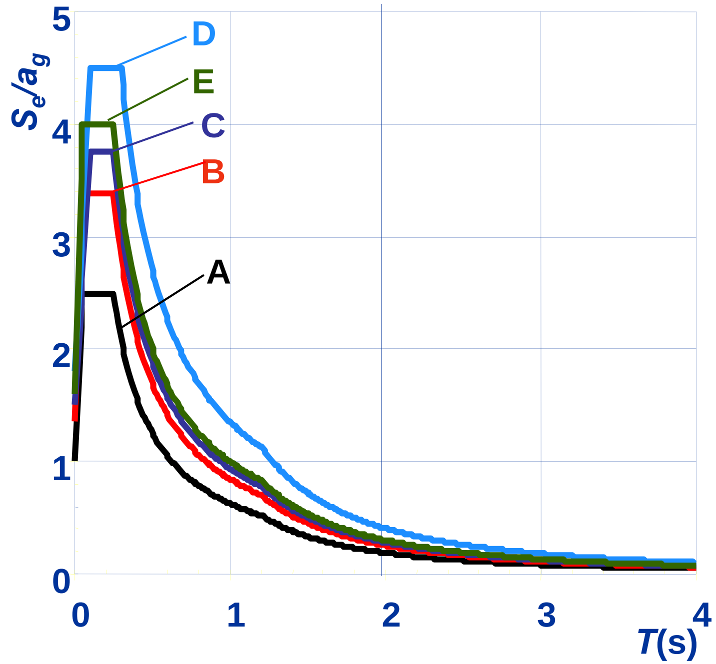


Recommended parameters for the definition of the response spectra for various ground types

	Seismic action Type 1				Seismic action Type 2			
Ground Type	S	T_B (s)	T_C (s)	T_D (s)	S	T_B (s)	T_C (s)	T_D (s)
A	**1,0**	**0,15**	**0,4**	**2,0**	**1,0**	**0,05**	**0,25**	**1,2**
B	**1,2**	**0,15**	**0,5**	**2,0**	**1,35**	**0,05**	**0,25**	**1,2**
C	**1,15**	**0,2**	**0,6**	**2,0**	**1,5**	**0,1**	**0,25**	**1,2**
D	**1,35**	**0,2**	**0,8**	**2,0**	**1,8**	**0,1**	**0,3**	**1,2**
E	**1,4**	**0,15**	**0,5**	**2,0**	**1,6**	**0,05**	**0,25**	**1,2**

