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Site classification and site effects in the seismic norms: Work in progress for the revision of Eurocode 8

R. Paolucci
Department of Civil and Environmental Engineering, Politecnico di Milano, Italy

ABSTRACT: In this paper an overview of the proposed criteria for site categorization and calculation of site amplification factors is presented, according to the final draft submitted by the Project Team 1 (CEN/TC250/SC8, 2018), in charge of redrafting the Part 1 of Eurocode 8, as regards performance criteria, seismic actions and general approaches for seismic analysis. A synthesis of the main requirements is illustrated, together with the comparison of the proposed site amplification factors with those adopted in the present Eurocode 1 Part1, and with those resulting from available ground motion prediction models calibrated on European records. Simplified criteria to be adopted when a complete site information is missing are presented, together with the alternative use of a site categorization based on f_0 (fundamental frequency of the soil deposit) instead of H_{800} (thickness of the soil deposit)

1 INTRODUCTION

As for the other structural Eurocodes, Eurocode 8 (EC8) is undergoing a major revision process that in the next years will progressively involve its different parts. Part 1 of EC8 is among the first ones that is being updated, as regards the seismic actions for design, seismic design criteria and methods of analysis.

One of the key and most debated problems for the seismic actions to be introduced into the norms is the definition of site amplification factors and its connection with classification of different soil types. The question is wide, and reflects the experiences and interests of different European regions with different prevailing site conditions, such as Scandinavia, where the dominance of thin soft clay layers may induce large amplification at high frequencies, or middle Europe, where at the opposite, geological conditions are dominated by thick soil sediments. The constrains are different: – the code should be simple and easy-to-use; – soil classification should be easily understandable by practicioners and directly related to well calibrated site amplification factors; – the classification should be quantitative, based on a limited number of parameters; – although it should be simple, the classification should be detailed enough to cover with no ambiguity the variety of stratigraphic profiles that may be present in whatever country of Europe; – the number of nationally determined parameters within the norms should be reduced, in order for the norm to be as widely as possible recognizable as a European norm; – there is a strong request that new norms do not involve an unnecessary increase of construction costs. As obvious, such requirements are very hard to be complied simultaneously, with satisfaction of all stakeholders.

The present EC8 approach, based on the definition of different site classes, each associated to different site amplification factors and corner periods and low vs high seismicity levels, was questioned in various countries, which in some instances, such as Italy, Spain, Germany, proposed independently evaluated site amplification factors and different classification criteria with respect to the standard EC8 ones. The following issues are probably the most debated ones: – are additional parameters rather than $v_{s,30}$ alone needed to provide a more reliable soil classification, such as the fundamental frequency f_0 of the soil from microtremor measurements? – are available studies sufficient to associate to such additional parameters a reliable site amplification factor? – is it advisable to propose a continuous variation of site amplification factors as a function of $v_{s,30}$, in order to avoid strong jumps of seismic action when moving from one class to the other one? – are the present correlations of geotechnical parameters, such as results of SPT or CPT in situ tests, with v_s reliable enough to be used for this purpose? – what, if any, penalty to be prescribed if only a limited amount of information is available for site classification? – are the current site amplification factors suitable to account for non-linear soil response, or do they tend to overestimate site effects for large levels of input motion, and how to account in a simple way such non-linear effects? – in which conditions should site-specific response analyses be prescribed as mandatory?

And, last but not least, if and how results of microzonation studies can be explicitly included as a possible alternative approach for the definition of soil subdivision and site amplification factors for specific areas, in order to let the quantitative work made in the microzonation process of support for seismic design.

This paper summarizes the proposal on these topics submitted in the final draft by the Project Team 1 (CEN/TC250/SC8, 2018a), appointed by the Steering Committee SC8 to draft the revised Part 1 of Eurocode 8 (EC8), related to performance criteria, seismic actions and general approaches for seismic analysis. More details can be found in the background document to the PT1 draft (CEN/TC250/SC8, 2018b), made available for evaluation to the national standardization bodies.

2 SITE CATEGORIZATION

Within the general requirement of Eurocodes revision, i.e., ease-of-use and reduction of nationally determined parameters, the main objectives were set as follows:

a. to avoid the present ambiguities in the site categorization, especially as regards how the site category is associated to the soil deposit thickness;
b. to associate site categories to spectral site amplification factors, based on the results from recent research on European strong motion records, and that do not present strong jumps at the boundary between adjacent categories;
c. to present such factors in a homogeneous format, to be adopted both by low seismicity and high seismicity countries;
d. to allow site-specific ground response studies, whatever the ground type and the consequence class of the structure, providing reasonable limitations on the final results.

