Soil amplification based on statistical analysis of NERIES European digital accelerometric data-base

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SUMMARY:
A new accelerogram distributed data-base has been created recently in the framework of NERIES Project. The eight European Networks, IGC, IST Azores, IST South Portugal, RAP, KOERI, ITSAK, ETHZ, IGN and ITDPC have contributed to the data-base with a total of 20,000 components. A working table organized by component (record) was created to assemble several parameters with engineering importance. It also contains local Magnitude, epicentral distance to the recording station, direction of component, and soil type at the station location.
A simple classification of the soil conditions associated to each station is available for all the contributing agencies and a more detailed soil classification based on EC8 classes exists for ITDPC, RAP, KOERI and IGN stations. We study the influence of the soil on the overall statistics of the entire data-base, in particular on magnitude and epicentral distance. Finally, comparisons are done with earthquake response spectra for Eurocode 8.

Keywords: *European accelerograms; PGA, PGV, HI; Spectral Shape; soil conditions, Eurocode 8.*

1. INTRODUCTION

In the frame of NERIES Project (2006) a distributed digital accelerometric data-base was developed by the Agencies participating (IGC, Institut Geològic de Catalunya; IST, Instituto Superior Técnico; ISTerre, Institut de Sciences de la Terre; KOERI, Kandilli Observatory and Earthquake Research Institute; ITSAK, Institute of Engineering Seismology and Earthquake Engineering; ETHZ, Swiss Federal Institute of Technology). Several tasks were developed: a detailed characterization of recording instruments and sites of the accelerometric stations; the development of a computer software to determine in a homogenized way a collection of waveform parameters of engineering interest; and the development of a web-portal (Earthquake Data Portal, 2011) to manage the access of users to retrieve parameter values and waveform data (Roca et al., 2011; Péquegnat et al., 2011).

These parameter values, besides waveforms, are important for a better characterisation of ground motion, and Earthquake Engineering uses them for the analysis of structural behaviour including damage assessment for risk mitigation.

In parallel, to the distributed data-base of accelerogram waveforms, we have compiled in an Events-Parameters table (Gassol, 2011) all the information related to earthquake sources (magnitude and epicentral distances) and to ground motion waveform parameters (PGA, PGV, AI, TD, CAV and HI, together with PSV(f) for 28 frequencies), which were computed by each agency in an homogeneous way.

In Oliveira et al. (2012) we have analysed, in a statistical way, the tendencies presented by ground motion parameters, considering either the entire set of data, or the data by classes of magnitude, epicentral distance and soil conditions.

A simple classification of the soil conditions associated to each station (Rock, R, Hard, H, and Soft, S) is available for all eight contributing agencies and a more detailed soil classification based on EC8 classes (A, B, C, D and E) exists for ITDPC, RAP, KOERI and IGN stations. We study the influence of the soil on the overall statistics of the entire data-base and their dependence on magnitude and epicentral distance.

These results allow discussing the dependence of soil amplification on R, H and S and for EC8 A, B and C soil classes based on a large set of accelerometric data representing weak and strong motion shaking. Comparisons with earthquake response spectra (ERS) for Eurocode 8 are also made.

2. DATA SETS CONTRIBUTING TO THE PRESENT STUDY

Figure 1a) shows a map with the location of the stations providing data (IGC, IST, RAP - Réseau Accélérometrique Permanent), KOERI, ITSAK, ETHZ, ITDPC - Dipartamento della Protezione Civil Italiana and IGN) and Figure 1b) presents the events recorded by the stations. A total of 37007 individual records (components) constitute this prototype (Earthquake Data Portal, 2011).

