EC8-2G

Il nuovo standard europeo per la progettazione sismica

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Azioni sismiche di progetto

EN1998-1-1 Spettri elastici di progetto ed effetti di sito

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Pavia - 5 Giugno 2025

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

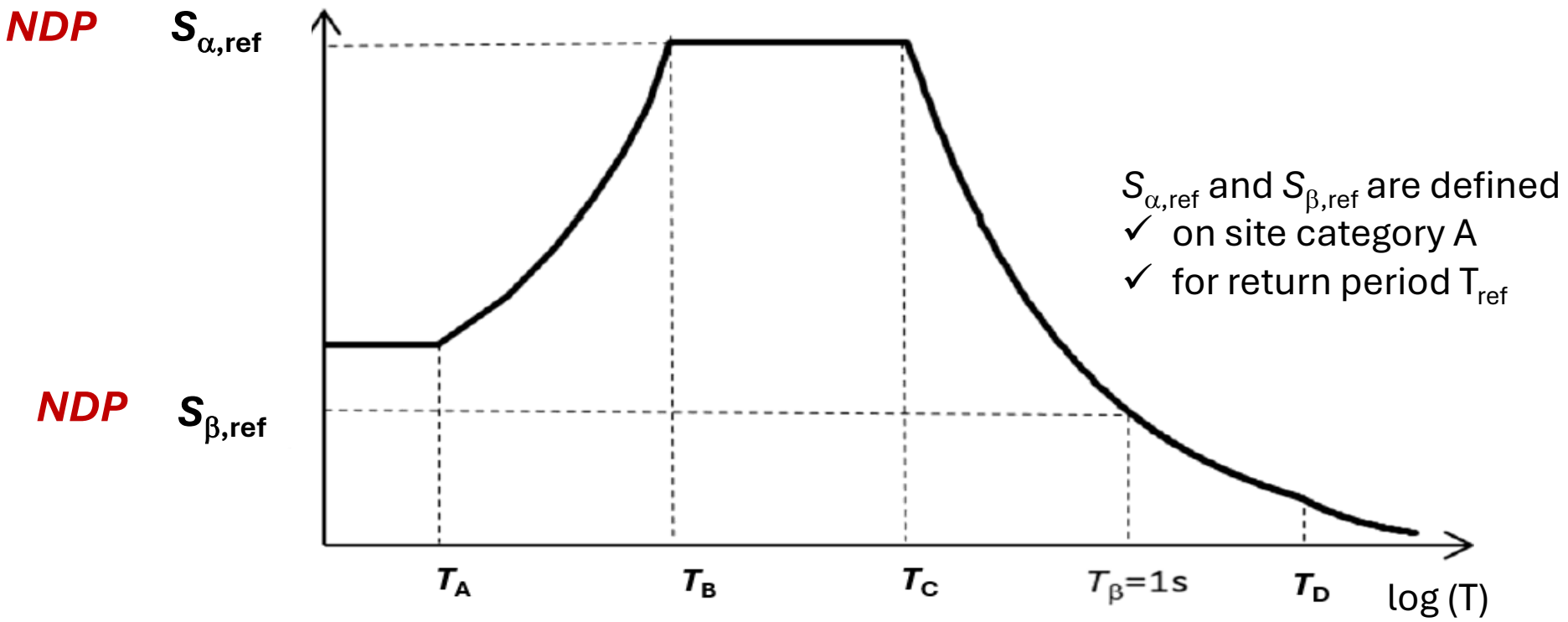
- **Spectral description of the seismic action**
- Site categorisation and site amplification factors
- Other aspects of the seismic action
- Conclusion

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

- Spectral description of the seismic action

For use of EN 1998, territories shall be mapped depending on the local seismic hazard.

NOTE …These parameters can also be grouped into seismic zones … .



$S_{\alpha,ref}$ and $S_{\beta,ref}$ are defined
- ✓ on site category A
- ✓ for return period T_{ref}

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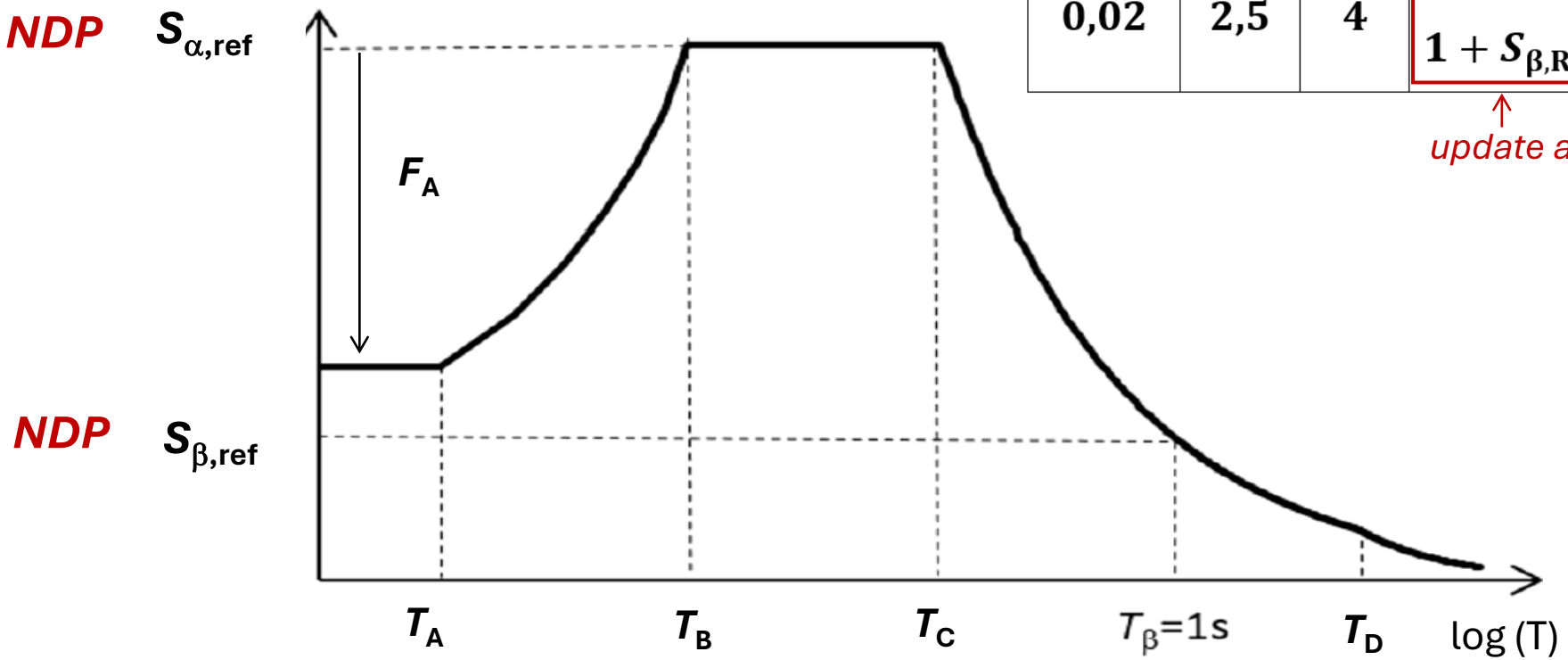
- Spectral description of the seismic action

T_C/T_B

NDPs

T_A (s)	F_A	χ	T_D (s)
0,02	2,5	4	2 if $S_{\beta,RP} \leq 1\ m/s^2$ $1 + S_{\beta,RP}$ if $S_{\beta,RP} > 1\ m/s^2$

update at long periods



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- Spectral description of the seismic action

$$S_\alpha = F_T\, F_\alpha\, S_{\alpha,RP}$$
$$S_\beta = F_T\, F_\beta\, S_{\beta,RP}$$

RP is the return period associated to the consequence class CC and the LS under consideration. For instance the recommended RP value for a CC3-a bridge verified at the NC limit state is 2500 yrs.

- $S_{\alpha,RP}$ and $S_{\beta,RP}$ can be obtained from hazard maps at the considered return period RP,
- or by applying performance factors:
  $S_{\alpha,RP} = \gamma_{SD,CC}\, S_{\alpha,Ref}$
  $S_{\beta,RP} = \gamma_{SD,CC}\, S_{\beta,Ref}$
- $S_{\alpha,Ref} = S_{\alpha,475}$ in the vast majority of countries
- F_α and F_α are the **site amplification factors**
- F_T is the **site topography factor**

Recommended return period values (years) for buildings (Part 1-2) and bridges (Part 2).

