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EVALUATION OF EC8 SITE-DEPENDENT ACCELERATION RESPONSE SPECTRA USING STRONG-MOTION ITALIAN RECORDS

Giuseppe Lanzo [a], Giuseppe Scasserra [b], YuQin Ding [c]

[a] *Università di Roma "La Sapienza", Rome, Italy, giuseppe.lanzo@uniroma1.it*
[b] *Università di Roma "La Sapienza", Rome, Italy, giuseppe.scasserra@uniroma1.it*
[c] *College of Civil Eng., Chongqing University, Chongqing 400045, P.R. China, visiting Ph.D. student at the Dip. di Ing. Strutturale e Geotecnica, Università di Roma "La Sapienza", dingyuqin@yeah.net*

ABSTRACT

The Eurocode 8 (EC8) elastic acceleration spectra are compared with those which were derived from a representative sample of acceleration records from Italy. The source of the records is the recently developed strong-motion database SISMA (Site of Italian Strong Motion Accelerograms). The data were carefully selected based on magnitude, distance, focal depth and free-field conditions, and grouped in the A, B and C subsoil categories as defined in EC8. Average normalized spectra were computed for each soil category and for two levels of earthquake magnitude ($M_L \leq 5.5$ and $M_L > 5.5$) for both horizontal and vertical components of motion. It has been found that average normalized horizontal spectra of records match satisfactorily Type1 and Type 2 EC8 provisions for all the subsoil classes whereas average normalized vertical spectra of records, unlike EC8 provisions, show spectral shapes dependent on earthquake magnitude and ground conditions.

KEYWORDS

EC8, accelerograms, SISMA database, acceleration spectra, horizontal and vertical motion.

1 INTRODUCTION

The Eurocode 8 (EC8) building code (CEN, 2004) recommends the use of two design horizontal acceleration spectra, i.e. the Type 2 spectrum for regions where maximum magnitudes are not expected to exceed 5.5-6.0 (low to moderate seismicity) and the Type 1 spectrum for regions where maximum magnitudes are expected to exceed 5.5-6.0 (high seismicity). For both seismicity levels, different site-dependent spectral shapes are assigned, according to the EC8 classification system, for five subsoil categories (A, B, C, D and E) defined in terms of stratigraphic conditions and representative geotechnical parameters. Conversely, the design vertical acceleration spectral shape is unique, independently on magnitude and ground conditions.

Earlier version of EC8 provisions is based on the work by the SC8 Project Team 1 (1999) whereas spectral shapes adopted by EC8 are mainly based on the background study of Rey et al. (2002). The dataset used by Rey and co-authors is derived from the European Strong Motion Database (Ambraseys et al., 2000) and it includes records from all over Europe (e.g. Greece, Italy) and adjacent countries (e.g., Turkey) with different seismotectonic environments and different fault mechanisms (normal, thrust, strike-slip, etc.). Therefore, it is of practical interest to see whether the EC8 spectra are in agreement with those that are constructed on the basis of a representative set of records from the Italian region which is mostly characterized by normal faults. Further, in the work by Rey et al. (2002) many Italian records were not used because of the lack of knowledge of geotechnical information at several instrumented sites. Finally, one central objective of the work is to serve as a background study for the national application document required for the introduction of EC8 in Italy.

In this paper a carefully selected and uniformly processed sample of Italian strong motion records is used as a basis for the evaluation of average acceleration spectra. These spectra are computed for the three components of motion (two horizontal and one vertical) and for the three soil classes A, B and C of EC8, for which the available sample of records is sufficiently large. The response spectra derived from the records were then compared to the EC8 spectral shapes in order to investigate spectral shapes as well as ground effects for different levels of seismicity, for both horizontal and vertical components of motion.

2 THE “SISMA” WEB DATA BANK

A database of Italian accelerograms recorded between 1972 and 2002, developed in the framework of a joint project between the University of Rome *La Sapienza* and the University of California at Los Angeles, was used for the analysis (Scasserra et al., 2008a). These data can be freely accessed through the SISMA (Site of Italian Strong Motion Accelerograms) website (http://sisma.dsg.uniroma1.it) whose main features are illustrated in Scasserra et al. (2008b). The principal objective of SISMA is to provide high quality Italian strong motion records whose associated parameters are consistent and reliable and can be used for most engineering applications.

The database is composed of 247 three-component accelerograms from 89 earthquakes and 101 recording sites. The accelerometric data were uniformly processed by the same team of seismologists responsible for the PEER (*Pacific Earthquake Engineering Center*) data processing. Pseudo-acceleration response spectra (5% structural damping) were then computed.