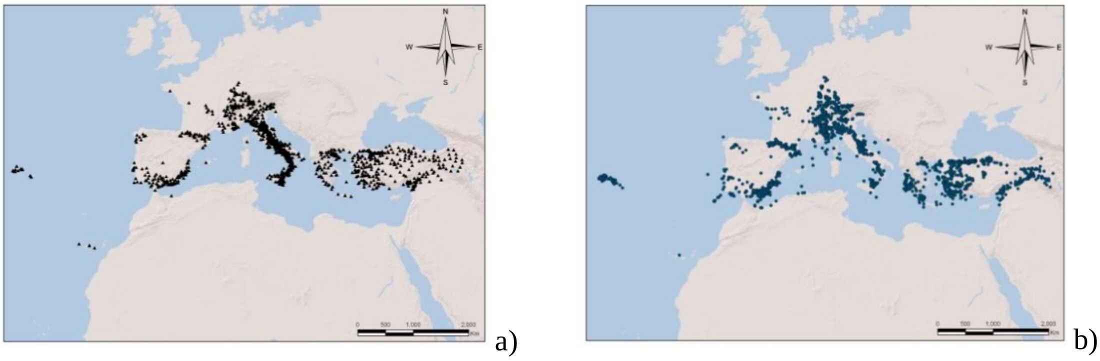

Figure 1. a) European station distribution providing preliminary data (courtesy S. Godey, 2010); b) Epicenters of recorded events (courtesy S. Godey, 2010)

The distributed data-base provides not only the raw and complete accelerograms, but also the response spectra and several engineering parameters computed by each contributing agency, in a homogeneous way for each record (component) using the software (PARAMACC), specially developed in the framework of NERIES (Roca et al., 2011).

A “working table” has been created to perform a complete analysis of all the available data. After a detailed evaluation of data quality, we retained events with M>3 for statistical analysis, and we have separated Azores Islands from South Portugal (S.P.) in the IST records (Gassol, 2011). This process has improved the quality of the final data-set permitting a statistical analysis with higher reliability. Moreover, the large number of data will allow establishing patterns of high statistical significance. This selection have reduced the total number of records (components) to 54% (19,961), essentially due to the elimination of events with M<3. The total number of stations is reduced to 510, with soil classification R, H and S. For approximately 60% of the selected records, i.e. for ITDC, IGN, KOERI and RAP stations, we dispose also of a more detailed classification on EC8 classes (12,288 individual records).The stations recorded 2,423 events with 3.0<M<7.4. The number of records (components) by each Network is shown in Table 2.1, with reference to the time interval of events and range of magnitudes.

Another observation should be made on the rather different number of stations and records per Network. While IST (South Portugal) and IGC have a small number of records (less than 200), ISTerre and KOERI (with more than 5,000 each), have more than half of the total number of records.

Table 2.1. Number of accelerometric (components) assembled in the working Table by Network, Stations, Dates, Events, magnitude range, epicentral distance (selected data) and number of records (components) (Gassol, 2011)

NETWORK	# Stations	Dates	# Events	Magnitude	Epic. Distance (km)	# components
IST Azores	21	1996-2006	159	3.0 - 5.9	1 - 253	786
IST (S.P.)	17	1996-2005	22	3.1 - 5.5	2 - 490	180
IGC	11	1996-2008	21	3.0 - 5.2	8 - 240	147
ESTerre/RAP	88	1995-2007	357	3.0 - 6.8	1 - 863	5232
KOERI	128	1998-2007	1076	3.0 - 7.4	1 - 653	6522
ETHZ	29	2003-2009	75	3.0 - 5.3	0 - 200	1902
ITSAK	39	2003-2008	362	3.0 - 6.9	2 - 496	1871
IGN	86	1993-2010	250	3.0 - 6.2	1 - 652	2226
ITDPC	91	1998-2004	101	3.0 - 5.6	1 - 477	1095
Total	510	1993-2010	2423	3.0 - 7.4	0 - 863	19961

To illustrate the importance of the assembled data-set, Figure 2 shows the distribution of PGA values of records on a magnitude-distance plot. All the analysis is done for the arithmetic average of both horizontal components[1]. Colours of dots are different for different bins of PGA values. It is very clear that this large amount of data points, covering a wide range of magnitudes and epicentral distances, is of great importance to check the attenuation phenomenon, especially for magnitudes up to M6. Similar attenuation trends are observed in plots of the other computed parameters.