Limit States	Part 1-2				Part 2			
	CC1	CC2	CC3-a	CC3-b	CC1	CC2	CC3-a	CC3-b
NC	800	1600	2500	5000	800	1600	2500	5000
SD	250	475	800	1600	250	475	800	1600
DL	50	60	60	100	50	60	100	200

Recommended performance factor values for buildings (Part 1-2) and bridges (Part 2).

Limit States	Part 1-2				Part 2			
	CC1	CC2	CC3-a	CC3-b	CC1	CC2	CC3-a	CC3-b
NC	1.2	1.5	1.8	2.2	1.2	1.5	1.8	2.2
SD	0.8	1	1.2	1.5	0.8	1.0	1.25	1.5
DL	0.4	0.5	0.5	0.6	0.5	0.5	0.6	0.7

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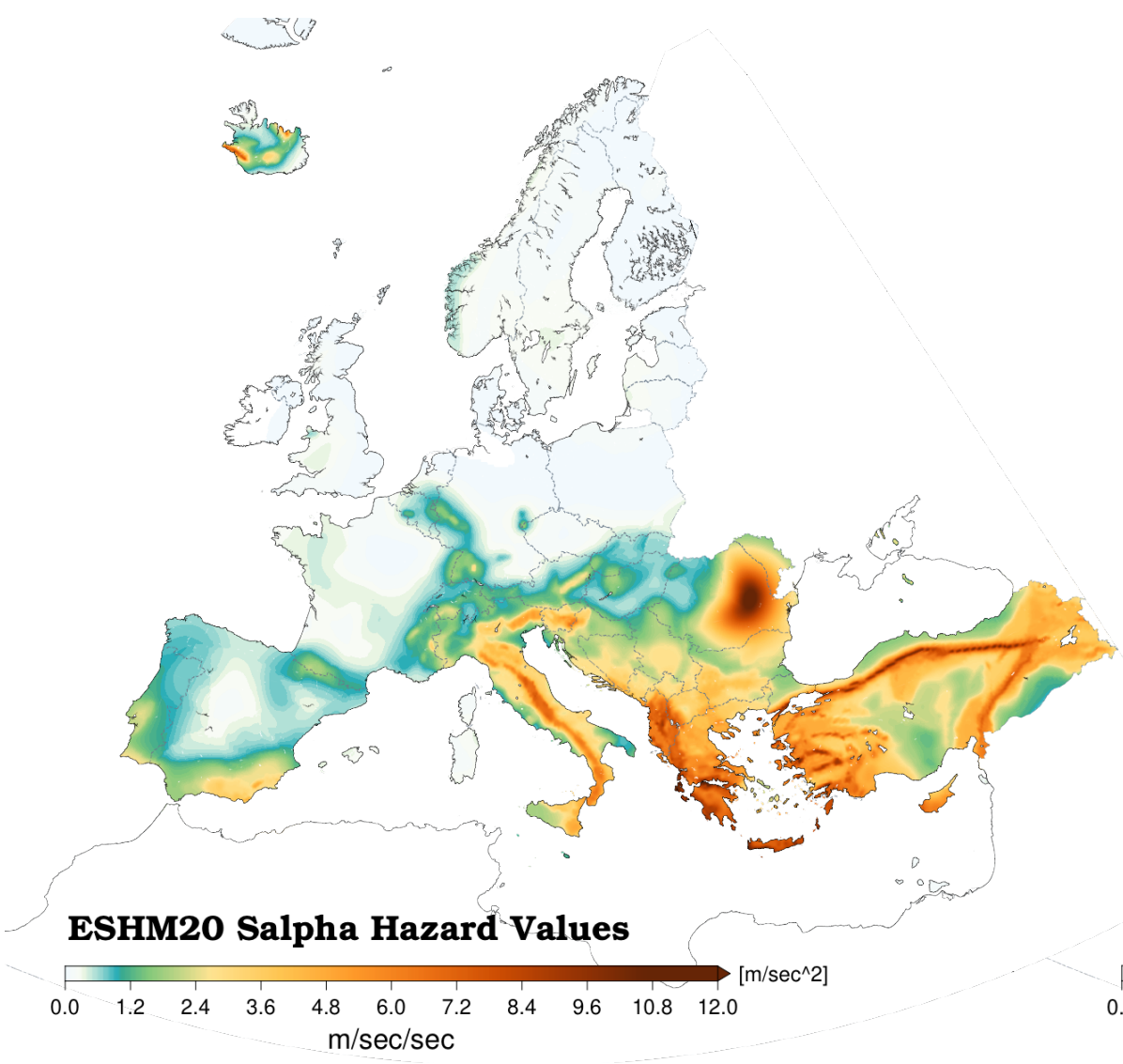
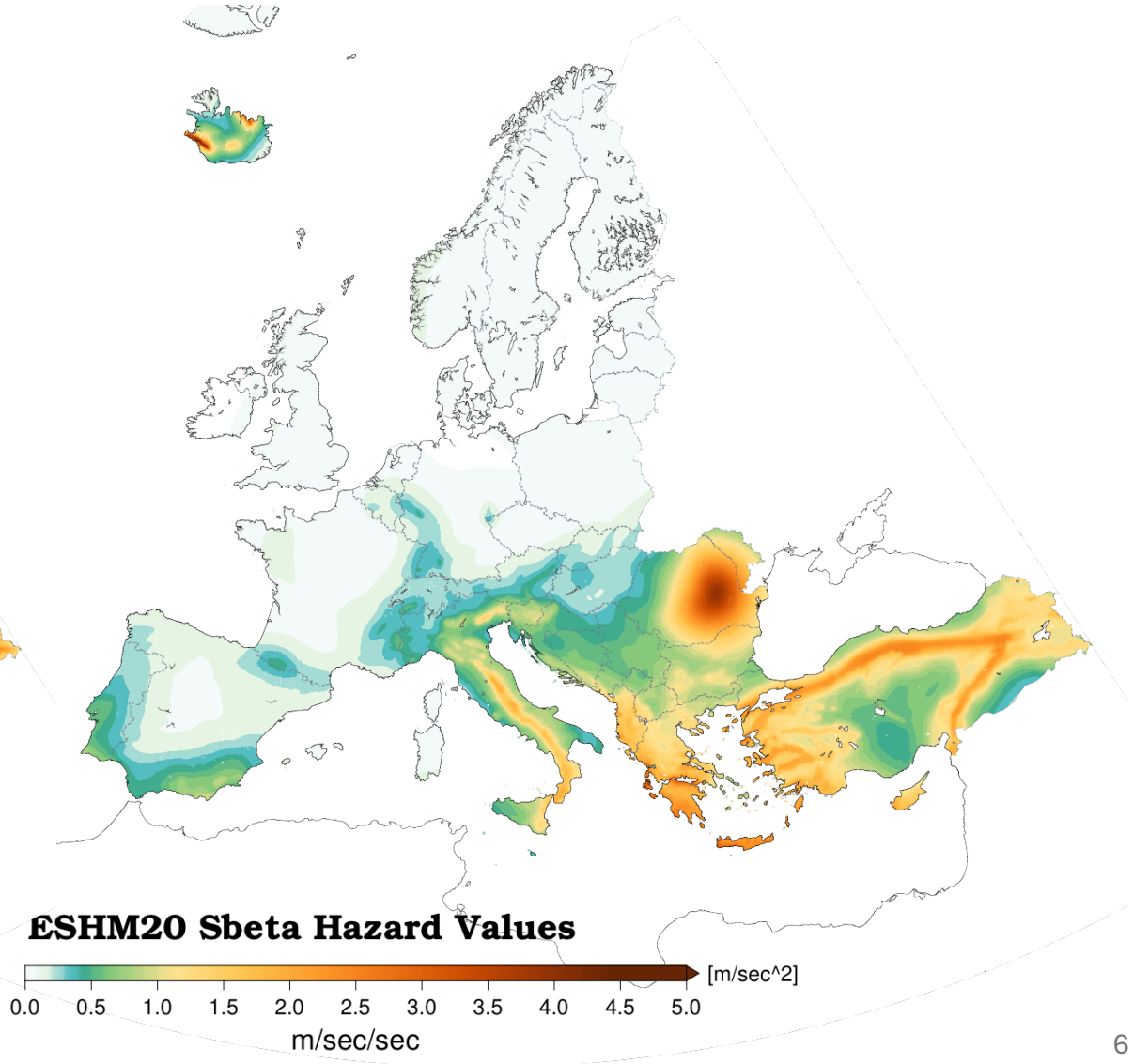
- ESHM20 Spectral acceleration maps





EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

- Spectral description of the seismic action
- **Site categorisation and site amplification factors**
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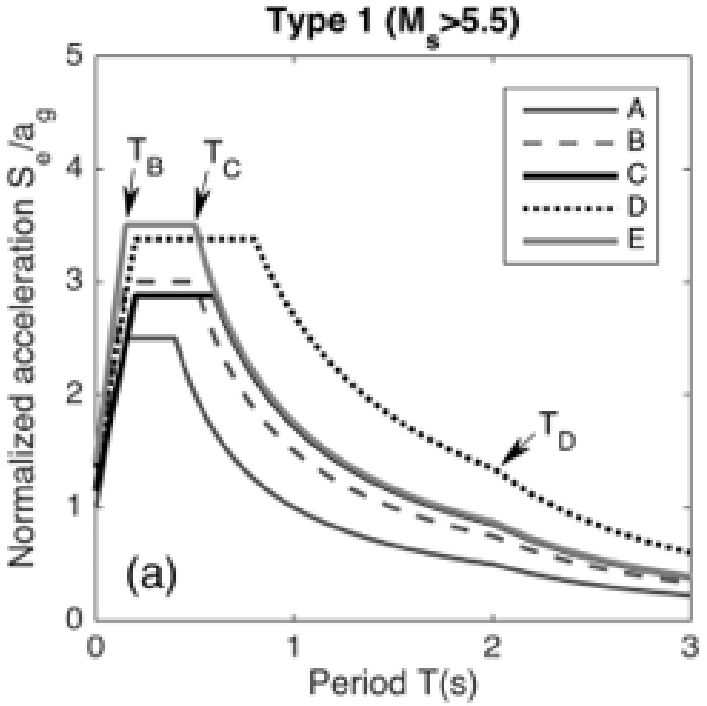
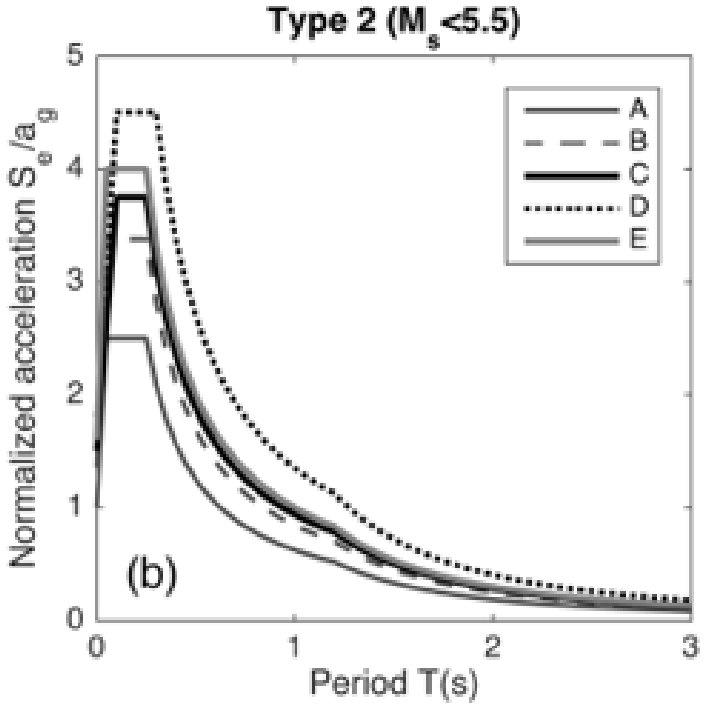
EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

Current EC8: normalized elastic response spectra for design



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



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

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Current EC8: site categorization

Table 1 Ground types according to EC8-1

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT}	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 meters in thickness characterized 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 meters	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			

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Current EC8: limitations of the site categorization scheme

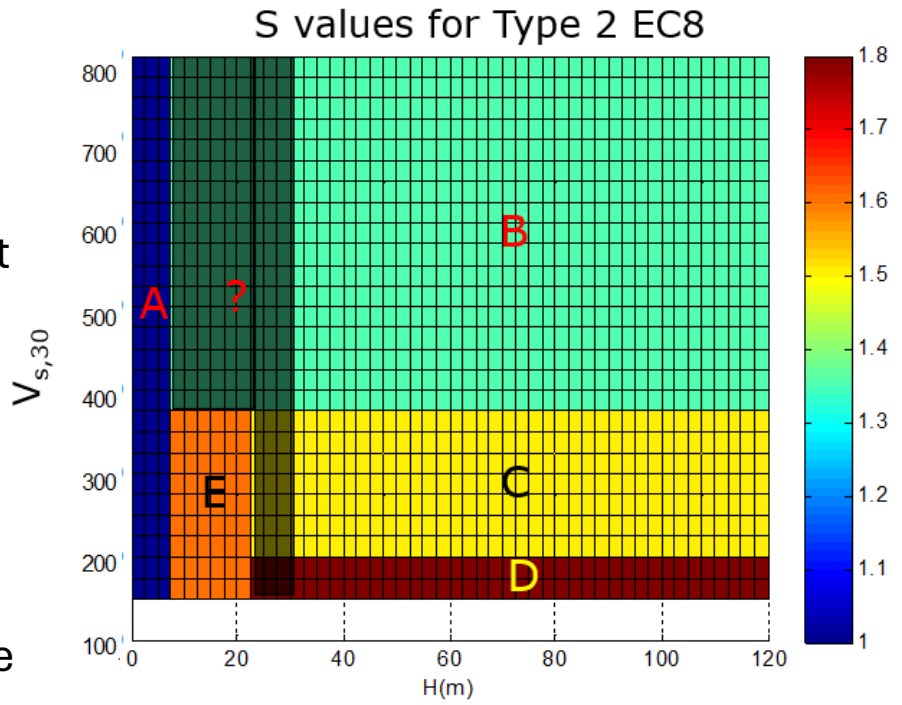
1) the **ambiguity to identify in some cases ground types** (e.g., what thickness? what to do if there is no gradual increase of mechanical properties with depth?);

2) the **classification may not be unique**, depending on whether different proxies are used (use of $V_{s,30}$ may provide a different output than using N_{SPT})

3) the **large jumps of site amplification factors** between adjacent site categories

4) the **alternative proxies** to $V_{s,30}$ (N_{SPT} and the undrained strength c_u) are related to soil strength, and only poorly related to the dynamic soil response;

5) no reference to **deep soils**.



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EN1998-1-1: site categorization scheme

	$v_{S,H}$ class	stiff	medium	soft
Depth class		400 m/s < $v_{S,H}$ < 800 m/s	250 m/s < $v_{S,H}$ < 400 m/s	150 m/s < $v_{S,H}$ < 250 m/s
very shallow	H_{800} < 5 m	A	A	E
shallow	5 m < H_{800} < 30 m	B	E	E
intermediate	30 m < H_{800} < 100 m	B	C	D
deep	H_{800} > 100 m	B	F	F

$v_{S,H}$=$v_{s,30}$

down to 100 m/s for low seismic action class.