Appropriate source parameters (magnitude, hypocenter location, fault mechanism, etc.) associated with the seismic events were included. The magnitude of the events is always available as local magnitude M_L. Moment magnitudes M_W are available for 60% of the earthquakes from moment tensor solutions. Surface wave magnitudes M_S is also available for 36% of the events. Re-calculated epicentral and hypocentral distances are available for all recordings while Joyner & Boore distances (r_{jb}) and closest distance from the rupture (r_{rup}) have been re-calculated only when fault solutions were available, corresponding to about 45% of the recordings. About 85% of the records have been obtained at distances of less than 50 km from the source while the remaining 15% data are essentially concentrated at distances between 50 and 100 km. Records from normal rupture mechanism dominate with 44 earthquakes belonging to this category; for 24 earthquakes fault rupture mechanism is unknown while remaining events are related to strike-slip, oblique and thrust ruptures.

A major effort was undertaken to improve the characterization of subsoil conditions at the ground motion stations. The site databank includes for every recording site the surface geology, a measurement or estimate of average shear wave velocity in the upper 30 m (V_{s30}), and information on instrument housing. In particular seismic velocities were extracted from the literature for 33 sites. Additional seismic velocities were measured using the seismic analysis of surface waves (SASW) technique for 17 sites that recorded the 1997-1998 Umbria and Marche earthquake sequence (Kayen et al., 2008). The compiled velocity measurements provided data for 51 of the 101 sites. For the remaining sites, the average seismic velocity in the upper 30 m (V_{s30}) was estimated using a hybrid approach, based on correlations with surface geology. Using the geotechnical data available for each station soil classification according to the ground categories prescribed in EC8 was achieved.

3 DATA SELECTION CRITERIA

In order to consistently compare the EC8 response spectra with those derived from Italian records, a representative subset of SISMA database was considered. The following criteria were applied in the selection: (i) focal depth $h \leq 30$ km; (ii) earthquake magnitude $M_L \geq 3.5$; (iii) Joyner & Boore distance ≤ 50 km; (iv) free-field accelerograms.

Local magnitude M_L was considered because available for all records; it is also approximately representative of surface wave magnitude M_S in the dataset magnitude range. Joyner & Boore distance was considered where available (generally for higher-magnitude events), epicentral distance was considered otherwise (generally for small-magnitude earthquakes); this assumption is reasonable considering that small-magnitude events generally correspond to small fault dimensions.

The final record sample used in the present study consists of 200 free-field three-component accelerograms from 77 earthquakes and 83 recording sites. Earthquake distribution versus M_L and focal mechanism is illustrated in Figure 1. The distribution of recordings with respect to local soil conditions, local magnitude and Joyner & Boore distance is summarized in Table 1. In this table the records selected were divided into three range of magnitude (3.5-4.5; 4.5-5.5; 5.5-6.5) and into two groups, near-field and far-field, according to the threshold value r_{jb}=15 km. The records were also classified into the three EC8 subsoil classes A, B and C considering that very few recordings (4) are available from very soft soils sites (class D of EC8) and no data for subsoil class E. In total, 34 records were selected from subsoil class A, 114 from subsoil class B and 48 from subsoil class C. A further subdivision according to the level of seismicity led to: (a) for $M_L \leq 5.5$, 19 records in class A, 90 in class B and 35 in class C; (b) for $M_L > 5.5$, 15 records in class A, 24 in class B and 13 in class C. The distribution of selected data versus M_L, r_{jb} and V_{s30} is illustrated in Figure 2.

Table 1. Distribution of records by local soil conditions, magnitude and distance.

Subsoil class in EC8	**Local magnitude M_L**			**Joyner & Boore distance r_{jb} (km)**		**Total**
	$3.5 \le M_L \le 4.5$	$4.5 < M_L \le 5.5$	$5.5 < M_L \le 6.5$	≤15	>15	
A	5	14	15	15	19	34
B	47	43	24	67	47	114
C	18	17	13	24	24	48
D	-	2	2	4	-	4
Subtotal	*70*	*76*	*54*	*110*	*90*	*200*
Total	*200*			*200*		*200*

