4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1620

ELASTIC DISPLACEMENT RESPONSE SPECTRA

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ABSTRACT

In view of performance based design, there are certain issues regarding the difficulties on the estimation of reliable displacement response spectra. In this paper, displacement response spectra based on the processing of strong ground motion records and theoretical analyses are being compared with the design displacement response spectra of the current seismic codes, as well as with new proposed displacement spectra. The issues discussed are the convergence between the computed normalized displacement spectra derived either from theoretical analyses or from the processing of actual seismic records from Japan and Greece and the design displacement spectra for different soil categories.

Keywords: elastic displacement response spectra, design response spectra, Seismic Codes

INTRODUCTION

A large number of carefully selected, reliable seismic records on well documented soil conditions (in terms of Vs profile, physical, mechanical and dynamic soil properties, depth of the basement rock), are used. They have been mainly provided from the Japanese strong motion network Kik-net and the Greek accelerograph network managed by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) in Thessaloniki and the Institute of Geodynamics, National Observatory of Athens (GNOA).

Regarding the theoretical 1D ground response analyses the selection of the soil profiles was based (a) on the consideration of the basic parameters that affect the characteristics of the seismic response applying an "equivalent linear" approach to model the seismic behavior of the ground and (b) the actual stratigraphy and ground properties in real conditions that are basically found in Greece.

The discussion is mainly focused on the elastic displacement spectra of soil classes B, C and E of Eurocode 8. They are being compared with the design response spectra of the Greek seismic code (EAK2000) and the revised Eurocode 8 (CEN 2004) as well as with the proposed new elastic response spectra related with the new proposed soil classification (Pitilakis et al., 2004). The aim of this paper is (a) to highlight, by using specific examples, the need for systematic research on design displacement spectra, given the fact that the suggested spectra in almost all the current Seismic Codes differ considerably from actual seismic records and (b) to propose even in a preliminary step a set of more reliable elastic displacement spectra.

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DISPLACEMENT RESPONSE SPECTRA

Performance-based seismic design requires the reliable estimation of displacement spectra for different damping ratios in a wide range of periods. First, Tolis and Faccioli (1999) and Bommer and Elnashai (1999) proposed displacement response spectra which were derived after the processing of a large number of strong motion data. Following, Faccioli et al. (2004), suggested analytical expressions in order to estimate displacement spectra for long periods using selected sets of high quality digital strong motion data. The results of the aforementioned research studies were basically adopted by the current Eurocode 8 (CEN 2004}. Recently, Bommer and Pinho (2006), query whether the implementation of PBSD will require a radical change in the way earthquake actions are specified in present seismic design codes, given the fact that the next generation of seismic design codes is expected to incorporate, to some degree, the principles of PBSD.

In current seismic codes, design displacement spectra derive from design acceleration spectra based on the basic relation:

$$S_D = S_A \left(\frac{T}{2\pi} \right)^2 \qquad (1)$$

However, design displacement spectra estimated by applying this methodology tend to overestimate displacement spectra values. In Figure 1, displacement spectra values produced from the processing of Greek seismic records classified in soil classes B and C, according to the Greek seismic code – EAK2000 and EC8 (CEN 2004}, are quite lower compared with the corresponding design displacement spectra of the seismic zones I and III. The only exception is design displacement spectra, EC8-Type 2, for both classes, which are in the same range of values with the absolute displacement spectra.