Definition of proxies for site categorization was probably the most debated issue, since, on one side, pursuing objective a) leads to increasing their number, but, on the other side, the ease-of-use requirement suggests to reduce it. Eventually, in order to provide a clear discrimination as a function of thickness of the soil deposits, a two proxies solution was adopted (see Table 1), i.e.

Table 1. Standard site categorization according to the EC8 draft (CEN/TC250/SC8, 2018a).

	Ground class	stiff	medium	soft
Depth class	$v_{s,H}$ range / H_{800} range	800 m/s > $v_{s,H}$ ≥ 400 m/s	400 m/s > $v_{s,H}$ ≥ 250 m/s	250 m/s > $v_{s,H}$ ≥ 150 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

- H_{800}, the depth of the bedrock formation identified by values of shear wave velocity v_s larger than 800 m/s,
- $v_{s,H}$, the equivalent value of the shear wave velocity of the superficial soil deposit, computed as the time-averaged weighted value:

$$v_{S,H} = \frac{H}{\sum_{i=1,N} \frac{h_i}{v_i}} \tag{1}$$

where h_i and v_i are the thickness and the shear-wave velocity of the *i*-th soil layer, N is the total number of soil layers from the ground surface down to the depth H, H = 30 m if $H_{800} \geq$ 30 m (in this case $v_{s,H}$ coincides with $v_{s,30}$); $H = H_{800}$ if $H_{800} < 30$ m.

Several simplifications are allowed in case the H_{800} and $v_{s,H}$ parameters are not available, as discussed in Section 4.

3 SITE AMPLIFICATION FACTORS

At variance with the present version of Eurocode 8 Part 1 (CEN, 2004), where seismic hazard is defined as a function of the single parameter a_g, i.e., the peak ground acceleration at ground category A, seismic hazard in the EC8 draft was defined based on the parameters $S_{\alpha,RP}$ and $S_{\beta,RP}$, corresponding, respectively, to the constant acceleration range of the horizontal 5% damped elastic response spectrum and to the T = 1 s vibration period, on the reference site category A and return period RP. This seismic hazard representation based on two parameter has the advantage to avoid the introduction of two fixed spectral shapes, as in the present EC8 with the discrimination of Type 1 (surface wave Magnitude Ms>5.5) and Type 2 (Ms<5.5) spectra. Therefore, by the suitable variation of $S_{\alpha,ref}$ and $S_{\beta,ref}$ throughout the national territory, each country may define the elastic design spectral shape in order to fit more closely the local seismic hazard.

The S_α and S_β values on site category other than A are defined as follows:

$$S_\alpha = F_T F_\alpha S_{\alpha,RP} \tag{2a}$$

$$S_\beta = F_T F_\beta S_{\beta,RP} \tag{2b}$$

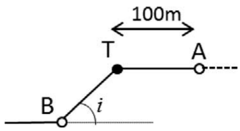
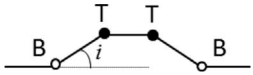
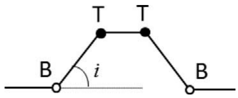
where F_T is the topography amplification factor, defined in Table 2, while F_α and F_β are the short and intermediate period (T = 1s) site amplification factors, defined in Table 3, as a contінous function of $v_{s,H}$ and H.

In Table 3, the r_α and r_β factors account for a non-linear reduction of the site amplification factors as a function of the intensity level.

Figure 1 provides a picture of the variability of F_α and F_β with $v_{s,H}$ for various intensity levels and intermediate depth conditions, while a comprehensive comparison of the proposed site amplification factors with those of the present EC8 Part1 is given in the Annex. In Figure 2 a comparison is shown between (left side) the period-dependent site amplification functions with respect to site category A deduced from two recent Ground Motion Prediction Equations (GMPEs) based on European records (Akkar et al., 2014; Bindi et al., 2014) and (right side) the ratio of elastic response spectra with respect to the ground type A, both from the existing EN 1998–1 (Type 1 and Type 2) and from the present proposal. Some comments are in order based on such comparison:

- the GMPEs do not distinguish shallow soil sites (category E), therefore the comparison should be considered for H > 30 m and take into account that results of GMPEs may be contaminated by such shallow soils;

Table 2. Topography amplification factors for simple topographic irregularities (CEN/TC250/SC8, 2018a).

