17th World Conference on Earthquake Engineering, 17WCEE
Sendai, Japan - September 13th to 18th 2020

TOWARDS THE REVISION OF EC8: PROPOSAL FOR AN ALTERNATIVE SITE CLASSIFICATION SCHEME AND ASSOCIATED INTENSITY-DEPENDENT AMPLIFICATION FACTORS

K. Pitilakis(1), E. Riga(2), A. Anastasiadis(3)

(1) Emeritus Professor, Aristotle University of Thessaloniki, kpitilak@civil.auth.gr
(2) Dr. Civil Engineer, Aristotle University of Thessaloniki, eviriga@civil.auth.gr
(3) Associate Professor, Aristotle University of Thessaloniki, anas@civil.auth.gr

Abstract

The current version of Eurocode 8 - Part 1 accounts for site effects through the suggestion of appropriate site-dependent elastic design spectra based on different soil classes. The main adopted parameter for site classification is the average shear wave velocity of the upper 30 m of the soil profile, $V_{s,30}$, which, despite its advantages, has been highly questioned for its appropriateness as a proxy to site amplification. The seismic hazard parameter used to define the elastic response spectra is the effective ground acceleration at rock site conditions (V_s>800m/s), a_g, amplified by a site class-dependent soil amplification factor, S, while soil nonlinearity is only indirectly taken into account through the suggestion of two different types of elastic response spectra for two different seismicity levels. The present work, which is based on a comprehensive analysis of a worldwide database of strong ground motion records from sites which dispose a very well-documented soil profile down to the seismic bedrock (V_s>800m/s), presents an alternative site classification scheme and associated intensity-dependent spectral amplification factors, aiming to contribute to the ongoing revision of Eurocode 8 (EC8). It is actually an evolution of the classification scheme proposed in the recent work by Pitilakis et al. (2018), which introduces herein the approximate depth to seismic bedrock, H_B, as main classification parameter for the estimation of seismic actions in addition to equivalent shear wave velocity $V_{s,H}$ (equal to $V_{s,30}$ in most cases). Moreover, the fundamental period T_0 of the site is used as a supplementary parameter allowing to better distinguish between specific subclasses. The main features of the new seismic design actions are summarized in the use of two anchoring spectral values, for short and intermediate periods, instead of only one of the present version of Eurocode 8 (i.e. PGA), and the scalar intensity variation of site amplification factors to account for soil nonlinearity. The effectiveness of the proposed classification system is compared to that of other classification systems using an inter-category error term, which represents the average dispersion of data within all categories of a given classification scheme.

Keywords: EC8; site classification; amplification factors

1. Introduction

Eurocode 8-Part 1 [1] accounts for site effects through the suggestion of appropriate site-dependent elastic design spectra based on different soil classes. The main adopted parameter for site classification in the current version of Eurocode 8 (EC8) is $V_{s,30}$, i.e. the average shear wave velocity of the upper 30 m of the soil profile, calculated from the total time needed for a shear wave to travel these 30 m. $V_{s,30}$ is used along with blow count N-SPT, plasticity index PI and undrained shear strength S_u to define five soil types (A to E), while two extra special ground types (S1 and S2) are also proposed for special soils (i.e. liquefaction prone sites etc.). The seismic hazard parameter used in the current version of EC8 to define the elastic response spectra is the effective ground acceleration at rock site conditions (V_s>800m/s), a_g, amplified by a soil amplification factor, S, which is dependent on the site class to account for local soil and site effects. Elastic response spectra are anchored to $S \cdot a_g$, and their shapes, defined by the corner periods T_B, T_C, T_D, are controlled by the site classes.

To indirectly account for soil nonlinearity, EC8 proposes different elastic response spectra for two different levels of seismicity and seismic action, Type 1 and Type 2. Type 1 spectra have more energy in long-period motions and are proposed for use in regions having high seismic activity and stronger earthquakes (M_s>5.5), while Type 2 spectra are recommended for $M_s \leq 5.5$, having larger normalized spectral amplitudes at short periods.