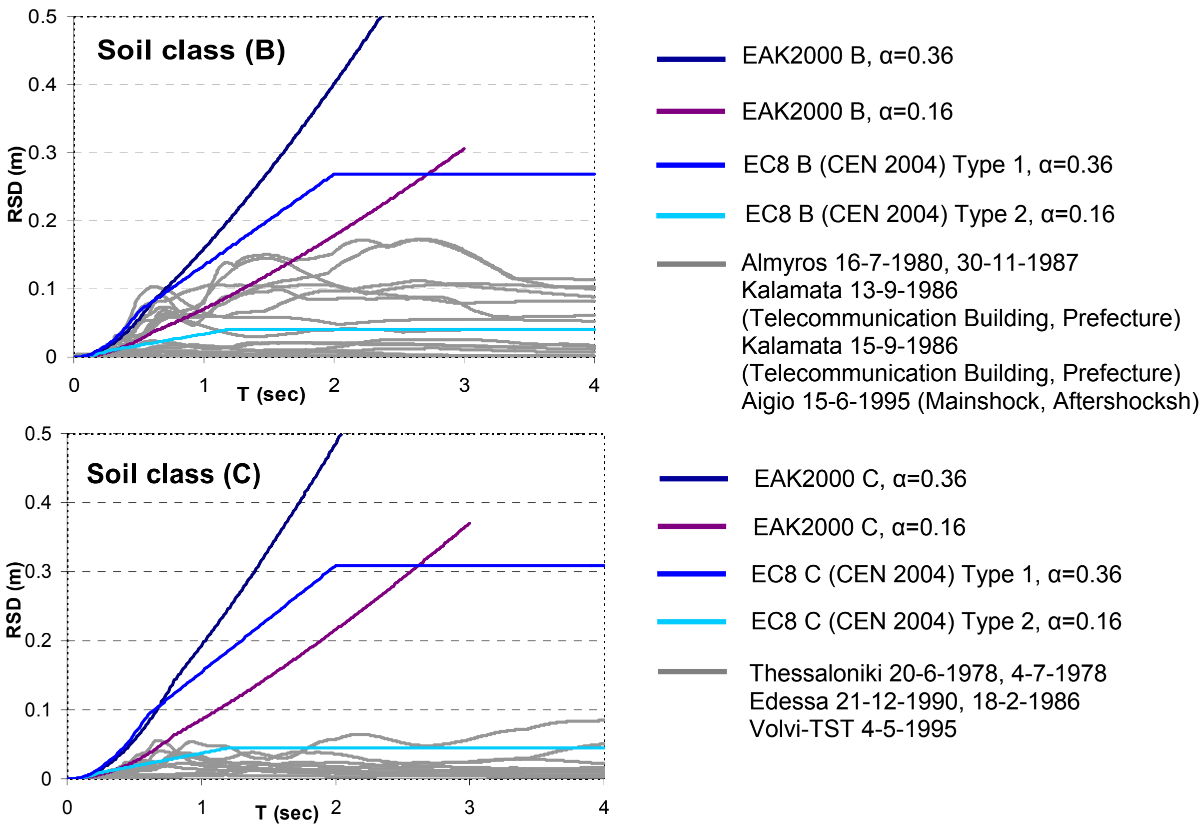

Figure 1. Absolute displacement response spectra of Greek seismic records compared to design displacement response spectra EAK2000 and EC8 (CEN 2004), for soil classes (a) B and (b) C.

PROPOSED DESIGN RESPONSE SPECTRA

The last revised version of Eurocode 8 (CEN 2004), introduces new design response spectra acceleration of two types based on a seismic hazard study for each region, Type 1, for Ms>5.5 and Type 2 for Ms<5.5, but also the corresponding design response spectra displacement for five basic soil classes (A, B, C, D, E).

At the same time, Pitilakis et al., (2004) proposed improved spectral amplification factors for different site conditions based on an extensive theoretical and experimental study of the characteristics of seismic ground response. A new improved soil classification was proposed based on the statistical processing of the basic parameters that affect the strong ground motion's characteristics (thickness of the soil deposit, depth of the bedrock, fundamental period of the soil profile, stratigraphy, mean shear wave velocity value of the soil profile etc.).

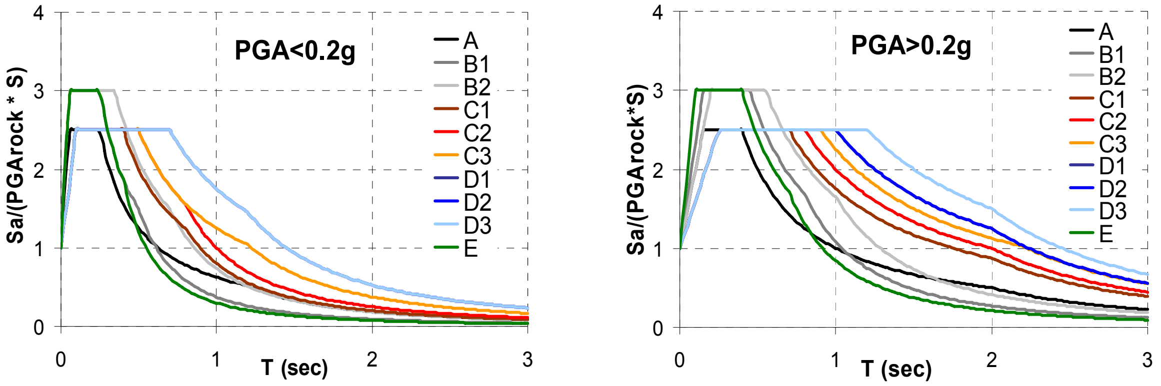

Figure 2. Proposed response spectra acceleration normalized to the peak ground acceleration value (PGA_{rock}*S) for (a) PGA<0.2g and (b) PGA >0.2g, (Pitilakis et al., 2004).