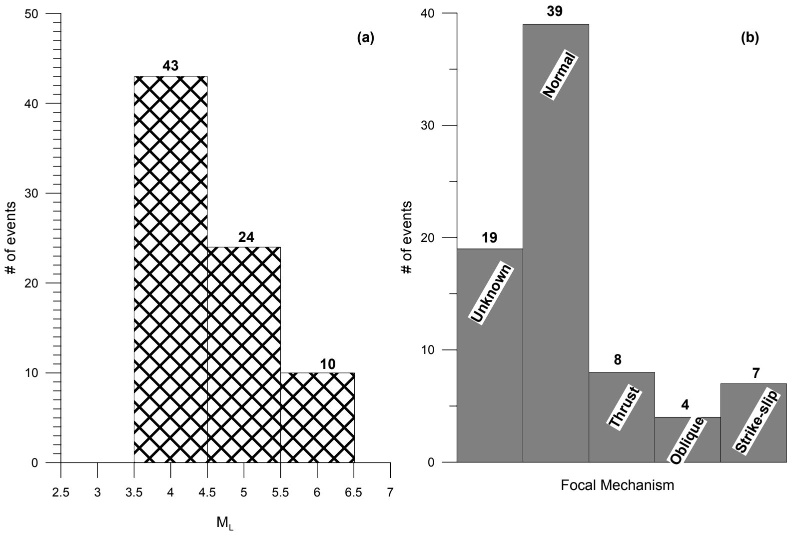

Figure 1. Distribution of events vs. (a) local magnitude and (b) focal mechanism.

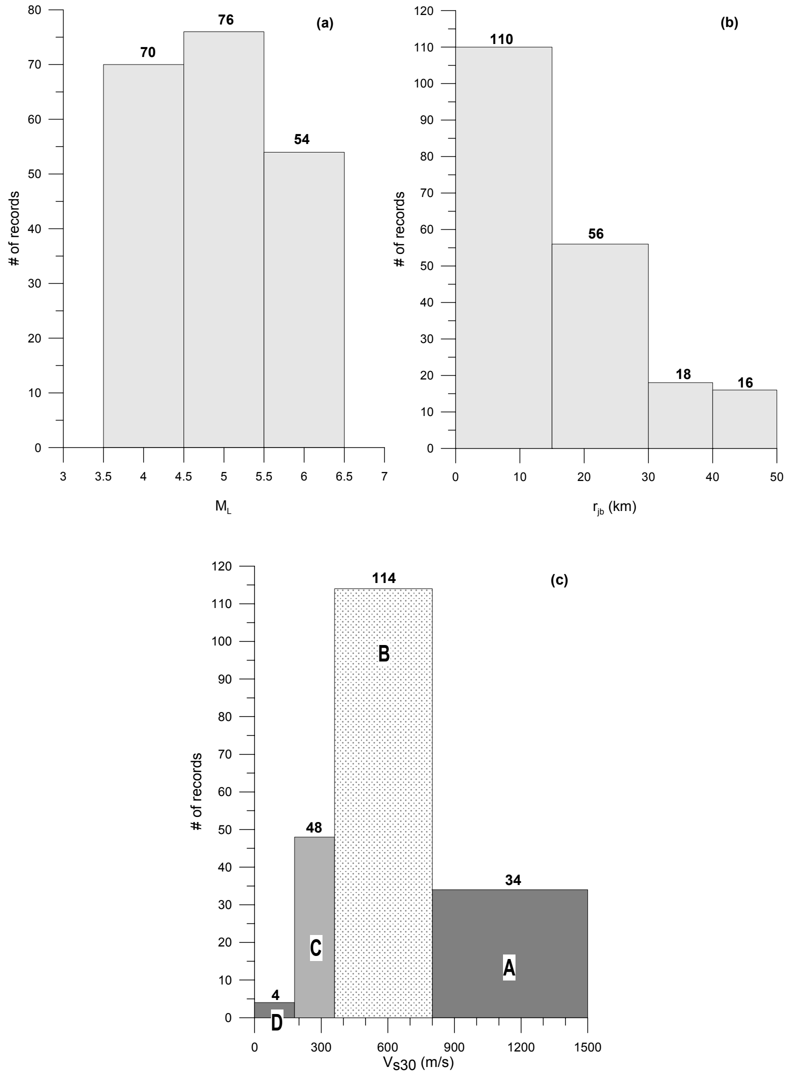

Figure 2. Distribution of records vs. (a) local magnitude, (b) Joyner & Boore distance and (c) V_{s30}.

4 ACCELERATION RESPONSE SPECTRA

4.1 Computed acceleration spectra from recordings

Acceleration response spectra (5% structural damping) were computed separately for each seismic record for the three components of motions. According to EC8 (Rey et al., 2002), the derivation of horizontal spectra was made using the envelope of the two horizontal components for each record intended as the larger of the two spectral ordinates at every period. Each envelope spectrum was normalized to the larger of the two values of the peak ground acceleration PGA. Average values of the corresponding normalized acceleration spectra were then computed for the two levels of earthquake magnitude, $M_L \leq 5.5$ and $M_L > 5.5$, each grouped in the A, B and C subsoil classes, as illustrated in Figure 3. As expected, ground conditions affect the frequency content of the spectra, which become richer of low frequencies moving from rock and stiff soils to soft soils, independently on the magnitude interval considered. The ratio between maximum spectral ordinate and PGA ($S_{a,max}$/PGA) is on average equal to 2.5 with the only exception of stiff soils (class B) for $M_L > 5.5$ which exhibit $S_{a,max}$/PGA=3, as shown in Figure 3b.