The use of $V_{s,30}$ as a proxy to seismic amplification has been questioned by several recent works and more specifically for cases of deep, low damping stiff deposits lying on much harder rock [2], for cases of a shallow velocity inversion [3], for sites with velocity profiles which are not monotonically increasing with depth or do not exhibit a strong impedance contrast in the first dozen meters [4] or in basin type structures like Adapazari basin in Turkey [5] . It is therefore more and more being argued that $V_{s,30}$ is not in all cases and site conditions the most appropriate indicator of soil amplification, resulting in the suggestion of alternative or supplementary indicators, such as depth-to-basement (e.g. [6]), average shear wave velocity over depths other than 30 m (e.g. 10-20 m) (e.g. [7]) or predominant site period/ frequency (e.g. [8]), as well as the proposal of alternative cite classification schemes (e.g. [9]). Zhu et al. [10] investigated different site characterization proxies alternative and complementary to $V_{s,30}$ and found that T_0 is the best-performing proxy when used a single proxy or complementary to $V_{s,30}$. Pitilakis et al. (2013) [11] proposed a new soil classification scheme appropriate for EC8, based on a comprehensive analysis of a worldwide database of strong ground motion records from sites which dispose a very well-documented soil profile (SHARE-AUTH database [11]). The main parameters considered for site classification are the average shear wave velocity of the entire soil deposit, $V_{s,av}$, the approximate thickness of the soil deposit above the seismic bedrock, H_B and the fundamental period of soil deposit, T_0, together with appropriate descriptive parameters of the geotechnical conditions. Moreover, following the basic rationale of the current version of EC8, i.e. the use of Type 1 and Type 2 elastic response spectra anchored to effective ground acceleration, Pitilakis et al. (2013) [11] proposed accompanying elastic response spectra for the soil classes of their soil classification scheme based on the conceptual assumption that the general spectral equations of the code should be higher than the median value and closer to the 84th percentile of the spectra of the strong-motion records of the SHARE-AUTH database, in order to account as much as possible for the uncertainties associated with the nature of the problem.

However, the most recent international seismic codes, as NEHRP 2015 [12] in the U.S.A., have moved to a more refined definition of elastic response spectra, where seismic hazard is introduced with two parameters, namely S_s (i.e. reference spectral acceleration at short periods) and S_1 (i.e. reference spectral acceleration at the vibration period T =1 s), instead of only one (effective ground acceleration) and nonlinearity in ground response is accounted for through a scalar variation of the site amplification factors F_a (for short periods) and F_v (for 1 s) for increasing seismic intensities. In line with the current version of NEHRP, and in the framework of the ongoing revision of EC8, Pitilakis et al. (2018) [13] improved the classification scheme by [11] and introduced (a) the use of two anchoring spectral values, for short and intermediate periods, instead of only one of the present version of Eurocode 8 and (b) intensity-dependent site amplification factors for each site category, to account for soil nonlinearity.

The present study, which continues to serve the ongoing revision of EC8, further elaborates the proposal by Pitilakis et al. (2018) [13]. In the classification scheme presented herein, the thickness of the soil deposit (i.e. depth of seismic bedrock), H_B and equivalent shear wave velocity of the superficial soil deposit, $V_{s,H}$ (equal to $V_{s,30}$ for soil deposits with depth greater than 30 m) are used as main classification parameters, while T_0 is provided as a supplementary parameter and is used to distinguish between specific subclasses. In addition, a simpler description of soil classes compared to the Pitilakis et al. (2013) [13] proposal is introduced, and amplification factors are re-estimated using the same procedure as in [13].

2. Proposed Soil Classification Scheme

Largely inspired from the soil and site characterization schemes of Pitilakis et al. [11, 13], the herein proposed classification scheme comprises six main soil classes, i.e. A, B, C, D, E and X, with sub-classes for site class B and C according to Table 1. Description of soil classes in the proposed scheme is simpler compared to the previous proposals [11,13], hence easier for application in common engineering practice. The two main classification parameters are the approximate thickness of the soil deposit capturing the main amplification effects, i.e. approximate depth of seismic bedrock, H_B (generally defined as the depth below which V_s exceeds 800 m/s) and equivalent shear wave velocity of the superficial soil deposit, $V_{s,H}$, defined in Eq. (1), which is equal to $V_{s,30}$ for soil deposits with depth greater than 30 m. T_0 is used as a supplementary parameter and to distinguish between specific subclasses, while correlations of soil classes with the average shear wave velocity of the entire soil deposit, $V_{s,av}$, and average values of standard penetration test blow count, N-SPT, and undrained shear strength, S_u are also provided. To obtain T_0 and $V_{s,H}$ or $V_{s,av}$, invasive (in-hole measurements) or non-invasive (e.g. surface-waves analysis) techniques at very small shear strains are suggested. In case of absence of direct measurement parameters, adequate correlations with SPT and CPT may be applied. Ranges of H_B, $V_{s,H}$, T_0 and $V_{s,av}$ for site classes of Table 1 were derived based on statistics from good quality experimental data from the SHARE-AUTH database and when needed from theoretical analyses of representative models of realistic soil conditions [14,15] applying classical statistics.