← new site class

Parameters retained for site categorization:

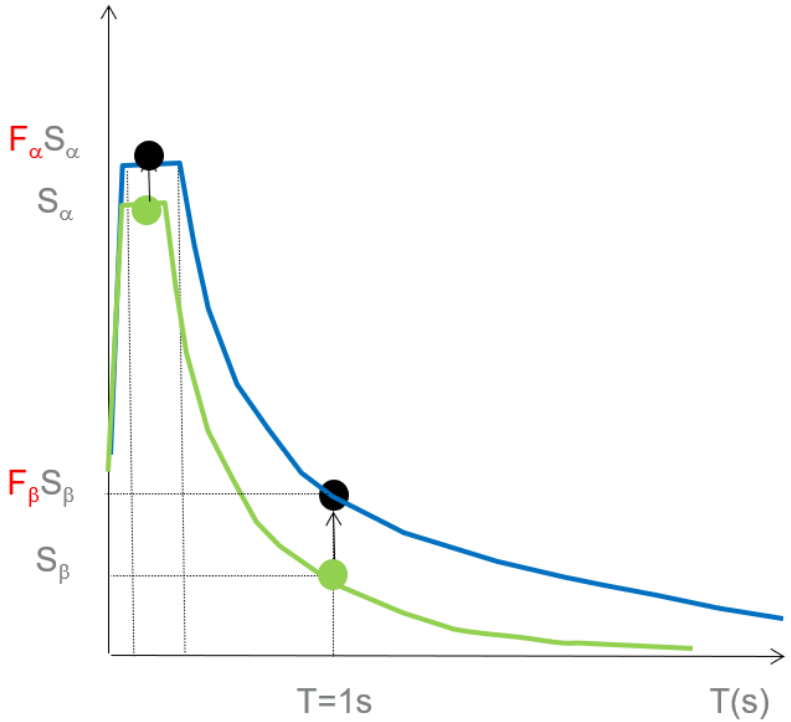
- $\mathbf{H_{800}}$ is the depth of the bedrock formation identified by v_s larger than 800m/s,
- $\mathbf{v_{S,H}}$ is the average superficial shear wave velocity, between the surface and the depth H defined by

H= 30 m if $H_{800} \geq$ 30m ($v_{S,H}$ is then designated as $v_{S,30}$)
H= H_{800} if H_{800} < 30m.

If the information on H_{800} and/or $v_{s,H}$ is not available or it is incomplete, **Annex B** may be used.

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: site amplification factors



conservative default values to be used in case of incomplete information

short-period site amplification factor

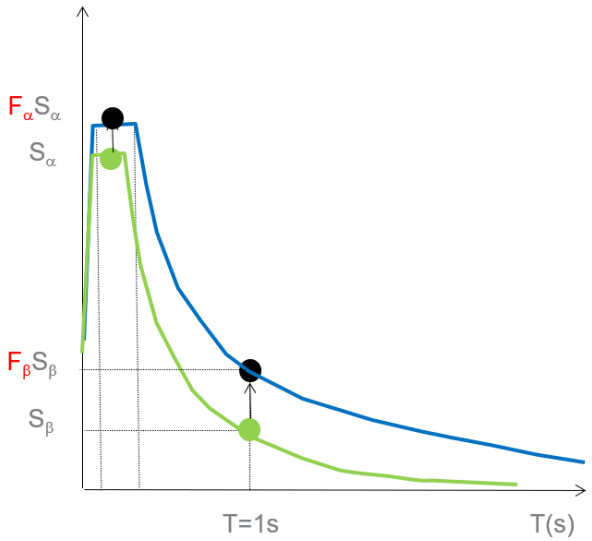
intermediate-period site amplification factor

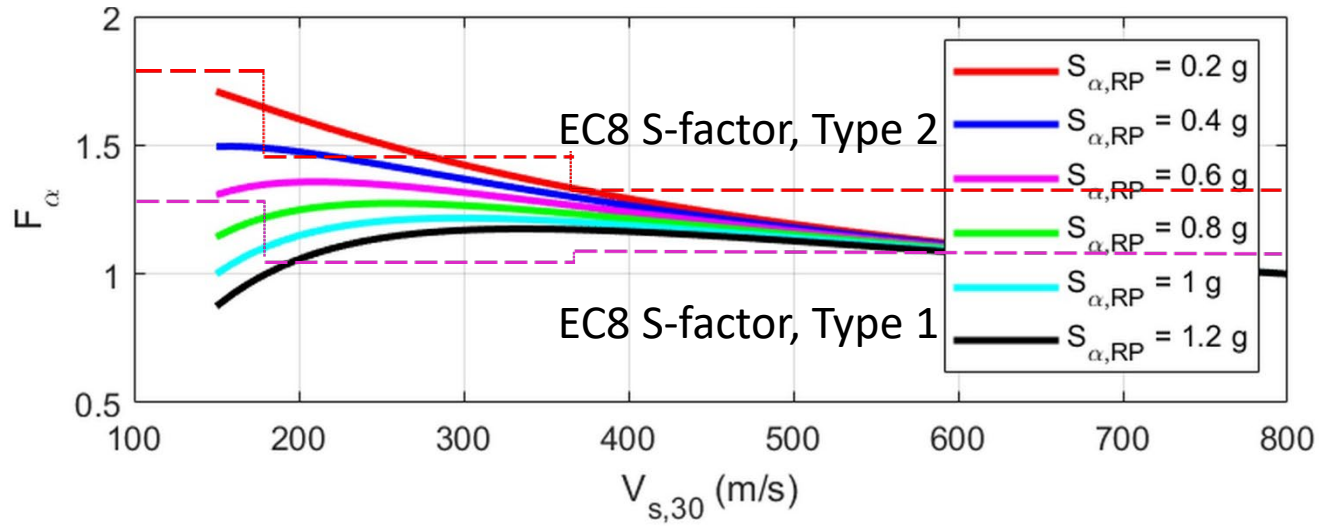
Site category	F_α		F_β	
	H_{800} and $V_{s,H}$ available	Default value	H_{800} and $V_{s,H}$ available	Default value
A	1,0	1,0	1,0	1,0
B	$\left(\frac{V_{s,H}}{800}\right)^{-0,40r_\alpha}$	$1,3 * (1 - 0,1 * S_{\alpha,RP}/g)$	$\left(\frac{V_{s,H}}{800}\right)^{-0,70r_\beta}$	$1,6 * (1 - 0,2 * S_{\beta,RP}/g)$
C		$1,6 * (1 - 0,2 * S_{\alpha,RP}/g)$		$2,3 * (1 - 0,3 * S_{\beta,RP}/g)$
D		$1,8 * (1 - 0,4 * S_{\alpha,RP}/g)$		$3,2 * (1 - S_{\beta,RP}/g)$
E	$\left(\frac{V_{s,H}}{800}\right)^{-0,40r_\alpha \frac{H}{30}\left(4-\frac{H}{10}\right)}$	$2,2 * (1 - 0,5 * S_{\alpha,RP}/g)$	$\left(\frac{V_{s,H}}{800}\right)^{-0,70r_\beta \frac{H}{30}}$	$3,2 * (1 - S_{\beta,RP}/g)$
F	$0,90 \cdot \left(\frac{V_{s,H}}{800}\right)^{-0,40r_\alpha}$	$1,7 * (1 - 0,4 * S_{\alpha,RP}/g)$	$1,25 \cdot \left(\frac{V_{s,H}}{800}\right)^{-0,70r_\beta}$	$4,0 * (1 - S_{\beta,RP}/g)$
	$r_\alpha = 1 - \frac{S_{\alpha,RP}/g}{V_{s,H}/150}$; $r_\beta = 1 - \frac{S_{\beta,RP}/g}{V_{s,H}/150}$			

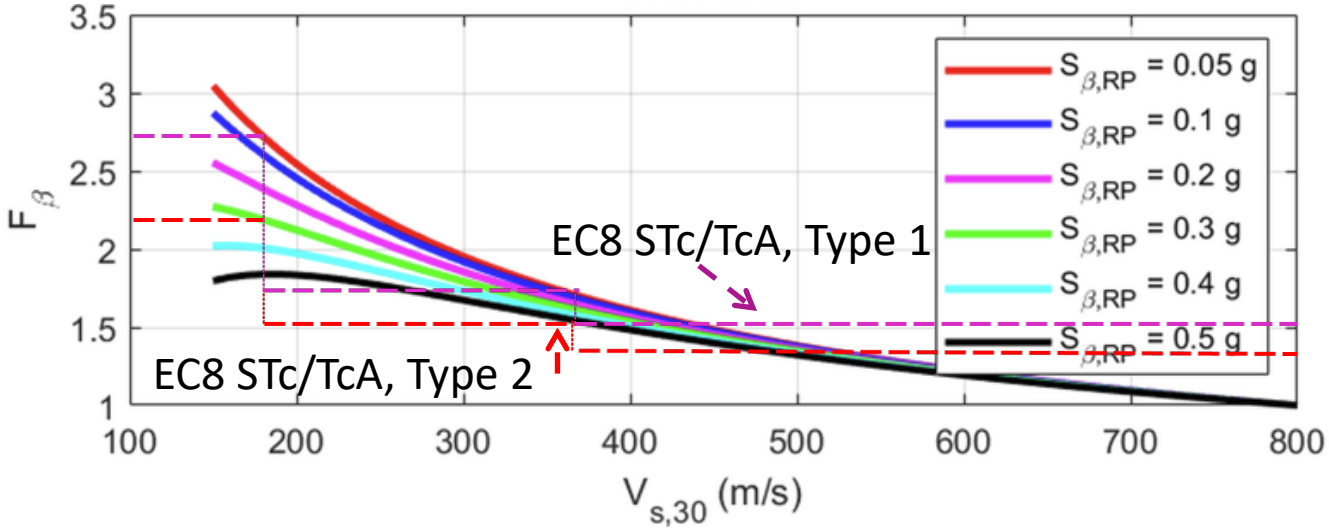
correction factors to account for non-linear site effects