A further analysis was carried out in which the derivation of spectra was made treating the two horizontal components of each record as independent. This issue was investigated to ascertain whether the approach followed by EC8 for derivation of spectra using the envelope would have a significant effect on their shape. As an example, Figure 4 shows that differences for subsoil class C using both approaches are not significant. Similar conclusions can be drawn for subsoil categories A and B.

For the vertical component of motion, average values of the normalized acceleration spectra computed for the two levels of seismicity and for each subsoil class are presented in Figure 5. As shown in the plots, different spectral shapes can be recognized for the two intervals of magnitude investigated and for the different subsoil categories (Figures 5a and 5b), similarly to the horizontal case. In fact, the $M_L > 5.5$ spectra are enriched in long periods while for $M_L \leq 5.5$ spectra exhibit a much smaller long period content.

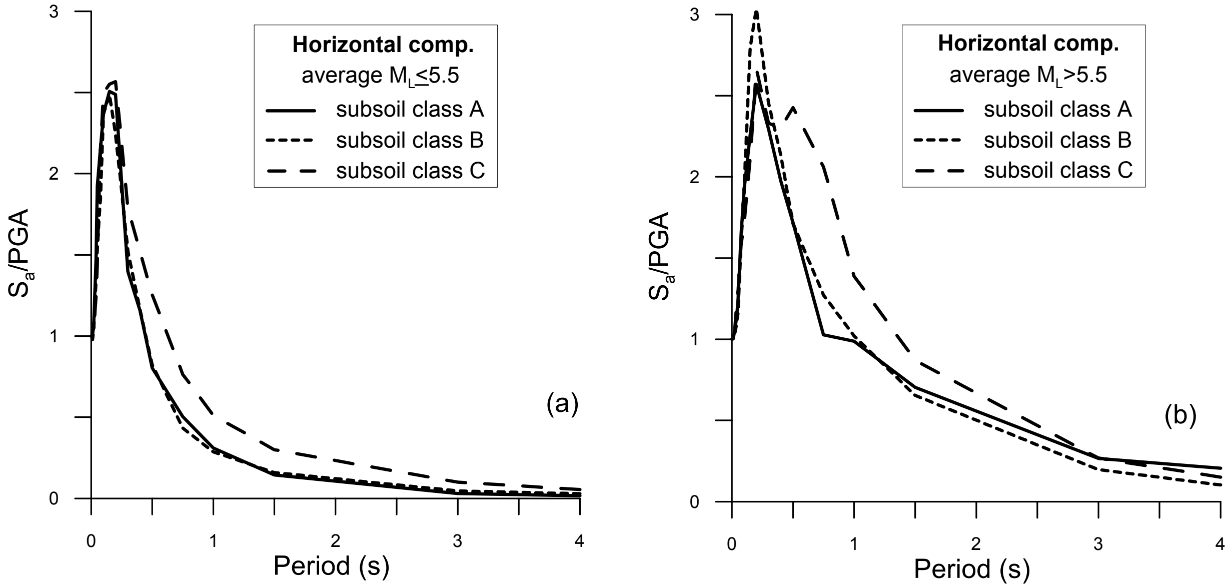

Figure 3. Average normalized horizontal spectra derived from records for A, B and C subsoil classes for (a) $M_L \leq 5.5$ and (b) $M_L > 5.5$.