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	

NOTE Values 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.

Table 3. Site amplification factors F_α and F_β for the standard site categories of Table 1 (CEN/TC250/SC8, 2018a).

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		1,20		1,60
C	$\left(\frac{v_{s,H}}{800}\right)^{-0,25 r_\alpha}$	1,35	$\left(\frac{v_{s,H}}{800}\right)^{-0,70 r_\beta}$	2,25
D		1,50		3,20
E	$\left(\frac{v_{s,H}}{800}\right)^{-0,25 r_\alpha \frac{H}{30}\left(4-\frac{H}{10}\right)}$	1,70	$\left(\frac{v_{s,H}}{800}\right)^{-0,70 r_\beta \frac{H}{30}}$	3,0
F	$0,90\cdot\left(\frac{v_{s,H}}{800}\right)^{-0,25 r_\alpha}$	1,35	$1,25\cdot\left(\frac{v_{s,H}}{800}\right)^{-0,70 r_\beta}$	4,0
	$r_\alpha = 1-2\cdot 10^3 \frac{S_{\alpha,RP}}{v_{S,H}^2}$; $r_\beta = 1-2\cdot 10^3 \frac{S_{\beta,RP}}{v_{S,H}^2}$ ($S_{\beta,RP}$ and $S_{\beta,RP}$ in m/s^2, $v_{s,H}$ in m/s)			

- while the Bindi2014 equations explicitly disregards an intensity-dependence of site amplification factors, because of lack of evidence from strong motion records, Akkar2014 account for a moderate dependence on peak ground acceleration (PGA);
- the r_α and r_β factors in Table 3 were calibrated in order for the resulting period dependent site amplification functions to approach results of GMPEs. As it can be seen by comparison of left and right columns of Figure 2 this is reasonably well established especially when considering the GMPE of Akkar2014;
- while there is an overall good agreement of site amplification functions for the high seismicity areas (Type 1 spectra of existing EN 1998–1), except for the case of $v_{s,30}$=200 m/s owing to the previously discussed limitations of the step-like variation of the existing EN 1998–1 factors, the site amplification functions for Type 2 spectra underestimate the long period amplification observed from strong motion records and made evident by the GMPEs.

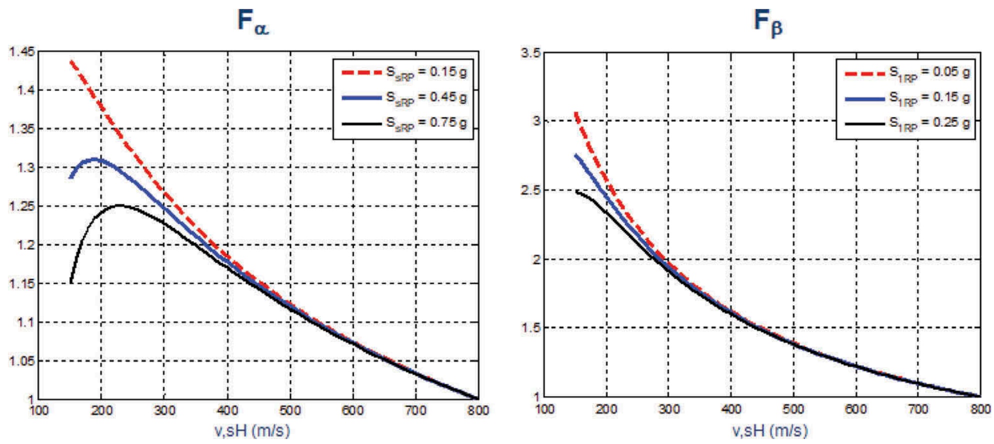


Figure 1. Site amplification factors F_α and F_β for different values of the intensity level and intermediate depth conditions.

4 SIMPLIFIED APPROACHES FOR SITE CATEGORIZATION

Annex A of the EC8 draft (CEN/TC250/SC8, 2018a) provides guidance for those situations where available information is not sufficient for a clear identification of the H_{800} and $v_{s,H}$ parameters, as summarized in Table 4.