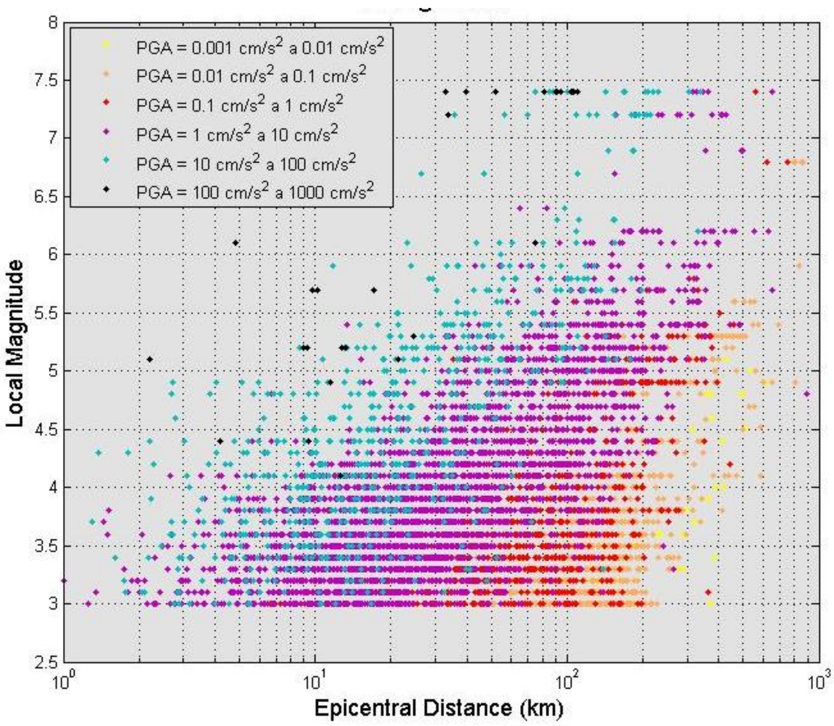

Figure 2. Distribution of the arithmetic average values of PGA of both horizontal components for all agencies, on a magnitude - distance plot

[1] Another criterion to combine horizontal components, namely the geometric mean, is not sensitive for the purpose of this paper due to the large number of samples analyzed.

3. SOIL DEPENDENCE OF THE ACCELEROMETRIC PARAMETERS

In order to study the soil influence in the ground motion we selected PGA as a parameter representing the high frequency content, PGV as medium frequency content and HI as overall frequencies content. Consequently, we concentrate in the analysis of the following accelerogram parameters: PGA, PGV, and HI, together with PSV(f) for 28 frequencies as a function of magnitude, epicentral distance and soil conditions for all data.

Dependence of horizontal components of PGA in magnitude and epicentral distance, without consideration of soil conditions have been analyzed in Oliveira et al. (2012).

As all stations have a soil classification as R, H and S, we start the analysis of data with this classification. Approximately 33% of the records are obtained in R, whereas 46% in H and 21% in S.

We consider the average of horizontal components of PGA, PGV and HI values multiplied by epicentral distance. Such distance normalization is supported by the attenuation relationships that generally are consistently proportional to the distance elevated to an exponent close to (-1) (Rey et al., 2002).

For illustration we have plotted in Figure 3, data points PGA*R normalized by the mean value of the distances in each bin for the range of magnitude 4-5 and for the following distance bins logarithmically equal-spaced: 1-10 km; 10-20 km; 20-50 km; 50-100 km; 100-200 km and >200 km. For each range of magnitude, mean value and standard deviation for data in each distance bin, for each R, H, S soil class were also computed.