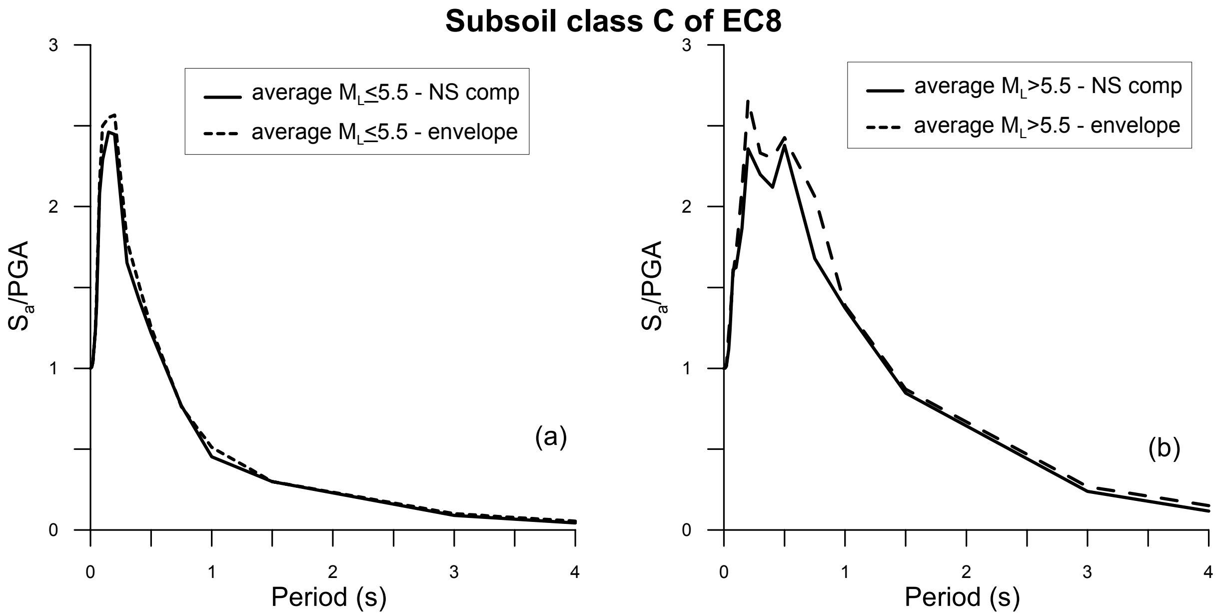

Figure 4. Comparison between average normalized acceleration spectra derived from records for NS horizontal component vs. envelopes of both components: (a) $M_L \leq 5.5$ and (b) $M_L > 5.5$.

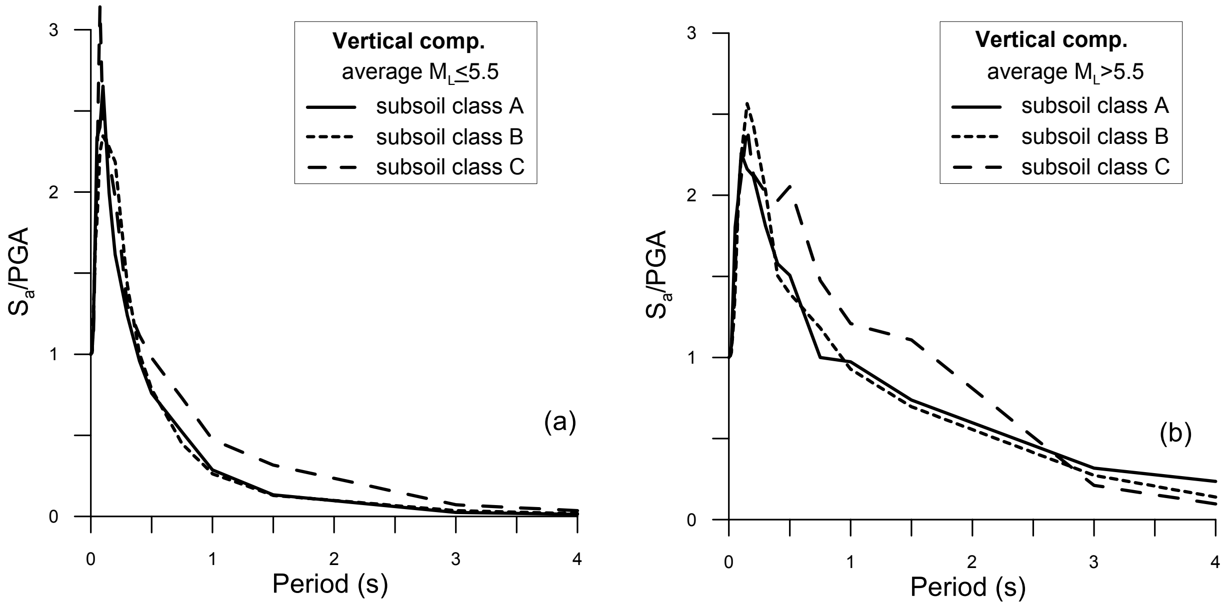

Figure 5. Average normalized vertical spectra derived from records for A, B and C subsoil classes for (a) $M_L \leq 5.5$ and (b) $M_L > 5.5$.

4.2 Comparison with EC8 provisions

The normalized acceleration response spectra derived from recordings were compared with those of EC8 (Type 1 and Type 2) for both horizontal and vertical components of motion.