Figure 3 shows the performance of such instrumental categorization, based on processing the available v_s profiles and instrumentally calibrated f_0 values from several accelerometric stations from both Italy and Swiss seismic networks. The proposed ranges, based on $v_{s,H}$ and f_0, fit reasonably well the site categories obtained based on $v_{s,H}$ and H_{800}.

Two examples of site categorization are provided for the soil profiles P1 and P2 in Figure 4. In both cases, the available vs values may either be based on direct measurements, or based on empirical correlations with geotechnical soil properties (Case 2 of Table 4).

Profile P1: since v_s is available down to a depth larger than 30 m, reference can be made to Case 1 of Table 1. $v_{s,H} = v_{s,30} = 260$ m/s is obtained, and, in the absence of further information, it is allowed to consider an intermediate depth class, providing site category C. For a more accurate identification of the site category, reference can be either made to geological, geophysical or geotechnical information, including microzonation maps, or to determination of f_0. In the latter case, assuming for example $f_0 = 0.8$ Hz from microtremor measurements, the site category based on Table 5 would be F.

Profile P2: in this case v_s is available only down to 15 m. Since the bedrock has not been found, the combination of Cases 3 and 4 in Table 4 should be considered and determination of f_0 is also required. Assume for example $f_0 = 2.5$ Hz and make the conservative approximation $v_{s,H} = v_{s,z}$=15 = 216 m/s. Based on Table 4, site category is E and $H = v_{s,H}/4/f_0 = 21.6$ m. The latter value of H is to be used together with $v_{s,H}$ for the evaluation of the site amplification factor from Table 3.