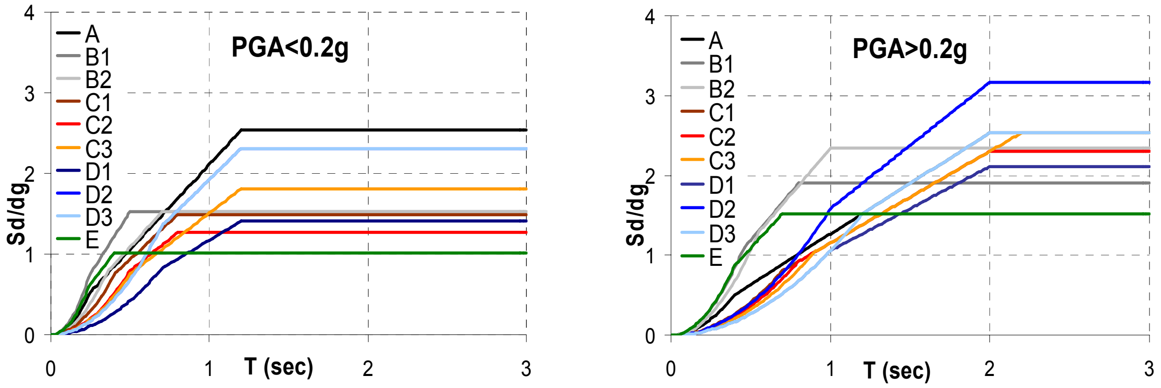

Figure 3. Proposed response spectra displacement normalized to the peak ground displacement value d_g, for (a) (PGA<0.2g) and for (b) PGA>0.2g.

As a result, the basic soil classes of Eurocode 8 were divided in more realistic and geotechnical engineering sub-classes (A_1, A_2, B_1, B_2, C_1, C_2, C_3, D_1, D_2, D_3, E) and spectral amplification factors were proposed for each soil category, for two levels of expected seismic intensity which is introduced in "outcropping" rock conditions. Finally, response spectra acceleration values are suggested for each site category (Figure 2) and two levels of earthquake intensity (Type 1, PGA>0.2g and Type 2, PGA<0.2g); normalized with respect to the maximum ground acceleration on rock conditions (PGA_{rock}*S), where S is the amplification factor depending on site conditions and seismic excitation.

New proposed displacement response spectra (Figure 3) were derived from the corresponding proposed acceleration response spectra based on relation (1) for two levels of seismic excitation, for each soil category, normalized to the peak ground displacement value d_g, as it is determined in EC8 (CEN 2004).

$$d_g = 0.025 \cdot a_g \cdot S \cdot T_C \cdot T_D \quad (2)$$

- a_g : design ground acceleration value on type A ground ($a_g = \gamma_I \cdot \alpha_{gR}$)
- S : soil factor
- T_C : upper limit of the period of the constant spectral acceleration branch
- T_D : value defining the beginning of the constant displacement response range of the spectrum

PROPOSED SOIL CLASSES B_1, B_2, C_1, C_2 AND E

The present work is focusing in soil classes B_1, B_2, C_1, C_2 and E (Pitilakis et al., 2004), the basic soil characteristics of which are presented in Table 1. The soil configurations classified in the proposed soil class B_1 are highly weathered rock formations (of thickness 5-30m), soft rock formations of great thickness or homogeneous soil formations of very dense sand–sand gravel or very stiff clay (<30m), while in soil class B_2 the soil configurations are formed by very dense sand–sand gravel or very stiff clay (thickness: 30-60m). In proposed soil category C_1 the soil formations are basically formed of dense to very dense sand-sand gravel or stiff to very stiff clay of great thickness (>60m), while in soil category C_2 are basically formed by medium dense sand-sand gravel or medium stiffness clay (thickness: 20-60m). Finally, in proposed soil class E the soil configurations are formed by surface soil formations of small thickness (5-20m), small strength and stiffness, likely to be classified in category C or D, which overlie category A soil formations (Vs≥800m/sec).

Table 1. Soil characteristics of the soil configurations classified in soil classes B_1, B_2, C_1, C_2, E.