Horizontal component

In Figure 6 a comparison is given between the acceleration response spectra suggested by EC8 and the average spectra derived in the present study for the two levels of seismicity and for each subsoil class. In the Figures 6a, 6c and 6e Type 2 spectra of EC8 are compared with the average spectra of records from earthquakes with $M_L \leq 5.5$ respectively for subsoil class A (19 records), B (90 records) and C (35 records). In the Figures 6b, 6d and 6f Type 1 spectra

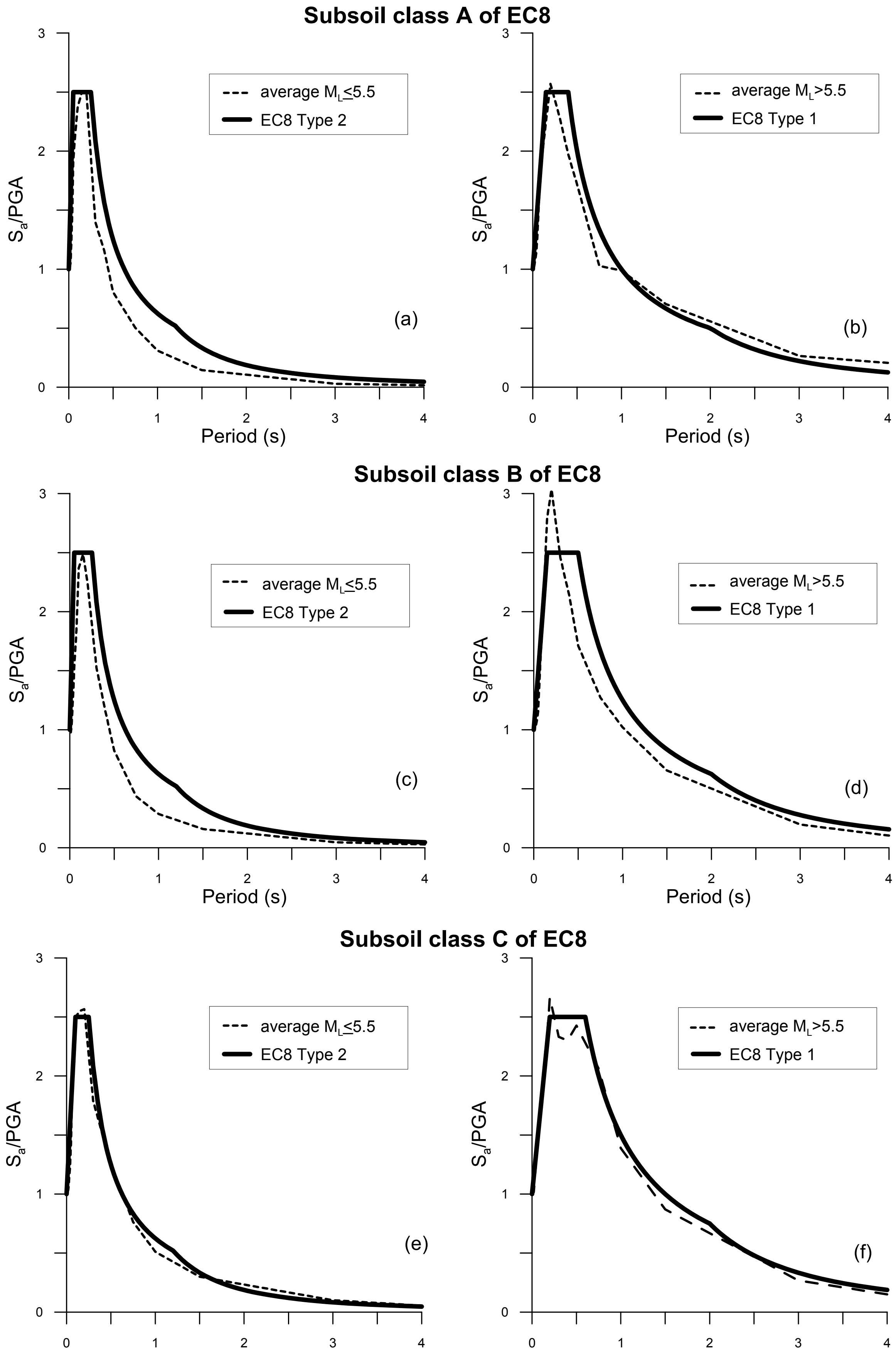

Figure 6. Normalized EC8 spectra and average spectra derived from records.

are compared with spectra of records from earthquakes with M_L >5.5 for subsoil class A (15 records), B (24 records) and C (13 records). It can be observed that for subsoil classes A and B recorded spectra are in good agreement, event though measured data for $M_L \leq 5.5$ show a faster decay of the spectral shape than EC8's. For subsoil class C, the mean values of the computed spectra almost overlap the corresponding EC8 spectra, for Type 1 as well as for Type 2 conditions in the whole range of periods.