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: site amplification factors (comparison with current EC8 and NEHRP)





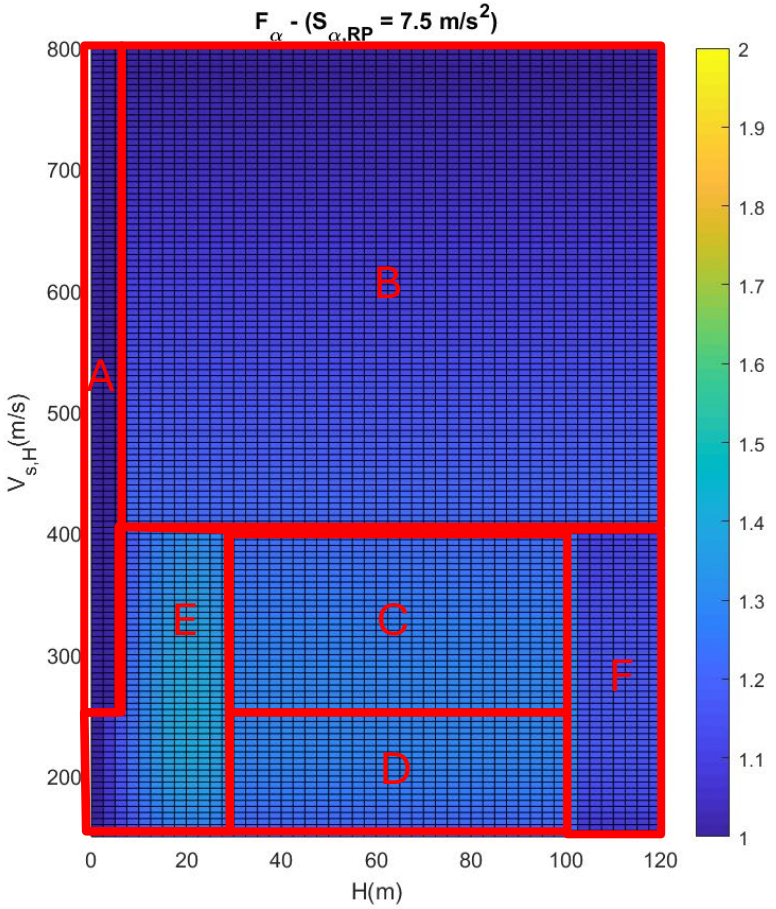


EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

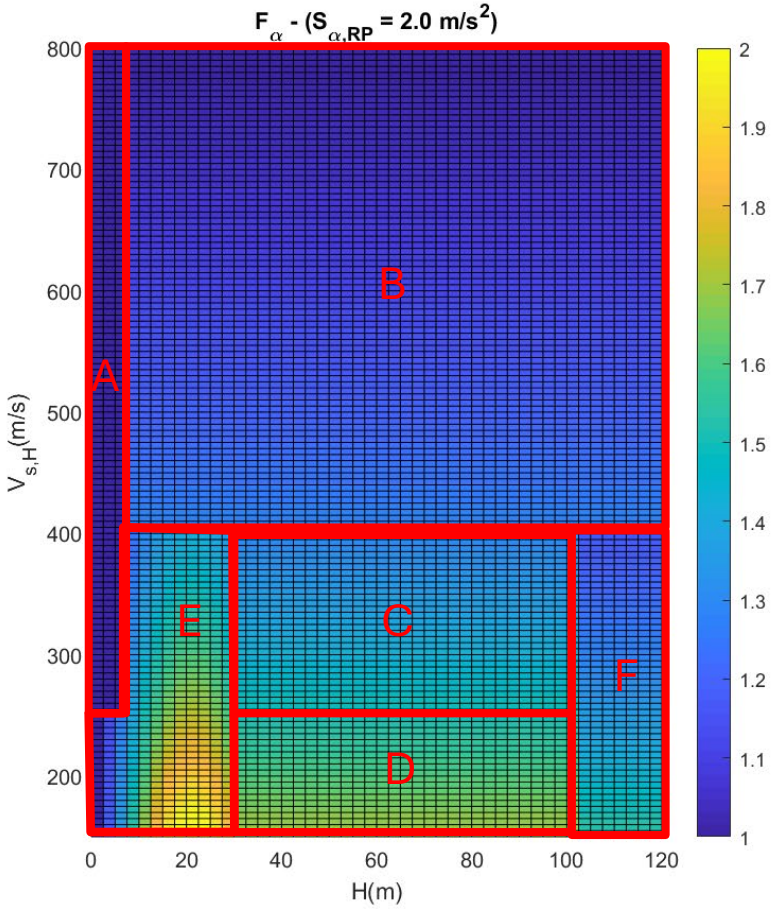
EN1998-1-1: site amplification factors (continous)