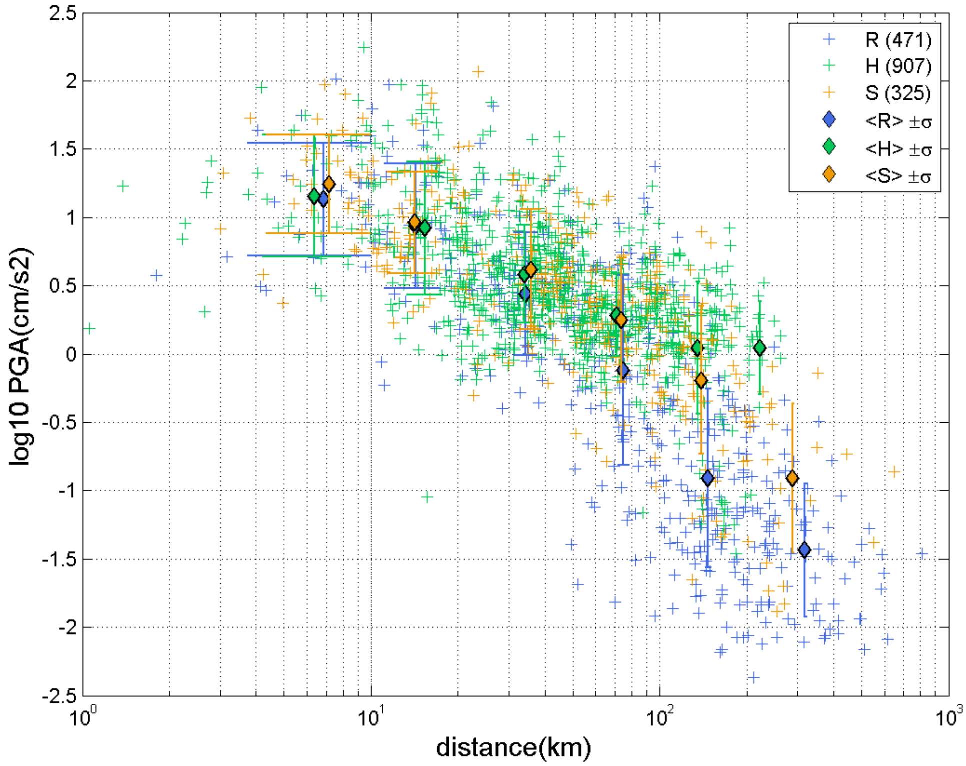

Figure 3. Arithmetic average of horizontal components of PGA values versus epicentral distances for the interval M4-5 with different soil classification (R, H and S). Number of data points for each soil class, mean value and standard deviation for $\log_{10}$ (PGA) data in each bin, for each soil class, are also shown.

This plot shows that R sites data present always lower values than H and S sites data. This clearly shows that H and S sites are amplifying ground motion (PGA) in relation to R sites. The same applies to PGV and HI. Due to the fact that there is no clear differentiation between H and S sites (Figure 3) we have analyzed in the same way, the data recorded in stations with available EC8 soil classification.

EC8 soil classes were defined essentially from Vs_{30} measurements for data provided by KOERI (Sandikkaya et al., 2010); RAP (Régnier et al., 2010) and ITDPC (Luzi et al., 2010). Data from IGN are classified based on geological criteria Alcalde (2012). EC8 (A, B, C, D and E) and (R, H, S) classifications in a total of 1174 stations have been compared in Figure 4. This last number corresponds to the total number of stations of these agencies and is greater than the number of stations which have recorded data.

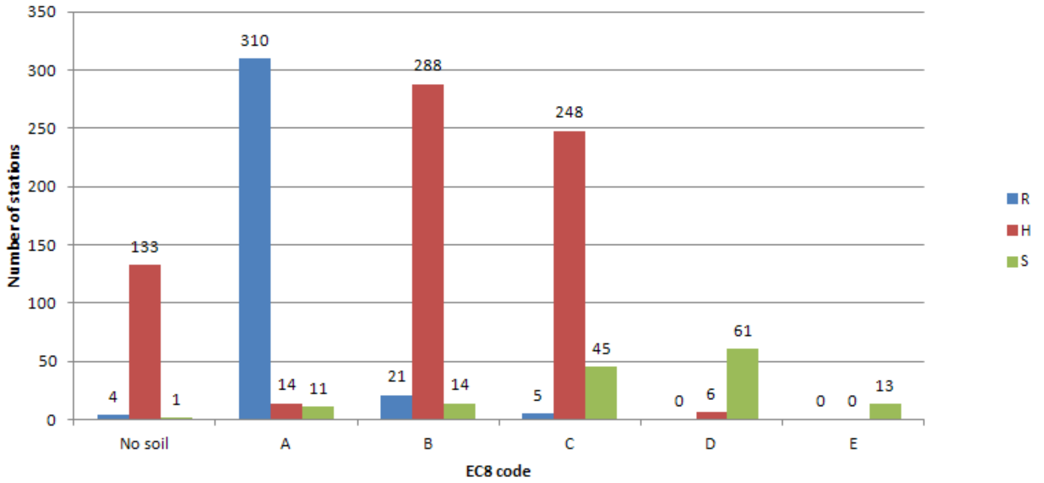

Figure 4. Comparison of EC8 soil classification (A, B, C, D and E) of ITDPC, KOERI, IGN and RAP stations with R, H, S soil classification

From this comparison we can observe that the majority of the stations are distributed equally in A, B and C classes and a few in D and very few in E. The 93% stations in class A correspond to R class, 89% of stations in class B and 83% of class C correspond to H. Consequently, we deduce that class H is shared in class B and class C of EC8. Another observation is that only classes A, B and C are enough represented in our data-base to allow a statistical analysis.