Equivalent shear wave velocity of the superficial soil deposit, $V_{s,H}$, and average shear wave velocity of the entire soil deposit, $V_{s,av}$, are defined as given in Eq. (1) and (2) respectively.

$$V_{s,H} = \frac{H}{\sum_{i=1}^{N} \frac{h_i}{v_i}} \tag{1}$$

$$V_{s,av} = \frac{H_B}{\sum_{i=1}^{Nb} \frac{h_i}{v_i}} \tag{2}$$

where:

h_i is the thickness of the i-th soil layer,
v_i is the shear-wave velocity of the i-th soil layer,
H_B is the depth to seismic bedrock
N is the total number of soil layers from the ground surface down to the depth H,
N_B is the total number of soil layers from the ground surface down to the depth H_B,
H = 30 m if $H_B \geq 30$ m ($V_{s,H}$ is then denoted by $V_{s,30}$);
= H_B if $H_B < 30$ m.

Table 1 – Proposed site categorization

Site class	**Description**	**H_B (m)**	**$V_{s,H}$ (m/s)**	**T_0 (s)**	**Remarks**
A	- Rock - Slightly weathered/ segmented rock formations with weathered layer of thickness z <5.0 m		≥ 800	≤ 0.2	For weathered zone: z<5m: $V_{s,av} \geq 300$ m/s
B1	- Weathered / soft rock - Shallow very stiff soil deposits, consisting either of very dense sand/gravel or very stiff to hard clay	≤ 30	300-800	0.2 ± 0.1	$V_{s,av}$: 400 - 800 m/s N-SPT > 50 S_u> 150 kPa
B2	Intermediate depth stiff soil deposits, consisting either of sand or clay, whose mechanical properties increase with depth	30 - 60	400-800	0.4 ± 0.2	$V_{s,av}$: 400 - 800 m/s N-SPT > 50 S_u> 150 kPa
C1	Deep stiff soil deposits, consisting either of sand/gravel or clay	> 60	400-800	0.6 ± 0.2	$V_{s,av}$: 400 - 800 m/s N -SPT> 50 S_u > 150 kPa
C2	Intermediate depth soil deposits, consisting of medium dense sand and gravel and/or medium stiffness clay (PI > 15, fines > 30%)	20 - 60	150-400	0.5 ± 0.2	$V_{s,av}$: 200 - 500 m/s N -SPT> 20 150 kPa> S_u>70 kPa
C3	Deep soil deposits, consisting of medium dense sand and gravel and/or medium stiffness clay	> 60	250-400	1.2 ± 0.5	$V_{s,av}$: 300 - 500 m/s N -SPT> 20 150 kPa> S_u >70 kPa
D	Deep soil deposits consisting of soft to medium stiffness clays and/or loose sandy to sandy-silt formations with substantial fines percentage (potentially non-liquefiable)	> 60	150-250	2.0 ± 0.8	$V_{s,av}$: 200 - 400 m/s N-SPT < 20 S_u < 70 kPa The dominant soil formations may be interrupted by layers of very soft clays (Su<25 kPa, W>40%, PI>25) or sands and sandy clays of relatively small thickness (<10m)
E	Shallow soil deposits, generally classified as type C2 or D according to its geotechnical propertied, which overlie type A formations	< 20	150-300	≤ 0.5	
X	Loose fine sandy-silty soils with high water table, potentially liquefiable Loose granular or soft silty-clayey soils, provided they have been proven to be hazardous in terms of dynamic compaction or loss of strength. Soils near obvious tectonic faults Steep slopes covered with loose soil deposits Recent loose landfills Soils with a very high percentage in organic material Peat and/or highly organic clays (H>3m) and/or very high plasticity clays (H>8m) and /or very thick. soft/medium stiff clays (H>30m) Loess Special soils and site conditions requiring site-specific evaluations - not included in types A – E				

The proposed site categorization is summarized in Table 2 in terms of depth and stiffness classes and is illustrated schematically in Fig. 1. The 536 sites of SHARE-AUTH database [11] are classified based on the herein proposed classification scheme according to Fig. 2.