Soil Class	H (m)	To (sec)	Vs (m/sec)
B_1	≤ 30	≤ 0.4	400 - 800
B_2	30 - 60	≤ 0.8	400 - 800
C_1	> 60	≤ 1.2	400 - 800
C_2	20 - 60	≤ 1.2	200 - 400
E	5 - 20	≤ 0.5	150 - 300
	≤ 60		≥ 800

THEORETICAL ANALYSES

In the frame of the new soil classification proposal, theoretical 1D computations of ground response were performed with different soil profiles in terms of impedance contrast, dynamic soil properties, relative thickness and depth of the rigid or non-rigid bedrock. The selection of the soil profiles (Table 2) was based (a) on the consideration of the basic parameters that affect the characteristics of the seismic response applying an "equivalent linear" approach to model the seismic behaviour of the ground and (b) the actual stratigraphy and ground properties in real conditions that are basically found in Greece.

For the seismic response study twelve real acceleration time histories were considered as input motions in the analyses, which are being presented in Table 3. They were carefully selected to satisfy the following criteria: a) been recorded at rock sites, b) cover a wide range of peak acceleration values

Table 2. Soil characteristics of the soil profiles used on theoretical analyses for every soil class.

Soil Class	H_{bed} (m)	$V_{s,30}$ (m/sec)	$V_{s,\mu\ bed}$ (m/sec)	T_0 (sec)
B_1	20 - 32	470 - 560	425 - 530	0.19 – 0.25
B_2	40 - 60	240 - 500	400 - 535	0.34 – 0.60
C_1	80 - 110	230 - 700	500 - 700	0.46 – 0.98
C_2	40	243	275	0.60
E	20 - 60	740 - 840	770 - 860	0.11 - 0.30

Table 3. Input motions used on theoretical analyses.

Seismic Motion	Date	Geology	PGA (m/s^2)	Epicentral Distance (Km)	Magnitude
Arnea, GR	04/05/95	Outcrop. bedrock	0.118	32.0	5.8
Northridge, CA	17/01/94	Metam. Rock	0.131	153.3	6.7
Thessaloniki,GR	04/07/78	Rock	0.945	15.0	5.1
Whittier, CA	04/10/87	Gran. Rock	1.360	17.2	5.3
Loma Prieta, CA	18/10/89	Rock	1.669	35.2	7.0
Kozani, GR	13/05/95	Stiff Clay	2.060	20.0	6.3
Northridge,CA	17/01/94	Sedim. Rock	2.580	38.3	6.7
Northridge,CA	17/01/94	Rock	3.715	14.0	6.7
Loma Prieta, CA	18/10/89	Rock	4.336	28.4	7.0
Northridge, CA	17/01/94	Sandstone	5.042	40.1	6.7
Northridge,CA	17/01/94	Sandstone	5.574	40.1	6.7
Kobe, JP	17/01/95	Dense gravel	6.780	12.0	7.2

(0.01g to 0.7g) and frequency content and c) match the response spectra provided by Eurocode 8 and EAK2000 for rock-site conditions.

Equivalent linear site response analyses were performed using CYBERQUAKE (Modaressi, 1998) computer code. For each earthquake-site model, a nonlinear site response analysis is performed in order to generate acceleration and displacement time histories and the corresponding displacement response spectrum with 5% damping ratio at ground surface. In total more than 350 theoretical analyses of various well- documented soil models were performed for the five soil classes that are

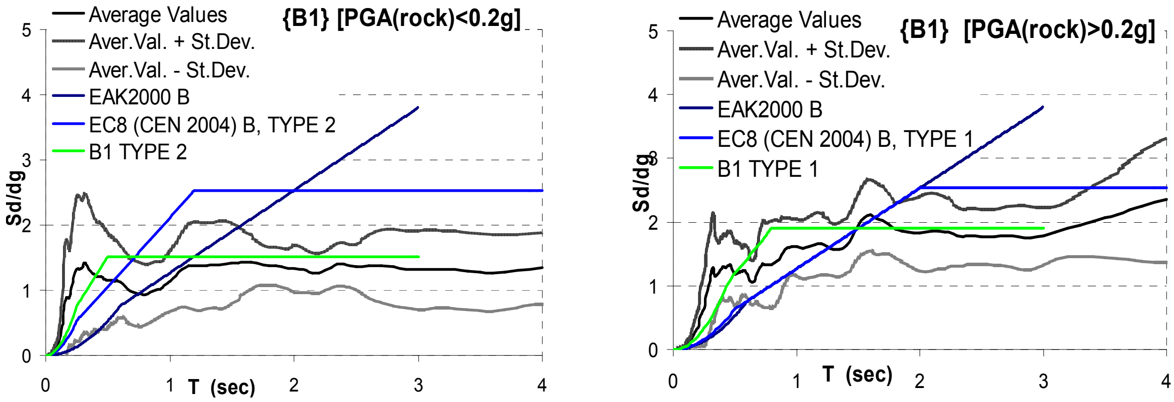

Figure 4. Soil class B_1 - Number of 1D analyses: 23
Average values of normalized displacement response spectra for (a) PGA<0.2g and (b) PGA>0.2g