We analyze not only PGA, but also PGV and HI, together with PSV(f) for 28 frequencies, considering the EC8 soil classes. The figures with plotted data are similar to Figure 3.

In Figure 5 we show the ratios between Mean values of PGA, PGV and HI of soil classes B and C in relation to A (B/A and C/A), per magnitude classes and distance bins. Ratios were computed from averages values over magnitude classes and distance bins, and taking into consideration a minimum of 10 points in each class of magnitude and distance. Ratios are interpreted as indicators of soil amplification.

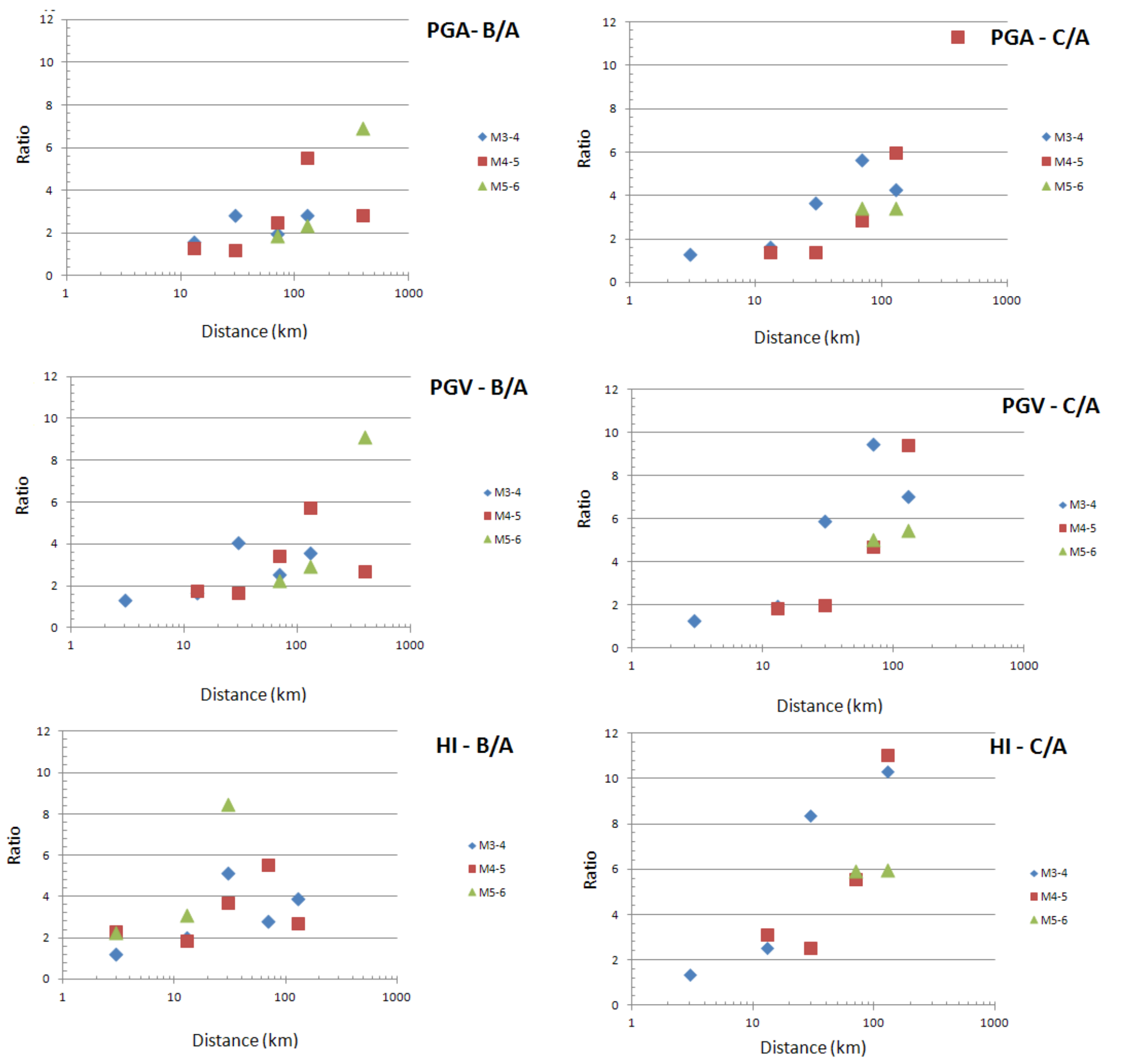

Figure 5. Ratios between Mean values of PGA, PGV and HI of different soil classes B, C and A (B/A and C/A), per magnitude classes and distance bins

We observed a strong influence of distance in the ratios, i.e., for short distances the amplification is almost inexistent, but it increases for larger distances. An important influence of magnitude is also observed. In all the figures the greater ratios are obtained for M3-4 data.