F_α

high seismicity



low seismicity

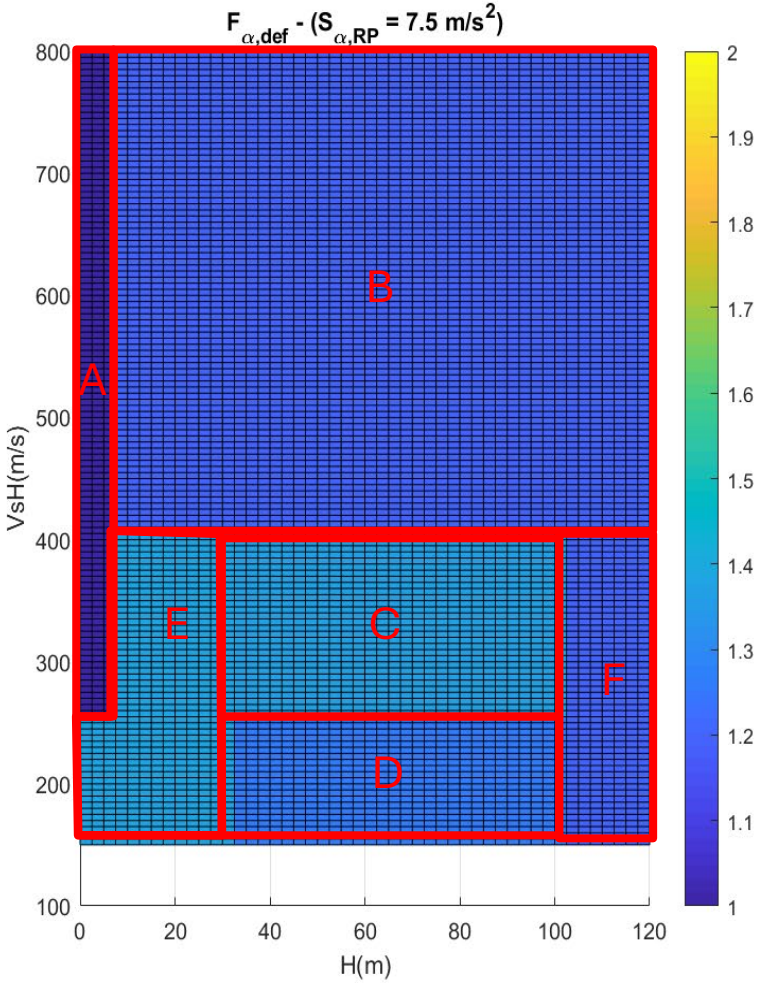


EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

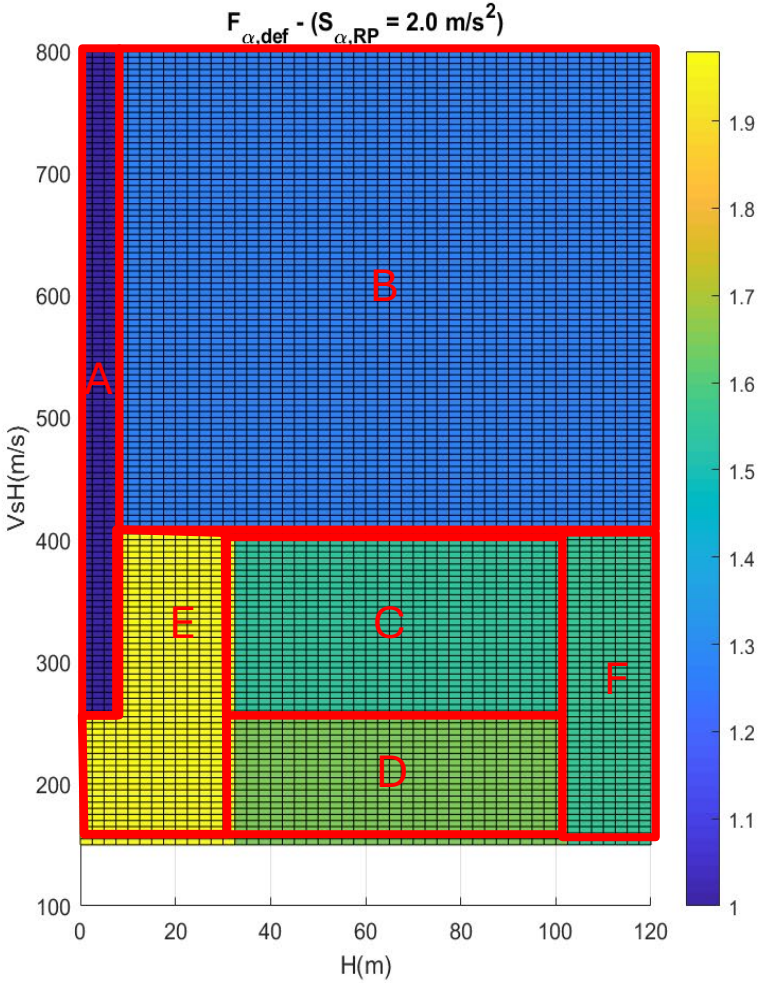
EN1998-1-1: site amplification factors (default)

$F_{\alpha,default}$

high seismicity



low seismicity



EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: remarks on the reference site category

The site amplification factors should be consistent with the reference conditions of the seismic hazard model that the seismic norms are based upon.

If the ESHM20 model for European Seismic Hazard is assumed, the reference site condition is V_{s30}=800 m/s, that does not coincide with the site category A ($V_{s30}\geq$800 m/s).

As a consequence, for the sites of category A harder than $V_{s,30}$ = 800 m/s, the ESHM20 model makes an “implicit” over-estimation of seismic hazard.

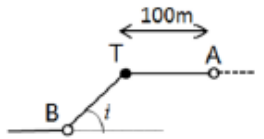
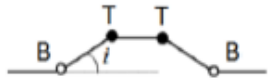
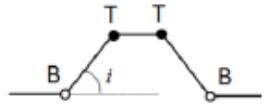
In other international codes, harder site categories are considered. This was avoided in the EC8 1-1, essentially aiming at ease-of-use.

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Topography amplification factor

(10) If topographic irregularities of height greater than 30 m are present, with average slope angles larger than 15°, and only for ground types A and B, a period-independent topography amplification factor F_T should be applied, evaluated according to Table 5.5. In the other cases, the value $F_T = 1$ should be used.

Table 5.5 — Topography amplification factors for simple topographic irregularities

Topography description	F_T	Simplified sketch*
Flat ground surface, slopes and isolated ridges with average slope angle $i < 15°$ or height < 30 m	1,0	
Slopes with average slope angle $i > 15°$	1,2	
Ridges with width at the top much smaller than at the base and average slope angle $15° < i < 30°$	1,2	
Ridges with width at the top much smaller than at the base and average slope angle $i > 30°$	1,4	

* Values of F_T in the second column refer to the top locations (point T in the simplified sketches). A linear decrease of F_T is considered between point T and point B (base) and point A (located at 100 m distance from T), where $F_T = 1$ applies.

(11) Site-specific studies may be carried out according to the general criteria specified in Annex C, to quantify the topography amplification with an improved level of accuracy, accounting for its frequency dependency

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex B: Alternative identification of site categories (1)

B.3 Simplified identification of site categories

(1) A simplified identification of site categories may be obtained from the combined use of Table B.1 and Table B.2.

(2) If site category is identified based on (1), default values in Table 5.4 should be used.

Table B.1 Simplified description of site categories.

Site category	
A	Rock or other rock-like geological material, including very shallow layers of very dense, dense or medium-dense sand, gravels, very stiff or stiff clay.
B	Deposits consisting prevalently of very dense sand, gravel, or very stiff clay, with representative values of the geotechnical parameters in the range defined in Table A.2 for stiff ground.
C	Intermediate depth deposits consisting prevalently of dense or medium-dense sand, gravel or stiff clay, with representative values of the geotechnical parameters in the range defined in Table A.2 for medium ground.
D	Intermediate depth deposits consisting prevalently of loose-to-medium cohesionless soil, or of soft-to-firm cohesive soil, with representative values of the geotechnical parameters in the range defined in Table A.2 for soft ground.
E	Shallow soil deposits consisting of prevailing alluvium layers, underlain by rock-like materials as described for site category A. Representative values of the geotechnical parameters are in the range defined in Table A.2 for medium or soft ground.
F	Deep deposits consisting of prevailing alluvium layers, with representative values of the geotechnical parameters in the range defined in Table A.2 for medium or soft ground.

Table B.2 Correspondence between ground class and geotechnical parameters

Test	Parameter		Ground class		
			stiff	medium stiffness	soft
SPT	N_{60} (SPT, ER = 60%) [blows/30cm]		> 60	30-60	15-30
CPT	q_c – sands (MPa)		> 30	15-30	5-15
	q_c – clays (MPa)		> 6	3-6	1,5-3
FVT or lab tests	c_u (kPa)		> 300	150-300	50-150
PMt	E_m (MPa)		25-100	8-25	4-8
	p_{lim} (MPa)	Sand	2,0-5,0	1,2-2,0	0,4-1,2
		Clay	>1,2	0,7-1,2	0,3-0,7

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex B: Alternative identification of site categories (2)

B.4 Case of incomplete quantitative information for identification of site categories

B.4.1 Missing direct measurements of Vs or values available only to a limited depth

(1) If direct measurements (…) are not available, the Vs profile may be estimated from well-established empirical correlations (…).

(2) If the Vs profile, obtained either according to direct measurements or according to (1), is available down to a depth 10 m $\leq z_d \leq$ 30 m and the top of bedrock formation has not been found, then the approximation given by Formula (B.1) may be used.

$$V_{s,H} = V_{s,z} \qquad (B.1)$$

where $V_{s,z}$ is the equivalent shear wave velocity calculated according to Formula (5.1) by replacing H with z_d.

NOTE Formula (B.1) provides in general a lower bound estimate of $V_{s,H}$, becoming more and more accurate as z_d approaches either H or 30 m.

(3) In case of strong soil profile irregularities, consisting of shallow stiff layers of several meters thickness over softer soil deposits, Formula (B.1) should not be used (…).

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex B: Alternative identification of site categories (3)

B.4 Case of incomplete quantitative information for identification of site categories

B.4.2 Missing quantitative information on H_{800}

(1) In alternative to the quantitative determination of H_{800}, the site category may be identified using Table B.3 by jointly considering $V_{s,H}$, either from direct measurements or from B.4.1, and f_0, i.e. the fundamental frequency of the soil deposit.

(2) In case site E category is obtained from Table B.3, the value of H to be used for application of formulas in Table 5.4 may be obtained by Formula (B.2).

$$H = V_{s,H}/4f_0 \qquad (B.2)$$

(3) As an alternative to (1) and (2), intermediate depth and deep soil deposits may also be identified from geological, geophysical or geotechnical information, including from microzonation maps.

(4) In case available information is not sufficient to discriminate between intermediate and deep soil deposits, the amplification factors should be evaluated according to a) and b):

a) for F_α consider intermediate depth soil deposits;
b) for F_β consider deep soil deposits.