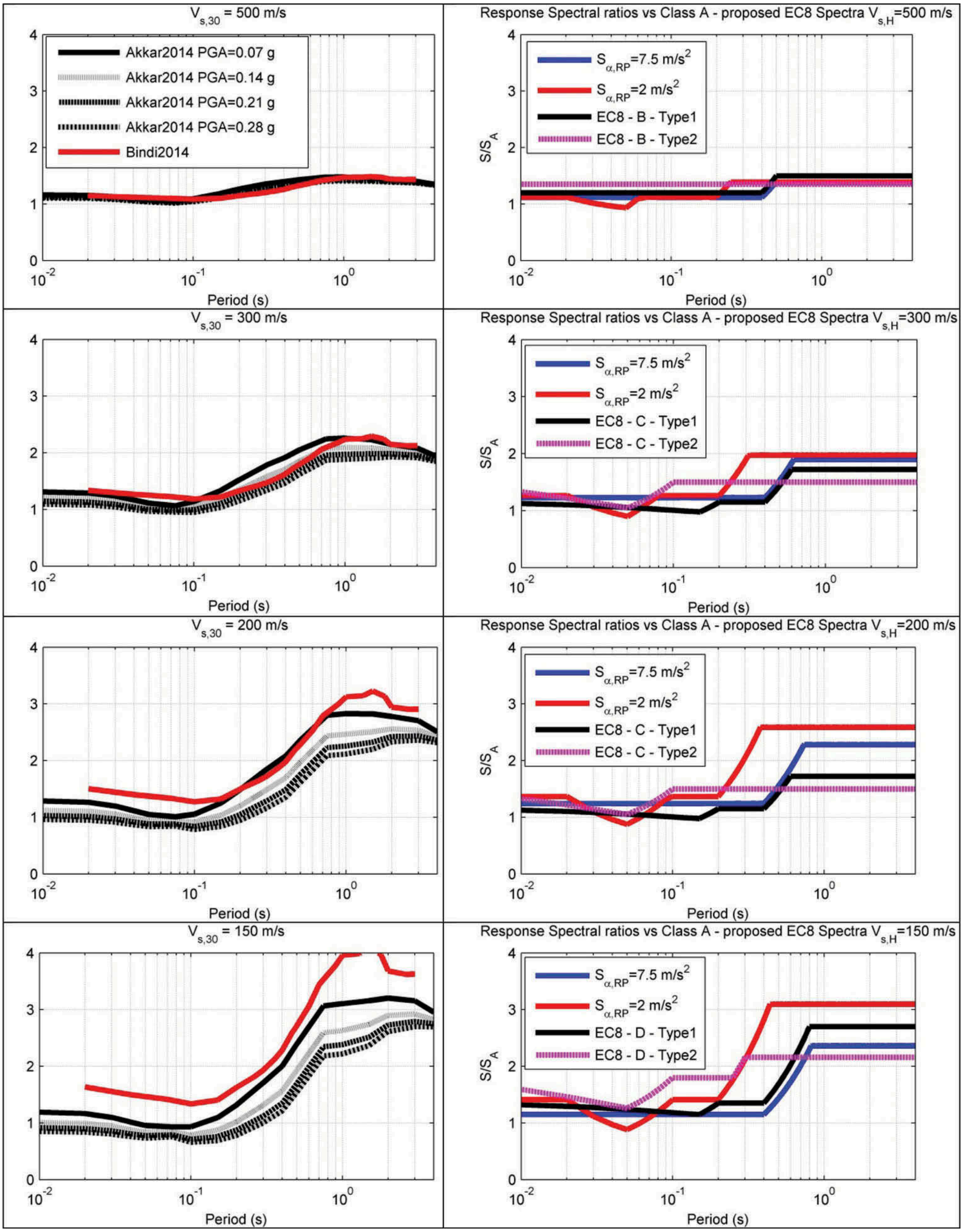


Figure 2. Left: Period dependent site amplification factors according to two recent GMPEs (Akkar et al., 2014; Bindi et al., 2014) for four values of $v_{s,30}$. Right: Ratio of elastic response spectra with respect to ground A type for EC8 (Type 1 and Type2) and according to this proposal (blue line: S_α=7.5m/s^2, S_β=3.0m/s^2; red line: S_α=2.0m/s^2, S_β=0.4m/s^2). From (CEN/TC250/SC8, 2018b).

Table 4. Suggested actions for the simplified site categorization (CEN/TC250/SC8, 2018b).

Case	What to do
1 v_s available in the first 30 m, but H_{800} not available	Estimate the site category according to alternative approaches a), b) or c): a. estimate depth class based on geological, geophysical or geotechnical information, including from microzonation maps; b. if the fundamental frequency of the soil deposit f_0 is available, estimate site category according to Table 5; c. if available information is not sufficient to discriminate between intermediate and deep soil deposits, the default selection should be the intermediate depth.
2 Direct measurements of v_s not available, but geotechnical parameters available down to at least 30 m	a. estimate the v_s profile from empirical correspondences of v_i with geotechnical parameters (provided in the Annex A of the draft), or from other well established empirical correlations, with due account of uncertainties; b. if H_{800} not available, proceed as in Case 1, 3 or 4.
3 direct measurements of v_s (or indirect estimates from empirical correspondances as in Case 2) available down to depth 10 m < z_d < 30 m, and the top of bedrock has not been found	a. verify that strong soil profile irregularities, such as shallow stiff layers over softer soil deposits, can be excluded; b. compute the equivalent shear wave velocity $v_{s,z}$ down to depth z_d, according to formula (1), replacing H with z_d; c. use the approximation $v_{s,H}=v_{s,z}$, that generally provides conservative values in view of the calculation of site amplification factors; d. proceed as in Case 4 for the evaluation of site category.
4 $v_{s,H}$ available (either from Case 1, 2 or 3), and the top of bedrock has not been found	a. estimate the fundamental frequency f_0 of the soil deposit; b. use Table 5 to estimate site category; c. if site category is E, then the value of H in the formulas of Table 3 should be estimated as $H = v_{s,H}/4f_0$.
5 all other situations not falling into Cases 1 to 4, (e.g., depth of investigation < 10 m), excluded for high seismicity areas	a. use Table 6 to relate the simplified geological description of the soil deposit to the site category; b. use default values of site amplification factors from Table 3

Table 5. Site categorization based on $v_{s,H}$ and f_0, the latter typically established based on microtremor measurements (CEN/TC250/SC8, 2018a).

Combination of f_0 (Hz) and $v_{s,H}$ (m/s)	Site category
$f_0 > 12$ and $v_{S,H} \geq 250$	A
$f_0 < 12$ and $800 > v_{S,H} \geq 400$	B
$v_{S,H}/250 < f_0 < v_{S,H}/120$ and $400 > v_{S,H} \geq 250$	C
$v_{S,H}/250 < f_0 < v_{S,H}/120$ and $250 > v_{S,H} > 150$	D
$v_{S,H}/120 < f_0 < 12$ and $400 > v_{S,H} > 150$ or $f_0 > 12$ and $250 > v_{S,H} \geq 150$	E
$f_0 < v_{S,H}/250$ and $400 > v_{S,H} > 150$	F