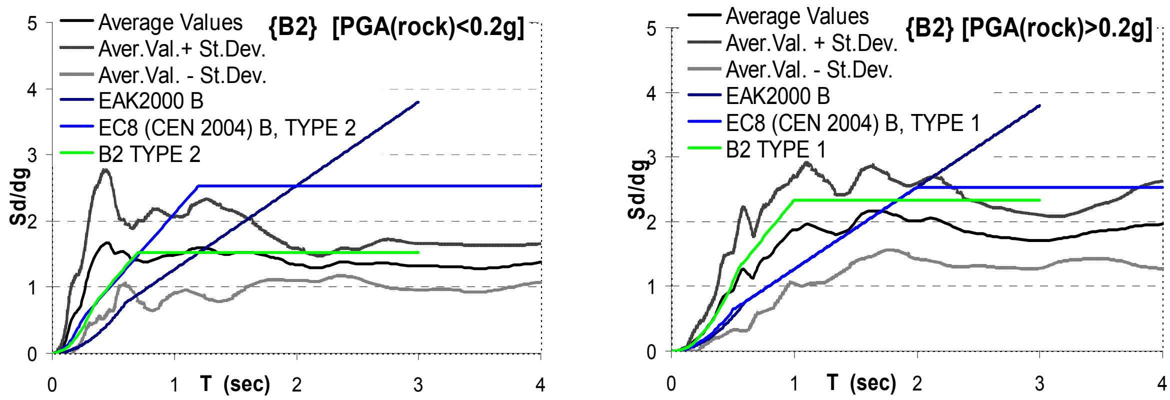

Figure 5. Soil class B_2 - Number of 1D analyses: 49
Average values of normalized displacement response spectra for (a) PGA<0.2g and (b) PGA>0.2g

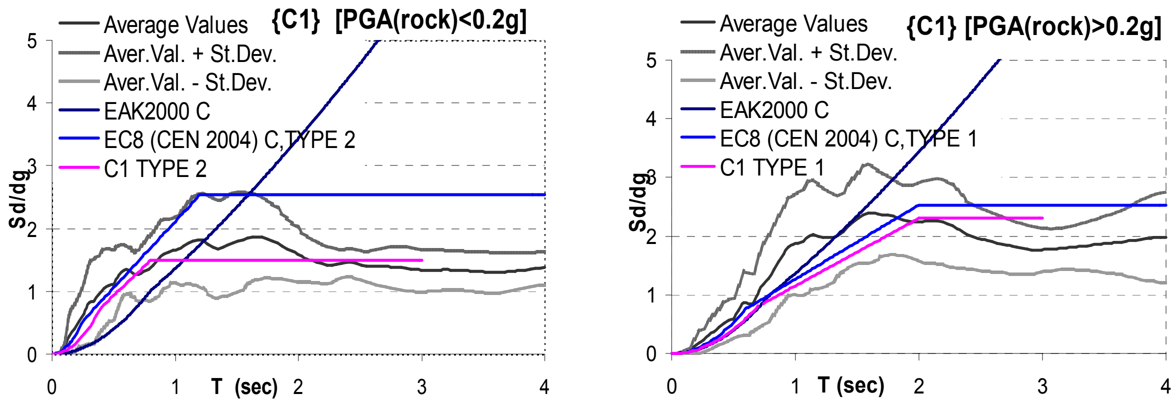

Figure 6. Soil class C_1 - Number of 1D analyses: 225
Average values of normalized displacement response spectra for (a) PGA<0.2g and (b) PGA>0.2g