Recommended elastic response spectra

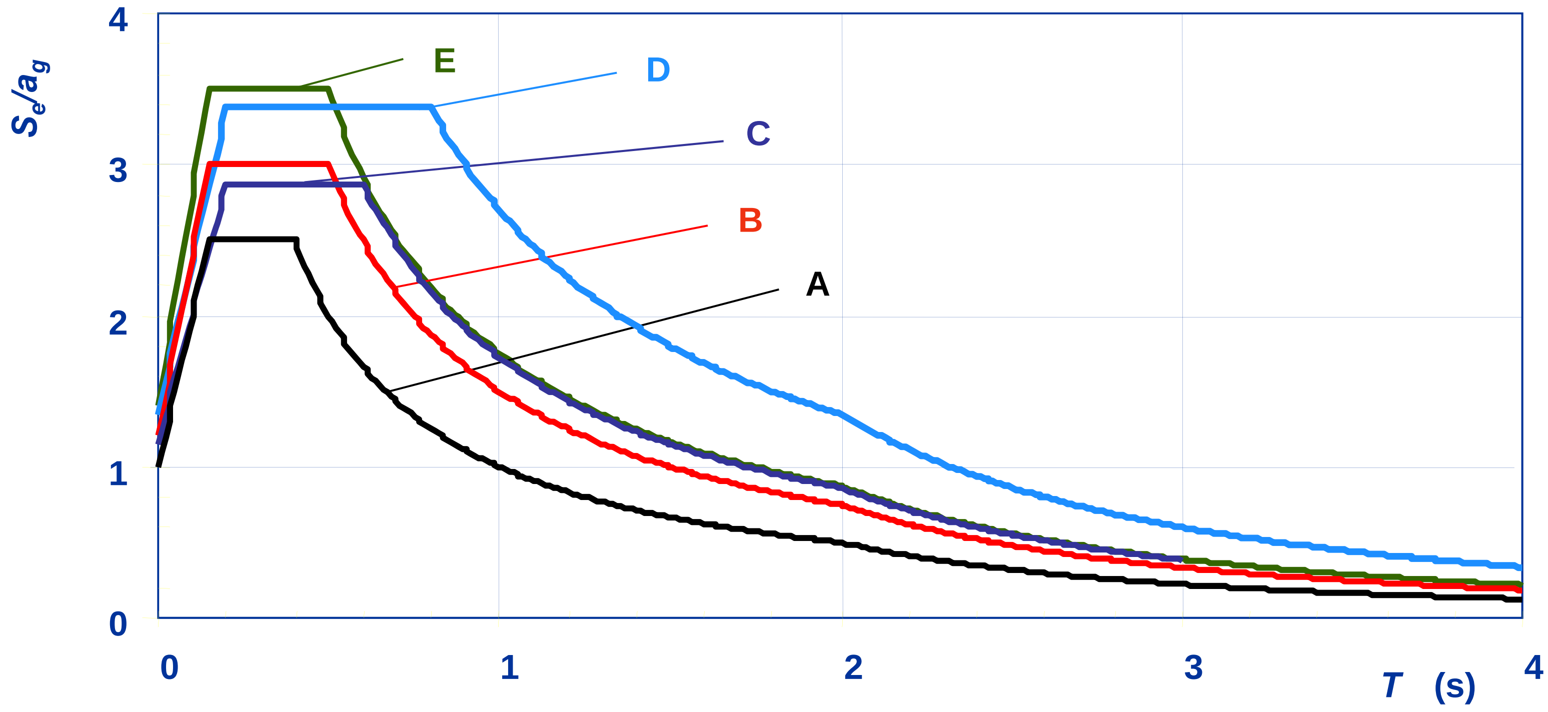




Type 1 - $M_s > 5{,}5$

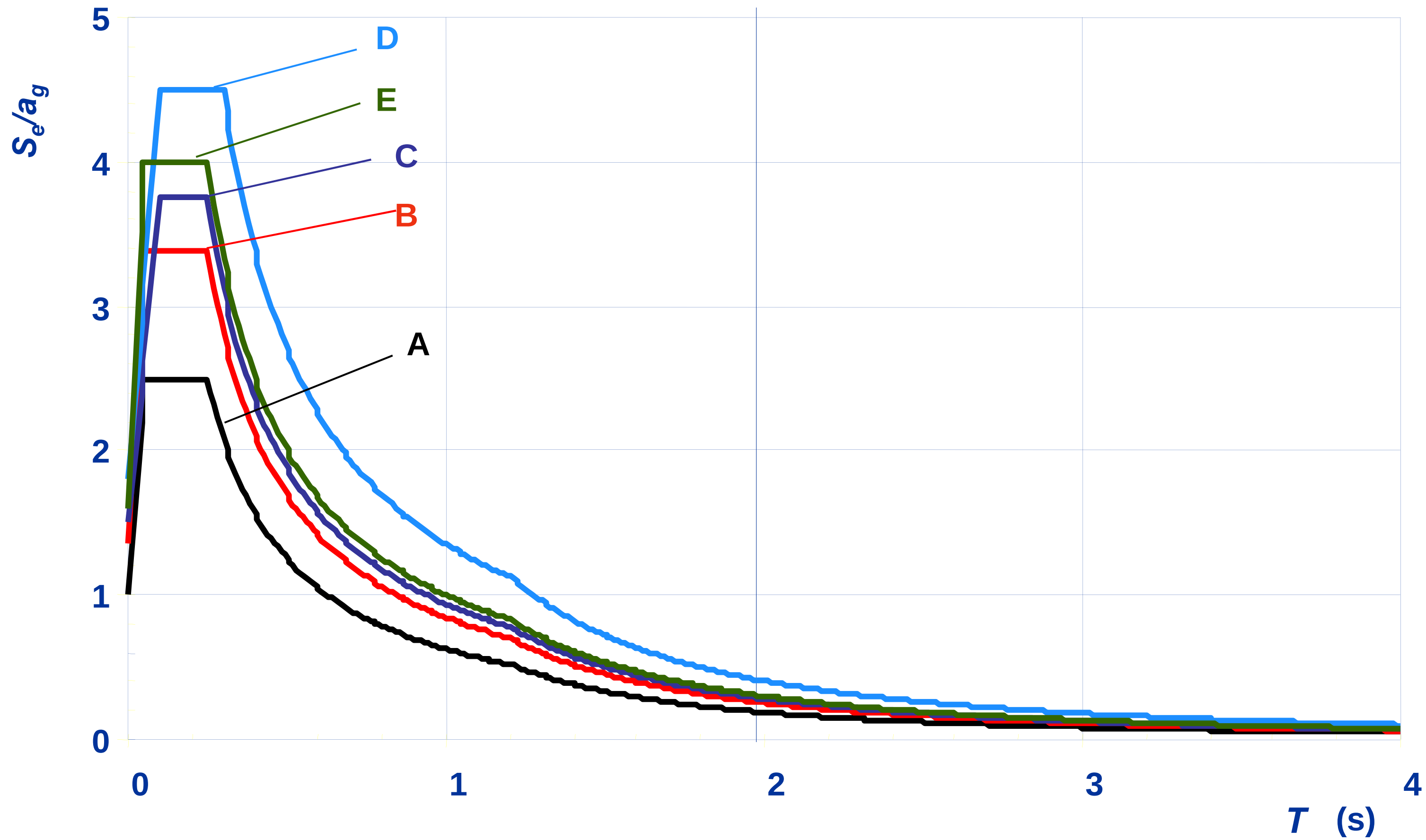
Type 2 - $M_s \leq 5{,}5$

Recommended elastic response spectra



Type 1 - M_s > 5,5

Recommended elastic response spectra



Type 2 - $M_s \leq 5{,}5$

Definition of the vertical elastic response spectrum

Four branches

$$0 \leq T \leq T_B \qquad S_{ve}(T) = a_{vg} \,.\, (1+T/T_B \,.\, (\eta \,.\, 3{,}0 - 1))$$