Vertical component

In Figure 7 a comparison between the normalized vertical spectrum proposed by EC8 and the average normalized spectra of records for the different ground conditions is carried out. As already said in the Introduction, EC8 ordinates of the vertical response spectrum are independent on the magnitude level and on the subsoil class while the recorded data do not show this feature. EC8 provisions seem adequate, on average, for Type 2 case whereas significantly underestimate average recorded spectra for all the subsoil classes for Type 1 case, almost in the whole range of periods. These latter findings are in agreement with the study by Ambraseys et al. (2005) that provides attenuation relationships for the vertical spectra acceleration. As an example, in Figure 8 spectra by Ambraseys and co-authors, for an average value of r_{jb}=15 km and for appropriate magnitude values, are compared with average spectra from records for subsoil classes A and C. The comparison strongly confirms the trend of measured data for $M_L \leq 5.5$ (Figure 8a); for $M_L > 5.5$ (Figure 8b) spectra from records overestimate spectral values from attenuation relations.

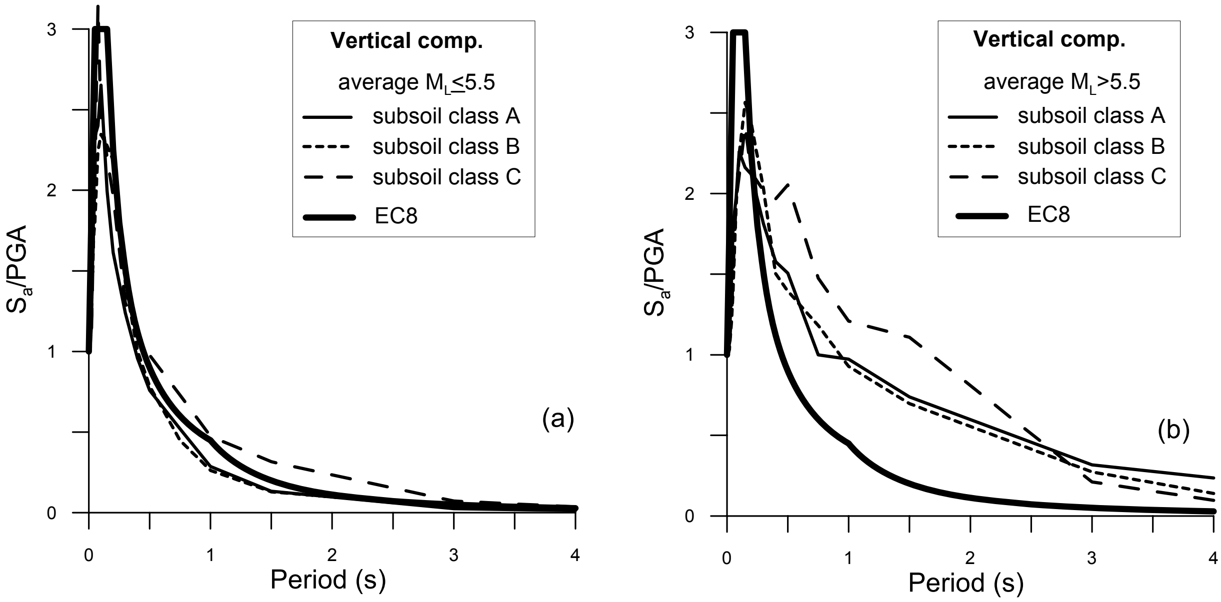

Figure 7. EC8 normalized vertical spectrum and average normalized vertical spectra derived from records for the three subsoil classes A, B and C and for (a) $M_L \leq 5.5$.and (b) $M_L > 5.5$.