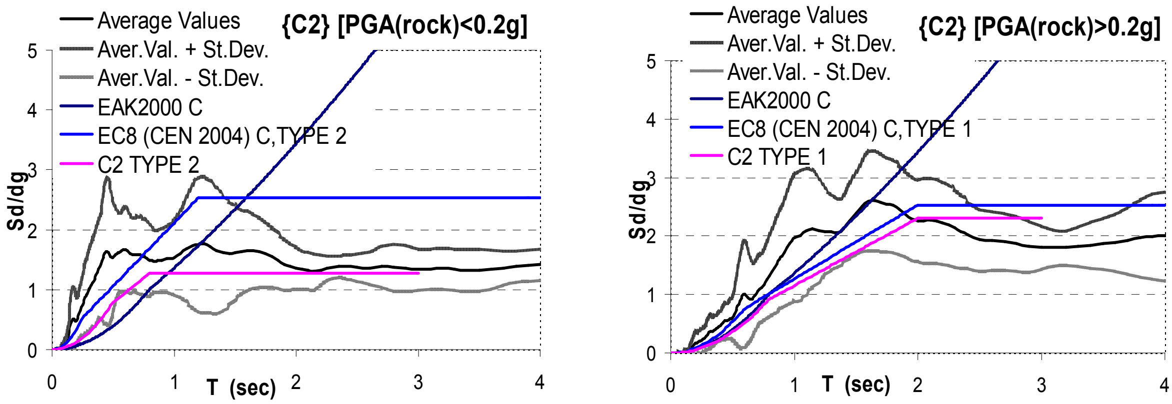

Figure 7. Soil class C_2 - Number of 1D analyses: 22
Average values of normalized displacement response spectra for (a) PGA<0.2g and (b) PGA>0.2g

being presented here, and in specific: (B_1: 23 1D analyses, B_2: 49 1D analyses, C_1: 225 1D analyses, C_2: 22 1D analyses and E: 33 1D analyses).

For each soil category, average ± standard deviation values of the displacement response spectra normalized to the peak ground displacement value (PGD) were computed, for two levels of seismic intensity, PGA>0.2g and PGA<0.2g. The normalized displacement response spectra, as it is depicted in Figures 4-8, are compared with the corresponding design displacement spectra of the Greek Seismic Code – EAK2000, EC8 (CEN 2004) Type 1 and Type 2, as well as with the proposed new design displacement spectra by Pitilakis et al., (2004) for two types of earthquake excitation, Type 1, PGA>0.2g and Type 2, PGA<0.2g.

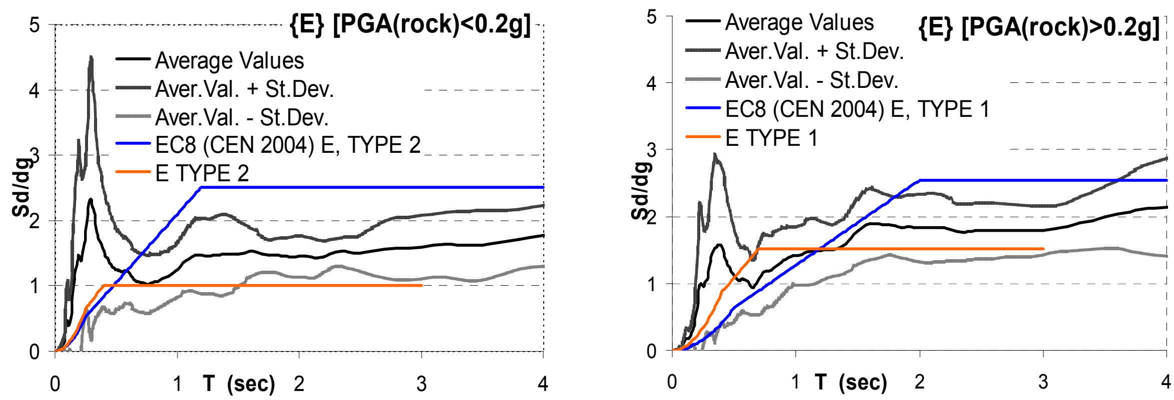

Figure 8. Soil class E - Number of 1D analyses: 33
Average values of normalized displacement response spectra for (a) PGA<0.2g and (b) PGA>0.2g

In soil classes B_1 and B_2, (Figures 4-5) the comparison between the average values of the computed normalized displacement response spectra and the proposed design displacement spectra by Pitilakis et al. (2004) is quite satisfactory, both for low and high seismicity cases. The proposed design displacement spectra B_1 and B_2 are falling within the average plus the standard deviation values of the computed normalized displacement spectra, opposed to the EC8 curves.

Regarding the soil categories C_1 and C_2, which are presented in Figures 6-7, the computed normalized displacement response spectra are in good agreement with the proposed design displacement spectra both for PGA<0.2g and PGA>0.2g, especially for soil class C_1 where the major number of 1D analyses was conducted, while the design displacement spectra of EC8 are not always equally compatible.