$$T_B \leq T \leq T_C \qquad S_{ve}(T) = a_{vg} \,.\, \eta \,.\, 3{,}0$$

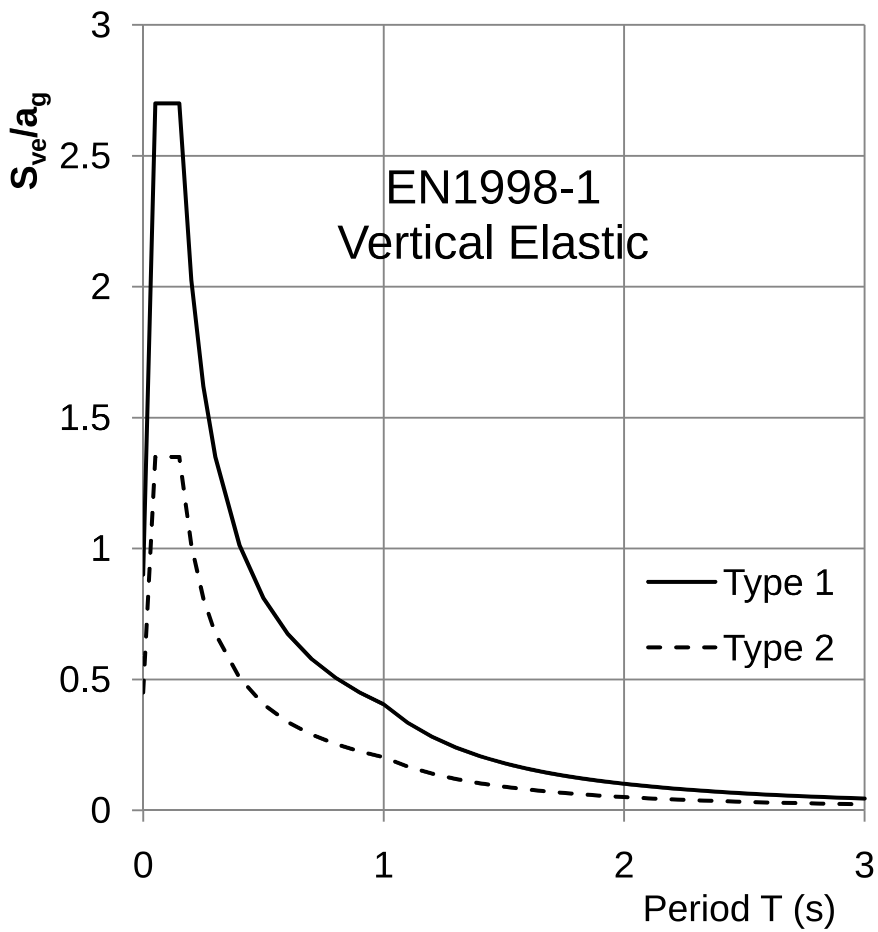
$$T_C \leq T \leq T_D \qquad S_{ve}(T) = a_{vg} \,.\, \eta \,.\, 3{,}0\, (T_C / T)$$

$$T_D \leq T \leq 4\ \mathrm{s} \qquad S_{ve}(T) = a_{vg} \,.\, \eta \,.\, 3{,}0\, (T_C \,.\, T_D / T^2)$$

$S_{ve}(T)$	vertical **elastic** response spectrum
a_{vg}	**vertical design ground acceleration** on type A ground
T_B T_C T_D	**corner periods** in the spectrum (NDPs)
η	**damping** correction factor (η = 1 for 5% damping)