Table 2 – Proposed site categorization in terms of depth and stiffness classes

	Stiffness class	stiff	soft to medium	very soft
Depth class	$V_{s,H}$ range H_B 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	$H_B \le 5$ m	A	A | E	E
shallow	5 m < $H_B \le 30$ m	B1	B1 | C2 | E	C2 | E
intermediate	30 m < $H_B \le 60$ m	B2	C2	C2
deep	$H_B > 60$ m	C1	C3	D

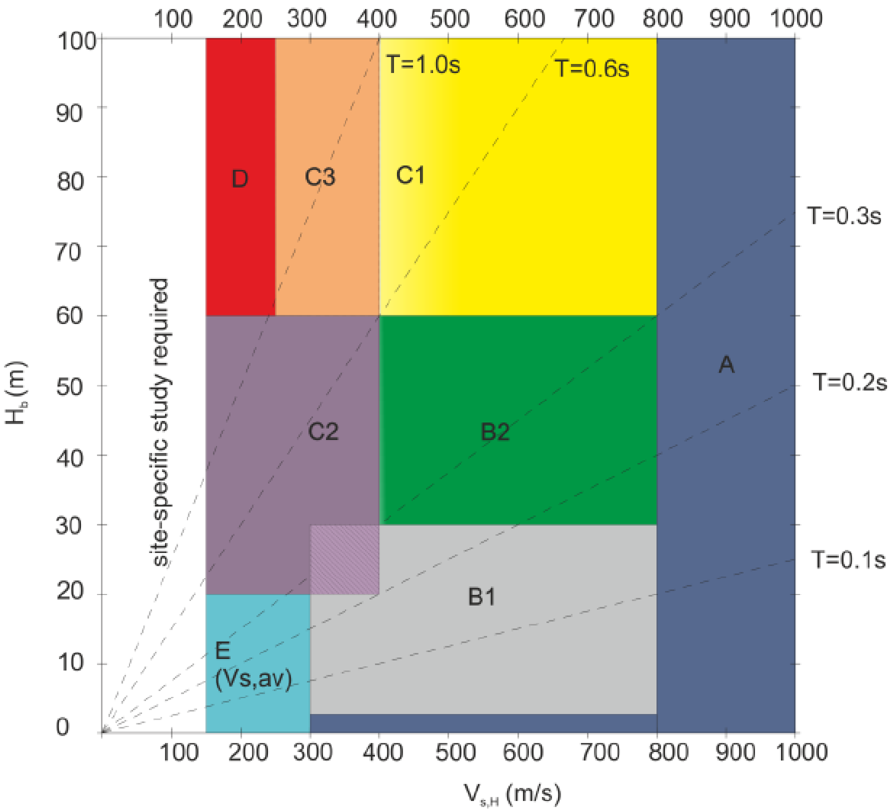

Fig. 1 – Illustration of ground types according to the proposed classification system of Table 1. Sites in the intersection of B1 and C2 are categorized in B1 or C2 according to the site period and their geotechnical properties

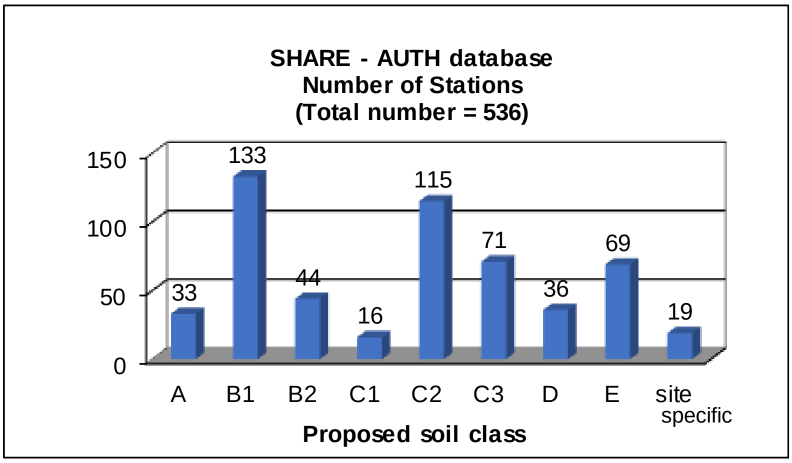

Fig. 2 – Classification of sites of SHARE-AUTH database [11] according to the proposed classification scheme.