Finally, in soil class E (Figure 8), the proposed design displacement spectra E for low seismic intensity (PGA<0.2g) is falling within the average minus the standard deviation values of the computed normalized displacement spectra, while for higher seismic excitation (PGA>0.2g), there is a quite satisfactory convergence between the average values of the normalized displacement spectra based on theoretical analyses and the proposed design displacement spectra.

PROCESSING OF STRONG GROUND MOTION RECORDS

A large number (~250) of well documented strong ground motion recordings with different PGA values, Mw magnitudes and epicentral distances were selected for the five soil classes that are presented here. They were mainly provided from the Japanese strong motion network Kik-net (191 records) and the Greek accelerograph network (57 records) managed by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) in Thessaloniki (53 records) and the Institute of Geodynamics, National Observatory of Athens (GNOA) (4 records). In Table 4, the total number of the seismic records used are presented, classified in two main categories depending on the level of seismic intensity, PGA<0.2g and PGA>0.2g. In total, both from Japan and Greece, 90 earthquake recordings were selected for soil class B_1, 53 for soil class B_2, 38 for soil class C_1, 32 for soil class C_2 and 35 strong ground motion recordings for soil class E.

The basic criterion for the selection of the records was the good knowledge of soil conditions such as soil stratification, Vs profile; shear modulus degradation curves, damping (G/Go-γ-D curves) and depth of the bedrock. The number and the more critical soil characteristics (fundamental period T_0 and

Table 4. Number of records classified in soil classes B_1, B_2, C_1, C_2 and E from the Japanese and the Greek strong motion network.

Soil Class	Records	PGA<0.2g	PGA>0.2g	Number of Records	Total
B_1	Japan	44	32	**90**	
	Greece	11	3		
	Total	**55**	**35**		
B_2	Japan	25	12	**53**	
	Greece	6	10		
	Total	**31**	**22**		
C_1	Japan	12	14	**38**	**248**
	Greece	9	3		
	Total	**21**	**17**		
C_2	Japan	12	5	**32**	
	Greece	10	5		
	Total	**22**	**10**		
E	Japan	28	7	**35**	
	Greece	-	-		
	Total	28	7		

Table 5. Soil characteristics of the soil profiles classified in soil classes B_1, B_2, C_1, C_2 and E where the strong ground motions were recorded.

Soil Class	Number of Soil Profiles	$T_{0,30}$ (sec)	$Vs_{,30}$ (m/sec)	$T_{0,bed}$ (sec)	$Vs_{,bed}$ (m/sec)
B_1	32	0.04 – 0.22	320 - 610	0.04 – 0.22	320 - 610
B_2	8	0.20 – 0.39	308 - 605	0.30 - 0.43	421 - 655
C_1	6	0.24 – 0.46	263 - 500	0.56 - 4.45	429 - 558
C_2	11	0.23 - 0.50	237 - 383	0.23 - 0.72	306 - 411
E	14	0.07 - 0.35	143 - 320	0.07 - 0.35	143 - 320

shear wave velocity Vs) of the sites where strong motion recordings were available for each soil category are presented in Table 5. Although EC8 (CEN 2004) defines site classes based on $Vs_{,30}$ values, it is also stated that the influence of the local ground conditions “may also be done by additionally taking into account the influence of the deep geology on the seismic actions”, so the aforementioned basic soil characteristics correspond both at the first thirty meters and at the total depth of the soil profile.

Displacement response spectra were computed for every seismic record using the computer code Seismosignal (2002), by applying linear baseline correction at the displacement time history which derives from the corresponding acceleration time history by double integration, application of three different digital band pass filters to correct the signal noise (Butterworth, Chebyshev, Bessel) and three different cutoff frequencies (0.10-20, 0.15-20, 0.20-20), in order to retain as much useful information of the signal. For each type of filter, all three combinations of cutoff frequencies were applied, resulting in the computation of nine absolute displacement response spectra for each seismic record. Finally, average values of the corresponding displacement spectra were computed, for two levels of seismic intensity PGA<0.2g and PGA>0.2g, for each combination of filter and cutoff frequency (nine + nine = eighteen mean values of absolute displacement response spectra), for every soil class (Figures 9-13).