This influence of distance and magnitude in soil amplification ratios seems to indicate that weak motion, corresponding to low magnitudes and larger distances show larger amplification than strong motion recorded at short distances, for large magnitudes. So, in order to interpret ratios as indicators of soil amplification we will retain only ratios for distances lesser than 200 km and for M<6 because data for this range of distances and magnitudes are better represented. We have established three ranges of distance, 0-20 km, 20-100 km and 100- 200 km and three ranges of magnitudes M3-4, M4-5 and M5-6. We present in Table 3.1 the ratios between mean values of PGA, PGV and HI of soil classes (B, C) and A (B/A and C/A), for the above conditions.

A first observation of values in Table 3.1 indicates the tendencies already seen in Figure 4, which shows very large amplifications for small magnitudes and large distances. This observation confirms that amplification of week motion for all frequencies is larger than amplification of strong motion, for soil classes B and C.

Table 3.1. Average ratio values between EC8 soil classes B/A and C/A for PGA, PGV and HI parameters. Three ranges of distances and magnitudes are considered

PGA

B/A		0-20 km	20-100 km	100-200 km
	M3-4	1.59	2.40	2.82
	M4-5	1.27	1.85	5.51
	M5-6		1.88	2.35
C/A				
	M3-4	1.48	4.66	4.28
	M4-5	1.37	2.13	6.00
	M5-6		3.43	3.42

PGV

B/A		0-20 km	20-100 km	100-200 km
	M3-4	1.51	3.30	3.56
	M4-5	1.76	2.55	5.74
	M5-6		2.26	2.95
C/A				
	M3-4	1.60	7.68	7.06
	M4-5	1.86	3.34	9.43
	M5-6		5.02	5.44

HI

B/A		0-20 km	20-100 km	100-200 km
	M3-4	1.61	3.97	3.87
	M4-5	2.29	2.77	5.51
	M5-6		2.25	3.11
C/A				
	M3-4	1.92	10.96	10.30
	M4-5	3.12	4.04	11.03
	M5-6		5.92	5.98

If for engineering purposes we restrict our analysis to a range of distances of 0-100 km and a range of magnitudes M4-6, which produces "significative ground motion", the amplifications values become smaller and with less variability. These results can be compared with the soil coefficient S for Type 2 EC8 response spectra (table 3.2). In fact, the proposed EC8 design seismic action considers the soil influence through the Elastic Response Spectra (ERS) shape and through a frequency independent amplification coefficient S, called "Soil Coefficient". Two types of ERS are proposed: Type 1 for large magnitudes M>5.5-6.0 and Type 2 for lower magnitudes. For each Type both the shapes and coefficient S are defined for each soil class (Rey et al., 2002).

Table 3.2 Average ratio values between EC8 soil classes B/A and C/A for PGA, PGV and HI parameters for 2 ranges of distances, for M4-6, compared to soil coefficient S for Type 2 EC8 response spectra

	Short Dist			Long Dist			EC8
	PGA	PGV	HI	PGA	PGV	HI	S-coeff
B/A	1.27	1.76	2.29	1.86	2.41	2.51	1,3
C/A	1.37	1.86	3.12	2.78	4.18	4.98	1,5

A large dependence on distance is observed for different amplification values on table 3.2. S-coefficient of EC8 is similar to PGA amplification for short distances. For larger distances these values are much larger. PGV amplification values show larger values, indicating the influence of spectral shapes (see next chapter). These differences are even larger for HI amplification values, as HI represents the entire spectral content (Rey et al., 2002).

4. SOIL DEPENDENCE OF SPECTRAL SHAPES

We will analyze the influence of soil conditions in the all spectral values (28 frequencies) for different ranges of magnitude and distances, comparing PSA values (5%) to different soil conditions of EC8

(2003) spectral forms. In order to analyze “spectral forms” we compute for each record PSA(f)=2πf×PSV(f) and normalize all values to their PGA.