3. Site amplification factors

Short period site amplification factor, F_s, and intermediate period (T1=1s) site amplification factor, F_1 for the soil classes of Table 1 are estimated for distinct values of S_{sRP} (reference maximum spectral acceleration at rock site conditions) following the approach described in detail in [13] and briefly presented herein. Amplification factors F_i (i=s,1) are considered to comprise two additive terms, i.e. a linear component, $F_{i,lin}$, which is practically independent of the amplitude of shaking, and a nonlinear component, $F_{i,nl}$, which modifies the linear term in order to decrease amplification for increasing shaking intensity:

$$F_i = \ln(F_{i,lin}) + \ln(F_{i,nl}), i = s, 1 \tag{3}$$

For the linear component, $F_{i,lin}$, the logic tree approach proposed by Pitilakis et al. (2013) [11] for Type 2 spectrum type [1] was applied for a subset of the SHARE-AUTH database [11], consisting of 336 strong motion records with surface wave magnitude $4 \leq M_s \leq 5.5$, PGA$\geq$20cm/s^2 and usable spectral period T$\geq$2.5s. First, the type 2 S factors and respective normalized spectra were estimated according to [11] for each soil class of Table 1. Then, the Type 2 period-dependent soil amplification factor were estimated for each soil class by normalizing the Type 2 elastic response spectrum of the specific soil class by the Type 2 spectrum for soil class A. The values of the period-dependent amplification factor corresponding to the constant acceleration branch of the spectrum and to T=1s were then identified, to obtain the linear terms for the short period site amplification factor, $F_{s,lin}$, and intermediate period site amplification factor, $F_{1,lin}$, respectively.

For the nonlinear term, $F_{i,nl}$, the nonlinear site amplification model developed by Seyhan and Stewart (2014) [16] and adopted in the Boore et al. (2014) [17] GMPE was used, which depends on $V_{s,30}$ and the amplitude of shaking on reference rock. Representative $V_{s,30}$ values for each soil class were selected as the median of $V_{s,30}$ values from the SHARE-AUTH database [11], shown in Table 3, following the rationale described in [16], according to which site amplification factors in codes reflect the observed distributions of within-category site conditions.

Table 3 – Representative $V_{s,30}$ values (in m/s) for the site classes of Table 1 obtained from statistical analysis of $V_{s,30}$ values of the SHARE-AUTH database [11]

Site class	Minimum $V_{s,30}$ (m/s)	Maximum $V_{s,30}$ (m/s)	Average $V_{s,30}$ (m/s)	Median $V_{s,30}$ (m/s)	16th percentile (m/s)	84th percentile (m/s)
A	603	1428	939	934	700	1148
B1	365	1122	604	592	462	731
B2	401	677	472	457	412	513
C1	400	681	480	461	424	525
C2	185	397	314	316	256	370
C3	250	395	316	309	273	356
D	159	249	203	199	176	226
E	232	1433	493	463	342	582

Site amplification factors F_s and F_1 were finally estimated for distinct values of S_{sRP} (reference maximum spectral acceleration at rock site conditions), equal to 0.125 g, 0.25 g, 0.5 g, 0.75 g, 1.0 g and 1.25 g as the sum of the linear and nonlinear components. The proposed values for F_s and F_1 (Tables 4 and 5) were obtained after adequate rounding. It is reminded that these values were estimated using for each class the median $V_{s,30}$ values of the SHARE-AUTH database [11] (Table 3). The use of the average $V_{s,30}$, also included in Table 3, as representative values would result in slightly higher amplification factors. For intermediate values of S_{sRP}, straight line interpolation of the values of F_s and F_1 of Tables 3 and 4 is suggested. For the computation of site amplification factors of site class X and for buildings of importance classes III or IV based on the current version of EC8 [1] located on sites classified as D or E, site-specific geotechnical investigation and dynamic site response analyses should be performed.