Soil factor not influencing the vertical response spectrum

Definition of the vertical elastic response spectrum



Recommended parameters

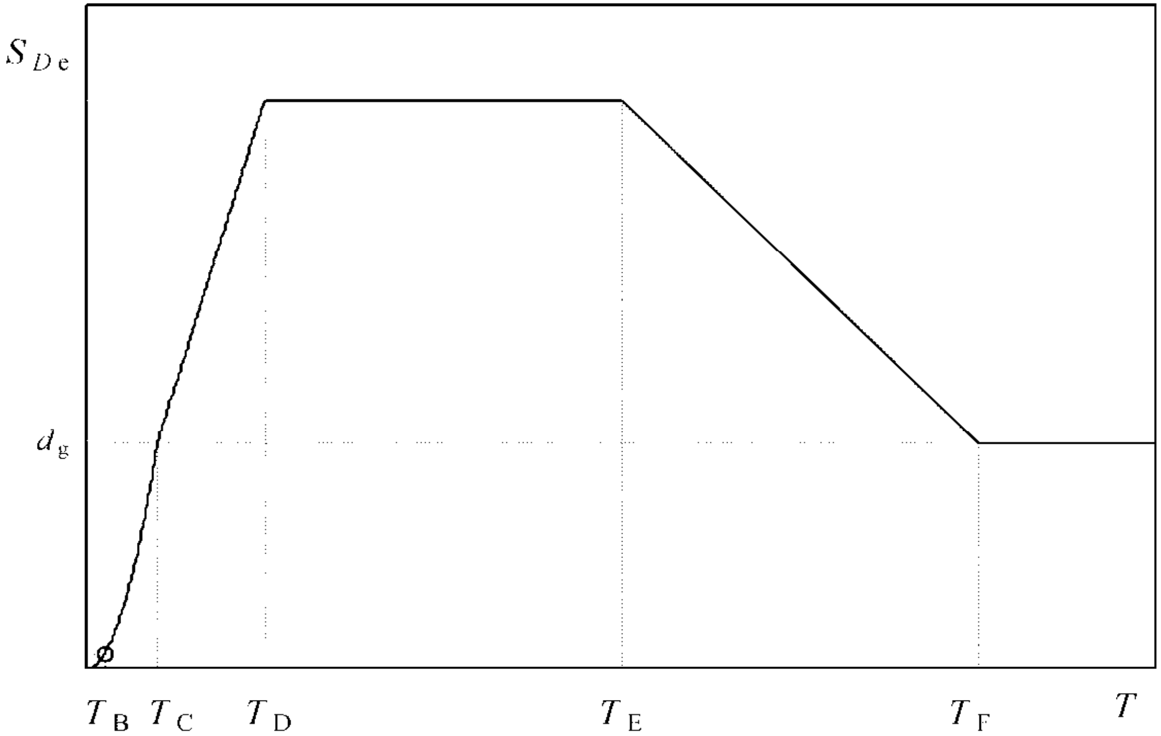
Seismic action	a_{vg}/a_g	T_B (s)	T_C (s)	T_D (s)
Type 1	0,90	0,05	0,15	1,0
Type 2	0,45	0,05	0,15	1,0

Displacements

Design ground displacement $d_g = 0{,}025 \cdot a_g \cdot S \cdot T_C \cdot T_D$

Elastic displacement response spectrum in Informative Annex A of EN 1998-1

Soil	T_E (s)	T_F (s)
A	4,5	10,0
B	5,0	10,0
C	6,0	10,0
D	6,0	10,0
E	6,0	10,0



<u>Design spectrum</u> for elastic analysis

Derived from the elastic spectrum

$0 \leq T \leq T_B \qquad S_d(T) = a_g \,.\, S \,.\, (2/3 + T/T_B \,.\, (2{,}5/q - 2/3))$

$T_B \leq T \leq T_C \qquad S_d(T) = a_g \,.\, S \,.\, 2{,}5/q$

$T_C \leq T \leq T_D \qquad S_d(T) = a_g \,.\, S \,.\, 2{,}5/q \,.\, (T_C/T)$
$\geq \beta \,.\, a_g$

$T_D \leq T \leq 4\text{ s} \qquad S_d(T) = a_g \,.\, S \,.\, 2{,}5/q \,.\, (T_C \,.\, T_D/T^2)$
$\geq \beta \,.\, a_g$

$S_d(T)$ **design** spectrum
q **behaviour factor**
β **lower bound** factor (NDP recommended value: **0,2**)