We have used the soil classes A, B and C to analyze the normalized spectral values of PSA(f). For all the available data we have computed the *mean value* and the *standard deviation* for each frequency of the normalized values, for the different classes of soil.

Figure 6 shows for all the agencies the *mean value* of the normalized spectrum (in relation to PGA) for the three classes of soil for M3-4, M4-5 and M5-6 ranges and the three classes of distances: 0-20 km; 20-100 km and 100- 200 km. For M>6 and D>200 km there are not enough data to pursue the analysis. Type 1 and Type 2 EC8 response spectral shapes are also shown for soil classes A, B and C (with design soil coefficient S assigned to 1).

In fact, very few differences exist in EC8 for the values of Tb and Tc, defining the spectral form for Type 2 (Tb=0.05 s for classes A and B and 0.10 s for class C; Tc=0.25 s for the three classes). For Type 1, these differences are higher Tc=0.4, 0.5 and 0.6 s for the three classes A, B and C. This means that the soil amplification proposed in EC8 Type 2 is essentially represented by the Design Soil Coefficient (S) and not by the spectral form.

The following observations can be made from Figure 6:

- Uncertainties shown on all normalized spectral values are partially due to the range of one degree of magnitude bins and to the range of distance on each bin considered in this analysis.
- These uncertainties are clearly larger than differences between average spectral values shown for different soil classes.
- In a general view, average spectral shapes show a consistent tendency of enlargement with increasing distances and increasing magnitudes.
- For class A (rock sites) the mean spectral shapes show a “plateau” less than 2.5 for almost all cases. For classes B and C the “plateau” is near 2.5 in all cases.
- For M3-4 spectral shapes are clearly below Type 2 spectral shape, especially for distances less than 100 km. For the shortest distances all 3 soil shapes are similar, whereas for large distances than 20 km important differences are observed between C, B and A. This observation agrees with the previous results found with PGA, PGV and HI analysis, where amplifications are larger for PGV and HI than for PGA.
- For M4-5, Type 2 spectral shape is more adapted to the average spectral shapes, even though important differences are observed between C, B and A, spectral shapes. The same comment as before can be made.
- For M5-6, no analysis is made for the shortest distances because no enough data are present. For distances between 20 and 100 km spectral shapes of class A and B are well adapted to Type 2 shape but for class C a clear amplification is shown. For large distances than 100 km spectral shapes for classes A, B and C show values between Type 1 and Type 2 EC8 spectral shapes. Differences between soil classes are very similar to those proposed for Type 1 shapes.

As in the previous section, if for engineering purposes we restrict our analysis to a range of distances of 0-100 km and a range of magnitudes M4-6, which produces “significant ground motion”, the main significant result is that average spectral shapes are well adapted to the Type 2 EC8 shape, but differences are observed between C, B and A class, in agreement with the observation of the previous section concerning the larger amplification of PGV and HI parameters for C and B classes, than PGA amplification.