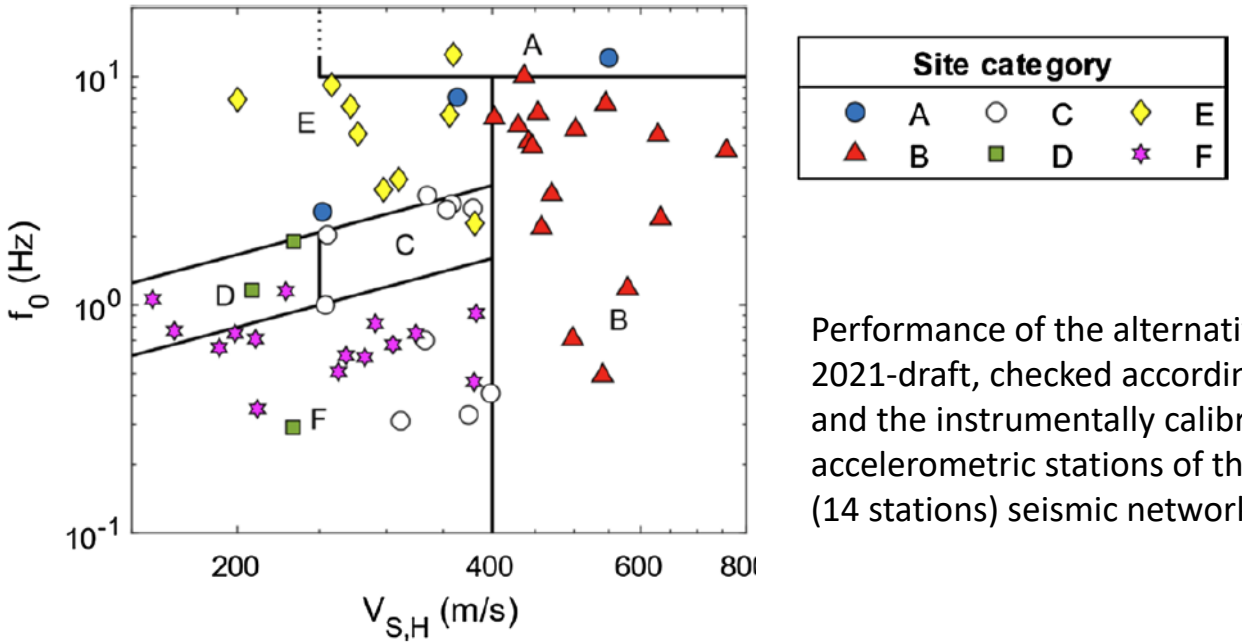
NOTE This is a conservative evaluation.

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex B: Alternative identification of site categories (4)

Table B.3 Site categorization based on $v_{s,H}$ and f_0

Combination of f_0 (Hz) and $V_{s,H}$ (m/s)	Site category
$f_0 > 10$ and $V_{S,H} \geq 250$	A
$f_0 < 10$ and $400 \leq V_{S,H} < 800$	B
$V_{S,H}/250 < f_0 < V_{S,H}/120$ and $250 \leq V_{S,H} < 400$	C
$V_{S,H}/250 < f_0 < V_{S,H}/120$ and $150 \leq V_{S,H} < 250$	D
$V_{S,H}/120 < f_0 < 10$ and $150 \leq V_{S,H} < 400$ or $f_0 > 10$ and $150 \leq V_{S,H} < 250$	E
$f_0 < V_{S,H}/250$ and $150 \leq V_{S,H} < 400$	F



Performance of the alternative site categorization scheme of 2021-draft, checked according to the available *Vs* profiles and the instrumentally calibrated f_0 values of 57 accelerometric stations of the Italian (43 stations) and Swiss (14 stations) seismic networks (Paolucci et al. 2021)

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex C: Site-specific elastic response spectra (1)

C.3 Site-specific elastic response spectra based on a local seismic hazard analysis

(1) According to 5.2.2.1(4), the elastic response spectrum for site category A may be defined based on a site-specific seismic hazard analysis. The shape of the site-specific spectrum may differ from that introduced in 5.2.2.2 for the horizontal component and in 5.2.2.3 for the vertical component. (…)

(2) A site-specific response spectrum based on a local seismic hazard analysis should be developed if the conditions in 5.1.1(5) apply (…)

5.1.1 General

(…)

(5) Specific analyses to account for the vicinity to well identified seismically active faults should be carried out if all the conditions a) to c) apply:

a) the return period, $T_{LS,CC}$, under consideration is longer than 1 000 years;

b) the maximum earthquake that the fault can generate has an expected moment magnitude Mw greater than 6,5;

c) the minimum distance of the site from the segment obtained by projecting the top edge of the fault to the ground surface is less than 5 km.

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Annex C: Site-specific elastic response spectra (2)

C.4 Site-specific elastic response spectra based on evaluation of local seismic wave amplification effects

(1) A site-specific elastic response spectrum may be obtained by seismic ground response analyses, aiming at evaluating the site amplification effects on seismic wave propagation with respect to a reference ground, hypothetically outcropping at the same site. (…)

(2) In the presence of complex geological or morphological conditions, such as steep topographic irregularities, deep valleys and basins, or vicinity of the site to the basin edge, the study should be based on 2D or 3D models.

(…)

(5) (…) NOTE Criteria for selecting and scaling input motions are provided in **Annex D.**

C.5 Limitations on site-specific spectral values

(1) (…)

(2) For all cases other than those addressed in (1), the site-specific elastic response spectrum should not be lower than 75% of the horizontal elastic response spectrum obtained from 5.2.2.2, for the same $v_{s,H}$ and site category and for the corresponding return period.

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

- Spectral description of the seismic action
- Site categorisation and site amplification factors
- **Other aspects of the seismic action**
- Conclusion

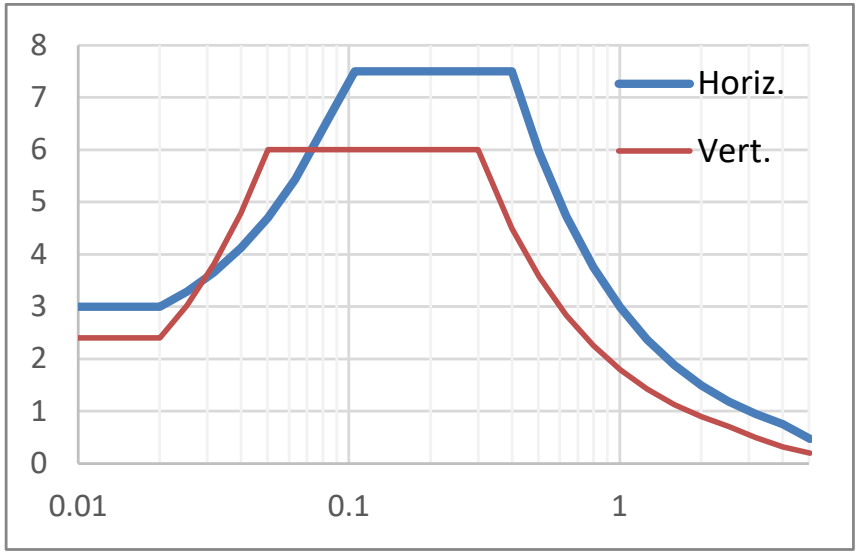
EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

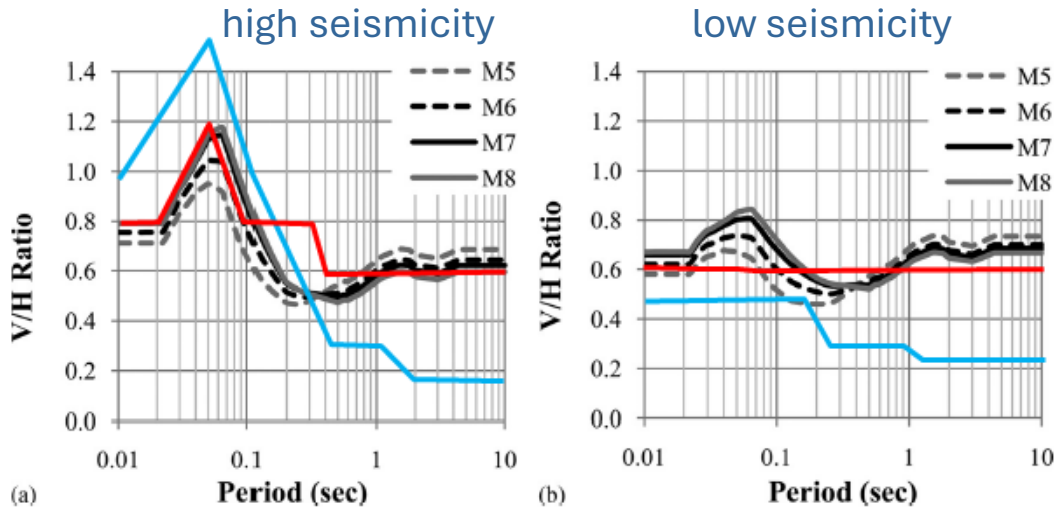
EN1998-1-1: Vertical elastic response spectrum