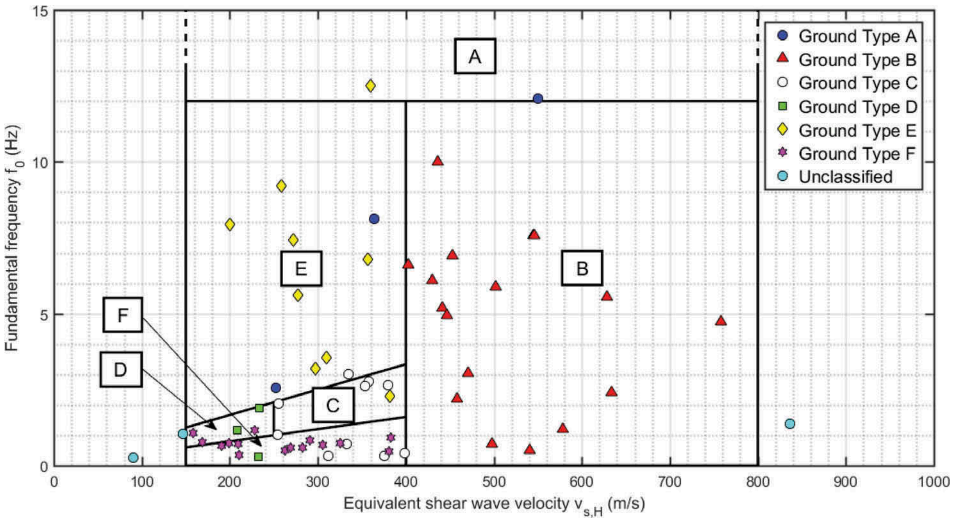


Figure 3. Check of the instrumental site categorization based on Table 5.2. For each point, the site category was identified based on vs,H and H800, as shown in the legend. From Aimar, 2018.

Table 6. Correspondence between the simplified geological description of the soil deposit and the site category. If this table is used for site categorization, default values of Table 3 should be adopted. (CEN/TC250/SC8, 2018a).

Description of the prevailing geological material in the shallow stratigraphic profile	*Site category*
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	A
Deposits of very dense sand, gravel, or very stiff clay	B
Intermediate depth deposits of dense or medium-dense sand, gravel or stiff clay	C
Intermediate depth deposits of loose-to-medium cohesionless soil, or of predominantly soft-to-firm cohesive soil.	D
Shallow soil deposits consisting of a surface alluvium layer of type C or D, underlain by stiffer material of type A.	E
Deep soil deposits consisting of prevailing alluvium layers of type C or D.	F

5 CONCLUSIVE REMARKS

The criteria for site categorization and calculation of site amplification factors proposed in the EC8 draft (CEN/TC250/SC8, 2018a) provide the following features:

- non ambiguous definition of site categories based on two parameters, related to velocity and thickness;
- possibility to use the fundamental frequency f_0 of the soil deposit if information on thickness is missing;
- simplified criteria covering all cases where information on the site is available for depths > 10 m;
- a continuous range of site amplification factors, covering from very shallow to very deep soils, calibrated based on the most recent ground motion prediction models in Europe;

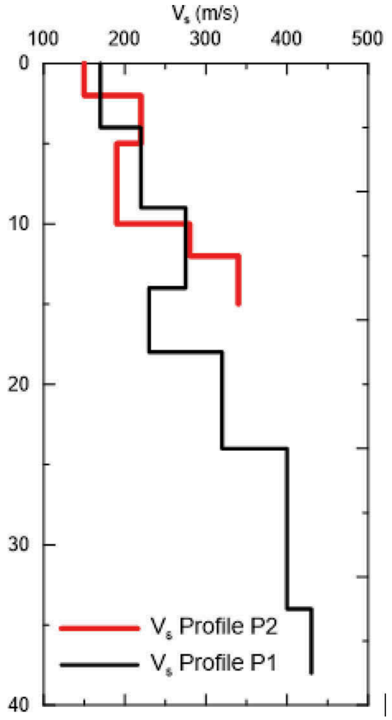


Figure 4. Sample vs soil profiles illustrated in the text for site categorization (CEN/TC250/SC8, 2018b).

- the possibility to use default (conservative) site amplification factors in the case the site categorization is based only on geological information;
- a closer interface between the site amplification factors of seismic norms and the results of seismic microzonation activities.

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