Table 4 – Proposed values for short period site amplification factor F_s

Site class	S_{sRP} (maximum response spectral acceleration at short period on site class A in g)					
	$S_{sRP}<0.25$	$S_{sRP}=0.25$	$S_{sRP}=0.5$	$S_{sRP}=0.75$	$S_{sRP}=1.0$	$S_{sRP}\geq1.25$
A	1.00	1.00	1.00	1.00	1.00	1.00
B1	1.30	1.30	1.30	1.20	1.20	1.20
B2	1.30	1.30	1.20	1.20	1.20	1.10
C1	1.70	1.70	1.60	1.50	1.50	1.40
C2	1.60	1.50	1.30	1.20	1.10	1.00
C3	1.70	1.60	1.40	1.20	1.20	1.10
D	1.80	1.70	1.50	1.40	1.30	1.20
E	1.70	1.60	1.60	1.50	1.50	1.40
X	-	-	-	-	-	-

Table 5 – Proposed values for intermediate period site amplification factor F_1

Site class	S_{sRP} (maximum response spectral acceleration at short period on site class A in g)					
	$S_{sRP}<0.25$	$S_{sRP}=0.25$	$S_{sRP}=0.5$	$S_{sRP}=0.75$	$S_{sRP}=1.0$	$S_{sRP}\geq1.25$
A	1.00	1.00	1.00	1.00	1.00	1.00
B1	1.10	1.10	1.10	1.10	1.10	1.10
B2	1.40	1.40	1.30	1.30	1.30	1.30
C1	1.50	1.50	1.40	1.40	1.40	1.40
C2	2.30	2.20	2.00	1.90	1.90	1.80
C3	2.40	2.30	2.10	2.00	2.00	1.90
D	4.00	3.50	3.00	2.70	2.40	2.30
E	1.20	1.10	1.10	1.10	1.10	1.10
X	-	-	-	-	-	-

4. Inter-category error term

The effectiveness of the herein proposed soil classification system was assessed and compared to the effectiveness of the previous proposals by Pitilakis et al. [11,13], as well as to the current EC8 soil classification system [1] and a very rough classification with only two soil classes (one with $V_{s,30}<400$ m/s and a second one with $V_{s,30}>400$ m/s), using an appropriate inter-category error term, σ_R [18,19]. This term, adopted also in [11], represents the average dispersion of data within all categories of a given classification scheme. In this way, the ability of each classification scheme to capture site-to-site variations of spectral acceleration can be quantified. The inter-category error term, σ_R, for a given classification scheme is calculated with the following equation:

$$\sigma_R = \sqrt{\frac{\sum_{i=1}^{M_C}\sum_{j=1}^{N_i}(\varepsilon_{ij}-\varepsilon_i)^2}{\left(\sum_{i=1}^{M_C}N_i\right)-df}} \qquad (4)$$

where M_c is the number of categories in the scheme, N_i is the number of records in site category i, df is the total number of degrees-of-freedom and ε_{ij} are the residuals of ground motion j within site category i. These residuals, which have a mean value ε_i, are calculated with the following equation:

$$\varepsilon_{ij} = ln(S_{ij})_{data} - ln(S_{ij})_{model} \qquad (5)$$

where $(S_{ij})_{data}$ is the amplification calculated from Eq. (9) and $(S_{ij})_{model}$ is the amplification prediction derived from least-squares regression analyses as follows:

$$ln(S_{ij})_{model} = a_i + b_i\, ln[(GM_r)_{ij}] + \varepsilon_{ij} \qquad (6)$$

a_i and b_i are the regression coefficients specific to site category i, and $(GM_r)_{ij}$ is the amplitude of reference ground motion. Peak reference ground acceleration (PGA_r) was selected as $(GM_r)_{ij}$, as in Stewart et al. (2003) [18].