Specific rules for **vertical action**: $q \leq 1{,}5$

Design spectrum for elastic analysis

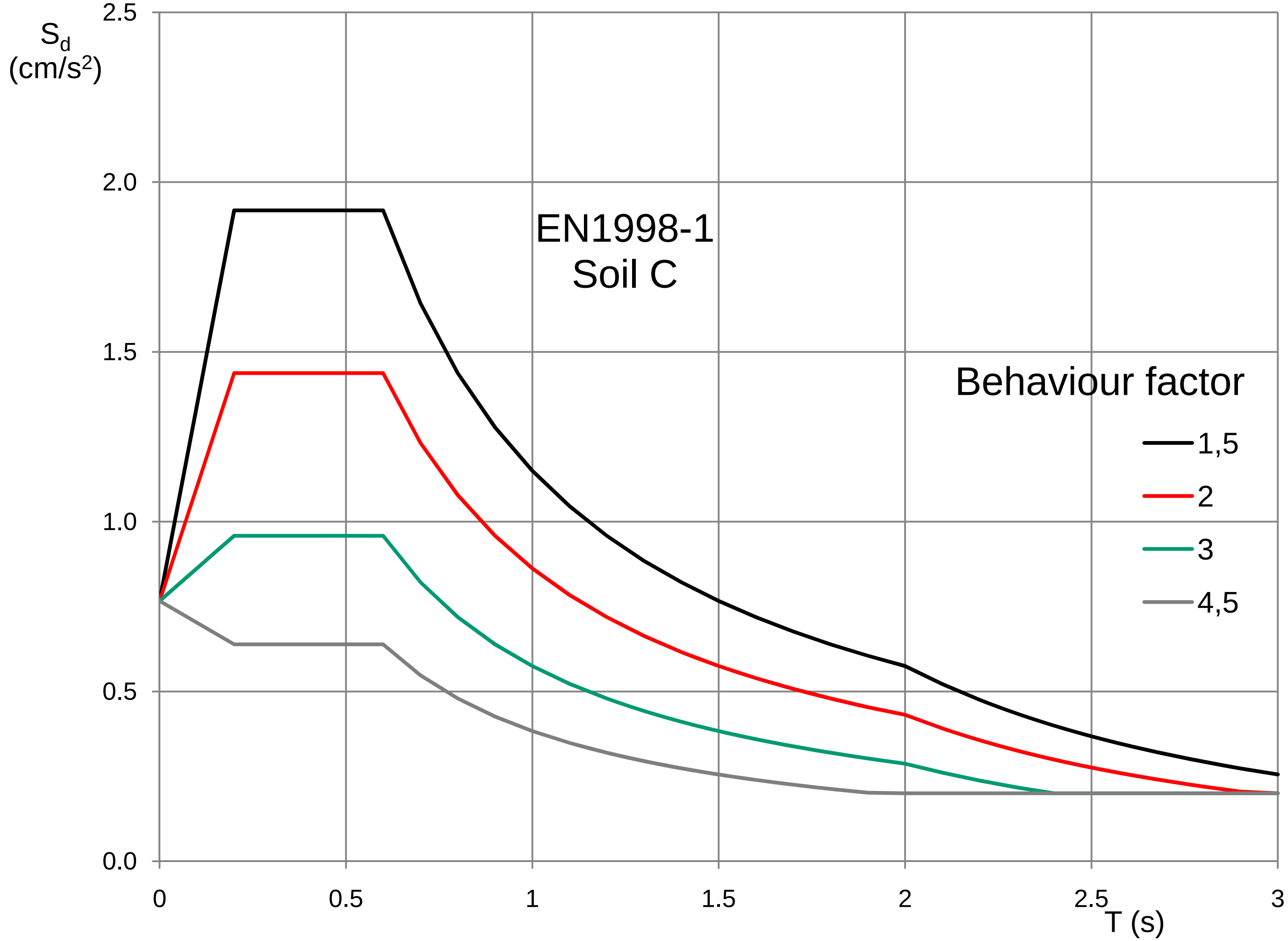
Derived from the elastic spectrum but:

Correction factor for damping *η* not included

Values of the behaviour factor *q* already account for the influence of the viscous damping being different from 5%

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.

Design spectra for elastic analysis



Alternative representations of the seismic action

Time history representation (essentially for NL analysis purposes)

Three simultaneously acting accelerograms

- **Artificial accelerograms**

  Match the elastic response spectrum for 5% damping
  Duration compatible with Magnitude ($T_s \geq$ 10 s)
  Minimum number of accelerograms: 3

- **Recorded or simulated accelerograms**

  Scaled to $a_g . S$
  Match the elastic response spectrum for 5% damping