$$S_{\alpha v} = f_{v\alpha}\, S_{\alpha} \qquad f_{v\alpha} = \begin{cases} 0{,}6 & \text{if } S_{\alpha} < 2{,}5\ \text{m/s}^2 \\ 0{,}04\, S_{\alpha} + 0{,}5 & \text{if } 2{,}5\ \text{m/s}^2 \le S_{\alpha} \le 7{,}5\ \text{m/s}^2 \\ 0{,}8 & \text{if } S_{\alpha} > 7{,}5\ \text{m/s}^2 \end{cases}$$

$$S_{\beta v} = f_{v\beta}\, S_{\beta} \qquad f_{v\beta} = 0{,}6$$

$$T_{Bv} = 0{,}05\ \text{s}$$





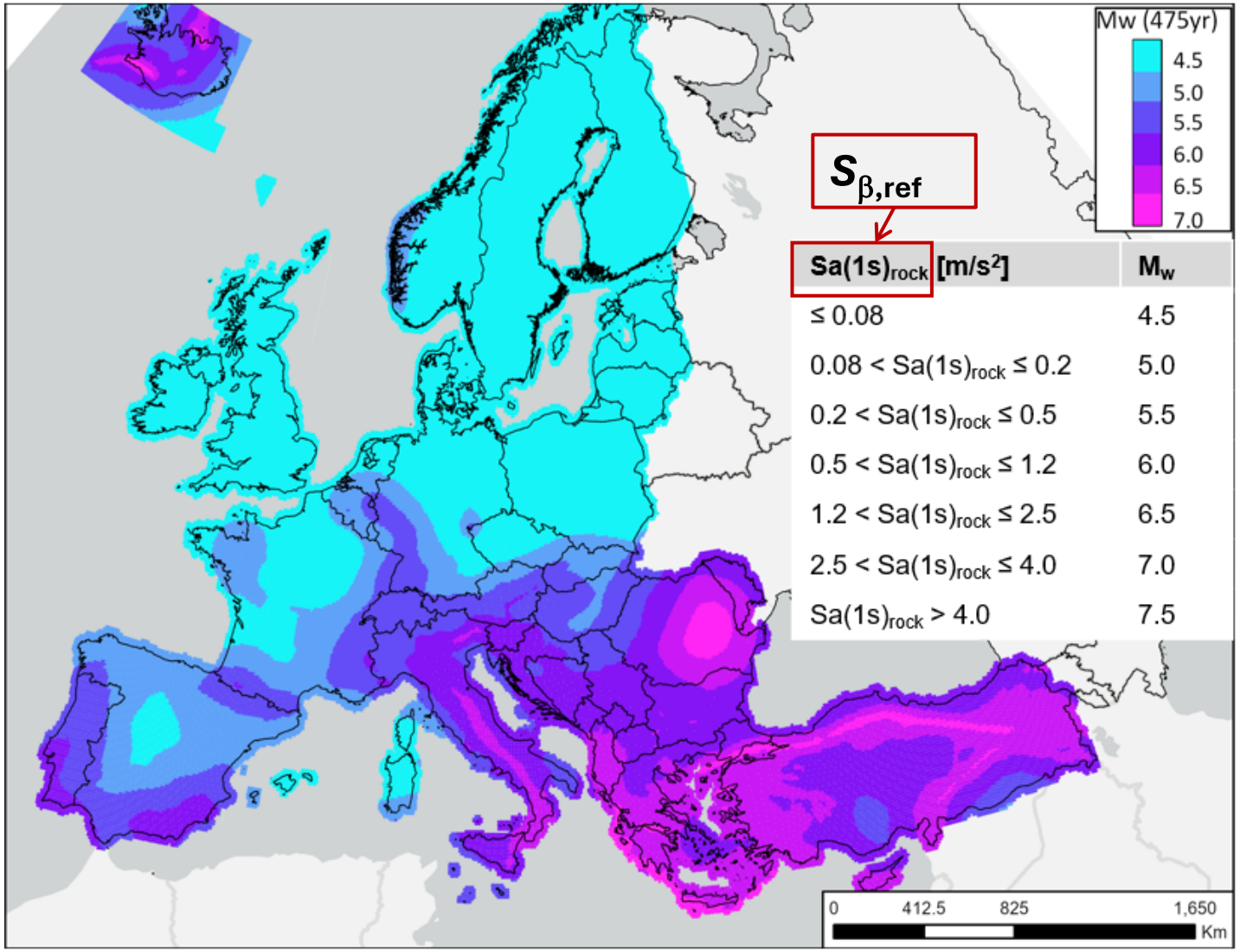
current EC8

next EC8

V/H from literature

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Conventional earthquake magnitude for design



Mapped values of the conventional earthquake Magnitude, for 475 years return period, according to the criteria introduced in the new EC8. Values of $S_a(1s)_{ref}$ are based on the ESHM20 model. Courtesy of L. Danciu.

Values of epicentral distances less than about 20 km are implicitly assumed …

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Design peak values

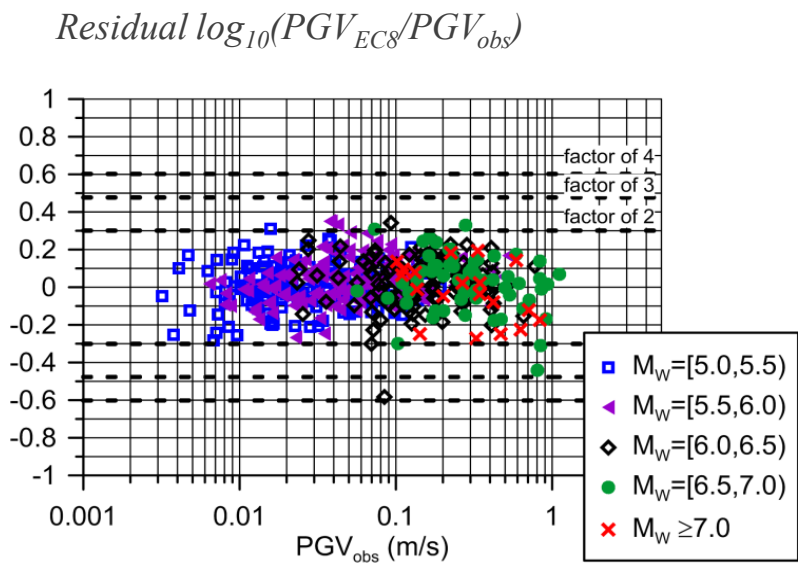
Displacement

$$PGD_e = S_{De}(T_F) = 0,025\, T_\beta T_D F_L\, F_T\, S_{\beta,RP}$$

F_L is the long period site amplification factor $\quad F_L = \left(\frac{v_{s,H}}{800}\right)^{-0,4}$

Velocity

$$PGV_e = 0,06\left(S_\alpha\, S_\beta\right)^{0,55}$$



→ Considerations on displacement and velocity are not anymore dispersed in other Parts of EC8

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

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EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

EN1998-1-1: Some remarks on site categorisation and site amplification factors

- ✓ the site categorisation in the EN1998-1-1 aims at **resolving with minimum ambiguities the variety of real foundation soils**
- ✓ the **smooth variability of site amplification factors** between adjacent soil categories reduces the criticality in selecting the site category
- ✓ the **resulting SAFs are close to the median values resulting from empirical Ground Motion Models**, supporting the hazard-consistency of the resulting spectra
- ✓ **reduction of site amplification factors for non-linear effects is limited**, leaving the possibility to take account larger effects of non-linear soil response within site-specific response analyses
- ✓ **simplified approaches are introduced in Annex B** in case of incomplete knowledge of site proxies
- ✓ an alternative soil categorization is introduced when $\mathbf{f_0}$ is known instead of soil thickness
- ✓ 2D-3D configurations are not dealt with explicitly, except for **site topography**

EN1998-1-1 - Spettri elastici di progetto ed effetti di sito

Grazie!