Inter-category error terms, σ_R, for the classification scheme proposed herein, the previous proposals by Pitilakis et al. [11,13], the current EC8 scheme [1] and the rough classification with only two soil classes (soft / stiff) are plotted as a function of period in Fig. 3. We observe that σ_R error terms for the proposed classification scheme are at all periods much lower than the respective error terms for EC8 classification system. The differences are amplified for longer periods (T>0.4 s). This highlights the inadequacy of the current EC8 classification scheme, which is further emphasized by the comparison of the error terms between EC8 and the rough classification scheme; the improvement observed when using the existing EC8 classification system instead of the simplified two-class system is almost negligible and, in any case, less significant than when using the proposed classification system instead of that of EC8. Compared to the previous proposal by Pitilakis et al. [11,13], the current proposal results in error terms, which are at the same levels for periods less than 0.4, but slightly higher for the period range between 0.8 s and 1.4 s. This may be attributed to the fact that the previous proposals used the average shear wave velocity of the entire soil deposit, $V_{s,av,}$ as classification parameter, and not the equivalent shear wave velocity, $V_{s,H}$ (equal to $V_{s,30}$ for most cases).

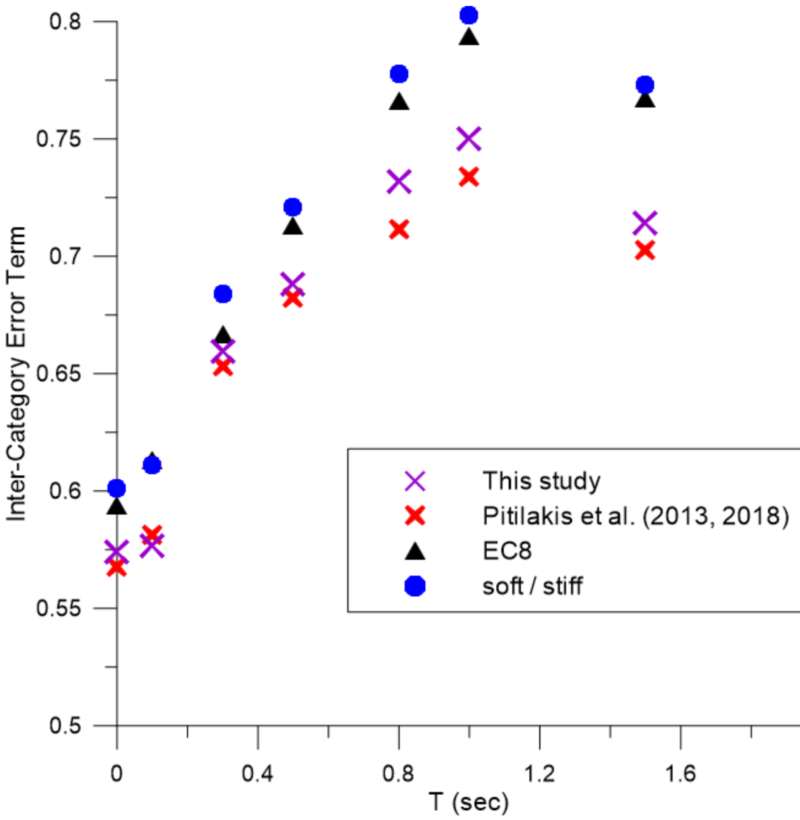

Fig. 3 – Comparison of inter-category error terms σ_R for the proposed classification scheme, the previous proposal by Pitilakis et al. [11,13], EC8 and a simplified classification system, as a function of period.

5. Conclusions

An alternative site classification scheme and associated intensity-dependent spectral amplification factors have been presented aiming to contribute to the ongoing revision of Eurocode 8. The new classification scheme, which is an evolution of previous proposals [11,13], introduces the approximate depth to seismic bedrock, H_B, as main classification parameter for the estimation of seismic actions in addition to equivalent shear wave velocity $V_{s,H}$ (equal to $V_{s,30}$ in most cases), while the fundamental period T_0 of the site is used as a supplementary parameter and to distinguish between specific subclasses. The proposed scheme is therefore much simpler to apply compared to [11,13]. The main features of the new seismic design actions are summarized in the use of two anchoring spectral values, for short and intermediate periods, instead of only one of the present version of Eurocode 8 (i.e. PGA), and the scalar intensity variation of site amplification factors to account for soil nonlinearity. The effectiveness of the proposed classification system is compared to that of other classification systems using an inter-category error term, which represents the average dispersion of data within all categories of a given classification scheme. The proposed classification system is found to exhibit an improved performance in terms of inter-category error σ_R compared to the current classification system of EC8 [1], and similar (or slightly reduced) performance compared to [11,13].