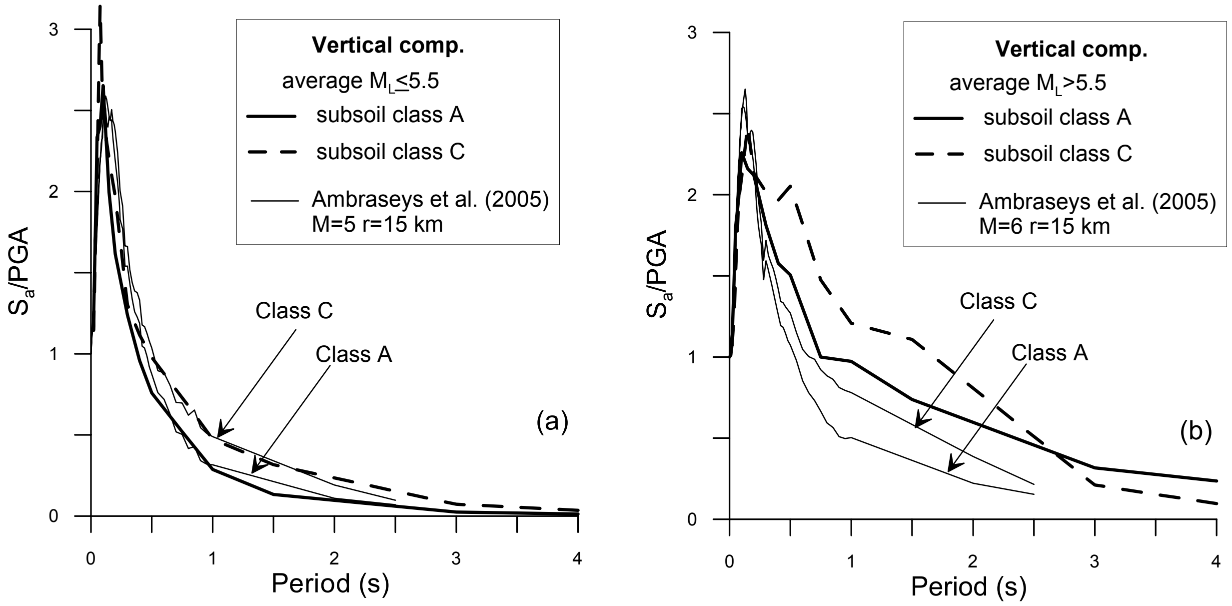

Figure 8. Comparison between spectral attenuation relationships by Ambraseys et al. (2005) and average normalized vertical spectra from records for subsoil classes A and C for (a) $M_L \leq 5.5$.and (b) $M_L > 5.5$.

5 CONCLUSIONS

In this study a comparison between both horizontal and vertical elastic acceleration spectra proposed by EC8 and corresponding acceleration spectra derived from Italian strong-motion records have been undertaken. The source of the records is the recently developed strong-motion database SISMA (Site of Italian Strong Motion Accelerograms). The comparison was carried out in terms of average normalized spectra distinguished into the three ground categories A, B and C, according to EC8, whose number of available data can be considered sufficiently large.

It was found that generally the average normalized spectra for the horizontal component are in good agreement with the spectra adopted by EC8 for Type 1 and Type cases as well as for the A, B and C subsoil classes. As vertical motion is concerned, the analysis has shown that EC8 spectral shape reasonably matches the mean response spectra for low to moderate seismicity context whereas it significantly underestimates the average spectra from recordings for high seismicity context, independently on the ground conditions. Further, it was found a dependency of average vertical spectrum on ground conditions, meaning that in the intermediate-to-long period range spectral ordinates corresponding to soft soils are higher than those pertaining to the stiffer materials A and B.

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7 REFERENCES

Ambraseys N., Smit P., Berardi R., Rinaldis D., Cotton F., Berge C. (2000). “Dissemination of European Strong Motion Data”, *CD-ROM collection, European Council, Environmental and Climate Programme*.

Ambraseys N., Douglas J., Sarma S.K., Smit P.M. (2005). “Equations for the estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle east: vertical peak acceleration and spectral acceleration”, *Bulletin of Earthquake Engineering*, 3, 55-73.

CEN (2004). Eurocode 8: “Design of Structures for Earthquake Resistance – Part I: General Rules, seismic actions and rules for buildings”, (EN-1998-1). Brussels, May 2004.

Kayen R., Scasserra G., Stewart J.P., Lanzo G. (2008). “Shear wave structure of Umbria and Marche, Italy, strong motion seismometers sites affected by the 1997 Umbria-Marche, Italy, earthquake sequence”, USGS, Menlo Park, California, USA, *Open File Report* 2008-1010, pp. 46 (http://pubs.usgs.gov/of/2008/1010/)

Rey J., Faccioli E., Bommer J. (2002). “Derivation of design soil coefficients (S) and response spectral shapes for Eurocode 8 using the European Strong-Motion Database”, *Journal of Seismology*, 6, 547-555.

SC8 Project Team 1 (1999). “Commentaries on Proposed Amendments to Eurocode 8, part 1-1”, *Unpublished Report*, December 1999.

Scasserra, G., Stewart, J.P., Kayen, R.E., and Lanzo, G. (2008a). “Database for earthquake strong motion studies in Italy”, *Journal of Earthquake Engineering*, Imperial College Press (in press)

Scasserra G., Lanzo G., Stewart J.P., D'Elia B. (2008b). “SISMA (Site of Italian Strong Motion Accelerograms): a web-database of ground motion recordings for engineering applications”, *Proceedings of the 2008 Seismic Engineering Conference commemorating the 1908 Messina and Reggio Calabria Earthquake*, MERCEA’08, Santini & Moraci Editors, July 8-11, Reggio Calabria, Italy, Vol. 2, 1649-1656.