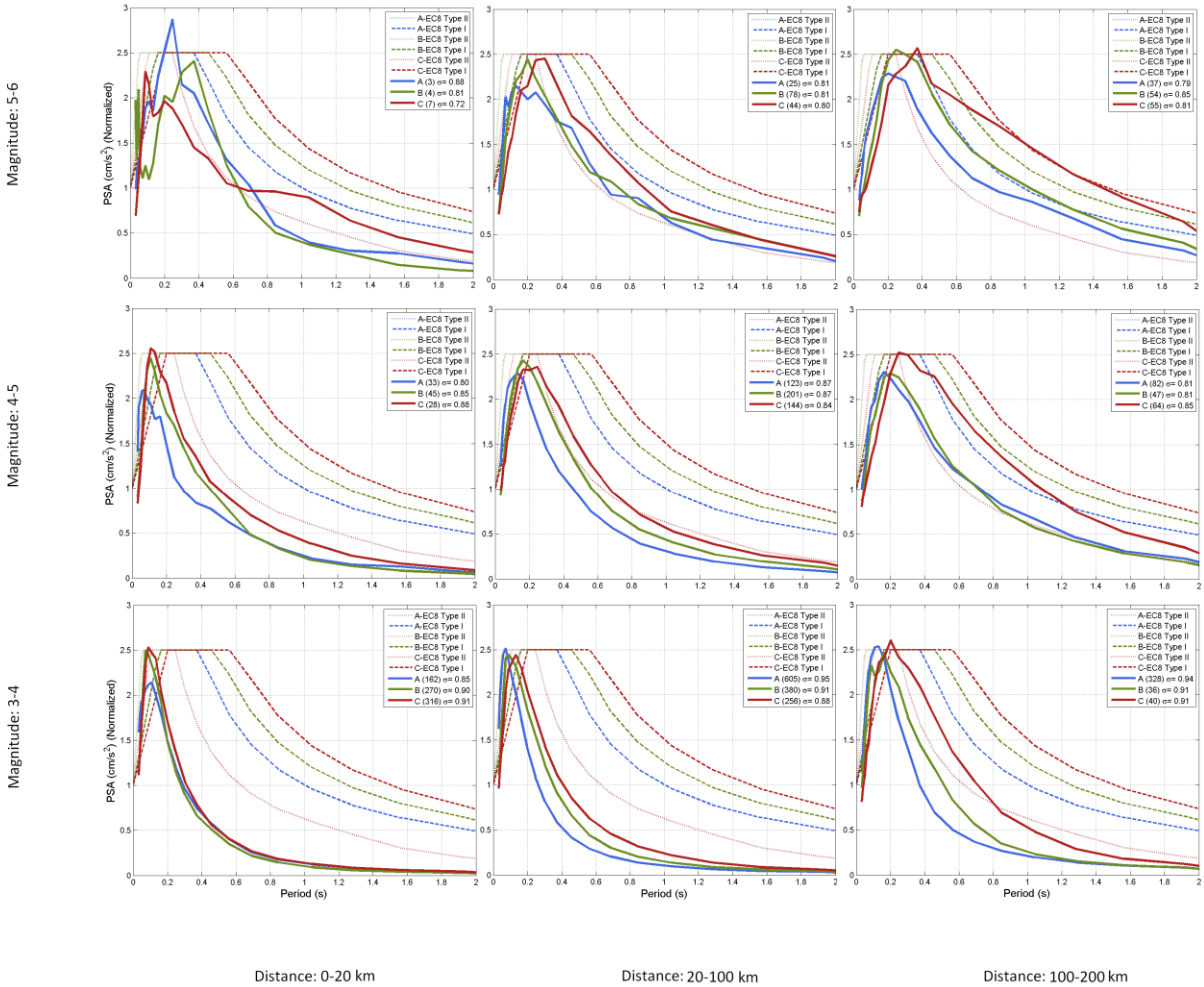

Figure 6. Average normalized response spectra for records on EC8 soil classes A, B, and C, for three magnitude and three distances ranges. The number of components analyzed and the standard deviation are indicated in the upper part of the figures. EC8 Type 1 and 2 for soils A, B and C classes are also plotted (S=1).

5. DISCUSSION

The statistical analysis of mean horizontal parameters, PGA, PGV, HI and PSV for 28 frequencies associated to records on accelerometric stations with EC8 soil classification contained in the European accelerometric NERIES data-base allowed us to the main following results:

- A clear soil dependence on classes A, B and C is put in evidence from the above mentioned parameters.
- This dependence is analyzed in function of magnitude and epicentral distance. Big differences were found between large amplifications observed for weak motions (small magnitude and large distances), and amplifications for moderate motions.
- For engineering purposes (M4-6) and distance 0-100 km, we found that:
  - PGA amplification for short distances is similar to S- coefficient of EC8. For larger distances these values are much larger.
  - PGV amplification values show larger values, indicating the influence of spectral shapes.
  - These differences are even larger for HI amplification values, as HI represents the entire spectral content.
  - Average spectral shapes are well adapted to the Type 2 EC8 shape, but differences are observed between C, B and A class, in agreement with the previous observations.

- For class A (rock sites) the mean spectral shapes show a "plateau" less than 2.5 for almost all cases. For classes B and C the "plateau" is near 2.5 in all cases.
- These observations could be incorporated in EC8 spectral shapes reducing the factor 2.5 for the "plateau" for class A, to a value of 2.2-2.3, and maintaining the 2.5 factor for classes B and C.

The material presented in this paper has a great potential for further development. The analyses presented and the interpretations made in this study constitute a first contribution to a better characterization of the digital accelerometric data recorded in the European Region. In particular, this study could be extended to other EC8 soil classes (D and E) when accelerometric agencies improve their station soil classification from geological, geotechnical and geophysical measurements and other Euro-Mediterranean agencies contribute to this data-base, in particular, with strong motion data.

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