6. Conclusions

The authors would like to thank all the members of CEN/TC250/SC8 Working Group 4 “Seismic action and site classification” for the fruitful discussions held within this working group.

7. References

[1] CEN (2004): Eurocode 8: *Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*, European Standard EN 1998-1:2004.

[2] Dobry R, Iai S (2000): Recent developments in the understanding of earthquake site response and associated seismic code implementation. *Proceedings of GeoEng2000, an international conference on Geotechnical & Geological Engineering*, Melbourne, Australia.

[3] Di Giacomo D, Gallipoli MR, Mucciarelli M, Parolai S, Richwalski SM (2005): Analysis and modeling of HVSR in the presence of a velocity inversion: The case of Venosa, Italy. *Bulletin of the Seismological Society of America* **95** (6), 2364–2372.

[4] Mucciarelli M, Gallipoli MR (2006): Comparison between Vs30 and other estimates of site amplification in Italy. *Proceedings of First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland.

[5] Ozcep T, Ozcep F, Ozel O (2011): Comparison between Vs30 and earthquake amplifications, and their reliability for seismic design codes: Adapazari (Turkey) case. *Geophysical Research Abstracts* **13**, 9744–9744.

[6] Steidl JH (2000): Site Response in Southern California for Probabilistic Seismic Hazard Analysis. *Bulletin of the Seismological Society of America* **90** (6B), S149–169.

[7] Boore DM, Joyner WB (1997): Site amplifications for generic rock sites. *Bulletin of the Seismological Society of America* **87** (2), 327–341.

[8] Cadet H, Bard PY, Duval, AM, Bertrand E (2012): Site effect assessment using KiK-net data: part 2—site amplification prediction equation based on f0 and Vsz. *Bulletin of Earthquake Engineering* **10** (2), 451–489.

[9] Zhao JX, Irikura K, Zhang J, Fukushima Y, Somerville PG, Asano A, Ohno Y, Oouchi T, Takahashi T, Ogawa H (2006): An empirical site-classification method for strong-motion stations in Japan using H/V response spectral ratio. *Bulletin of the Seismological Society of America* **96** (3): 914–925.

[10] Zhu C, Pilz M, Cotton F (2020): Which is a better proxy, site period or depth to bedrock, in modelling linear site response in addition to the average shear-wave velocity? *Bulletin of Earthquake Engineering* **18** (3), 797-820.

[11] Pitilakis K, Riga E, Anastasiadis A (2013): New code site classification, amplification factors and normalized response spectra based on a worldwide ground-motion database. *Bulletin of Earthquake Engineering* **11** (4), 925–966.

[12] BSSC (Building Seismic Safety Council) (2015): *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*. FEMA P-1050-1/2015 Edition 2015.

[13] Pitilakis K, Riga E, Anastasiadis A, Fotopoulou S, Karafagka S (2019): Towards the revision of EC8: Proposal for an alternative site classification scheme and associated intensity dependent spectral amplification factors. *Soil Dynamics and Earthquake Engineering* **126**.

[14] Pitilakis K, Gazepis C, Anastasiadis A. (2004): Design response spectra and soil classification for seismic code provisions. *Proceedings of 13th World Conference on Earthquake Engineering*, Vancouver B.C., Canada.

[15] Pitilakis K., Gazepis C, Anastasiadis A (2006): Design response spectra and soil classification for seismic code provisions. *Proceedings of the ETC-12 Workshop on Geotechnical Evaluation and Application of the Seismic Eurocode EC8 2003-2006*.

[16] Seyhan, E, Stewart JP (2014): Semi-Empirical Nonlinear Site Amplification from NGA-West2 Data and Simulations. *Earthquake Spectra* **30** (3), 1241–1256.

[17] Boore DM, Stewart JP, Seyhan E, Atkinson GM (2014): NGA-West2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes. Earthquake Spectra 30. *Earthquake Spectra* **30** (3): 1057-1085.

[18] Stewart JP, Liu AH, Choi Y (2003): Amplification factors for spectral acceleration in tectonically active regions. *Bulletin of the Seismological Society of America* **93** (1), 332–352.

[19] Stewart JP, Choi Y, Graves R (2005): Empirical characterization of site conditions on strong ground motion. *Technical Report 2005/01*, Pacific Earthquake Engineering Research Center, Berkeley, USA.