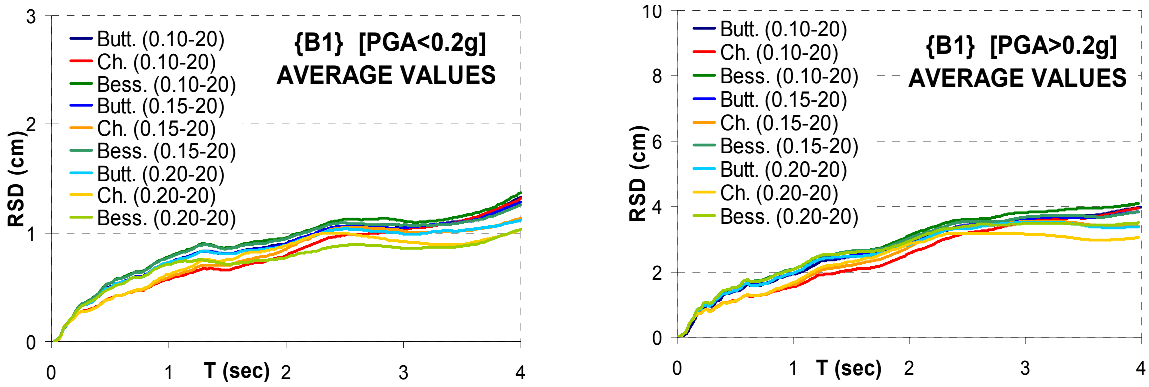

Figure 9. Soil class B_1 – Records: average values of absolute displacement response spectra

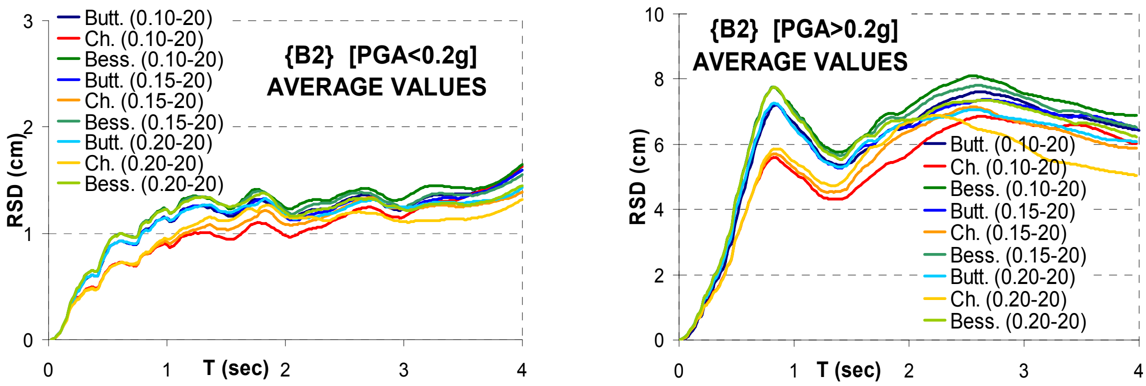

Figure 10. Soil class B_2 – Records: average values of absolute displacement response spectra

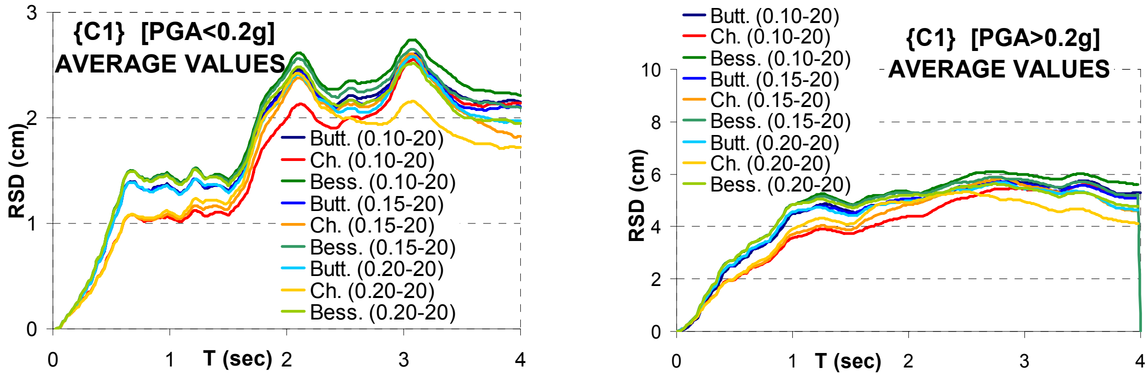

Figure 11. Soil class C_1 – Records: average values of absolute displacement response spectra

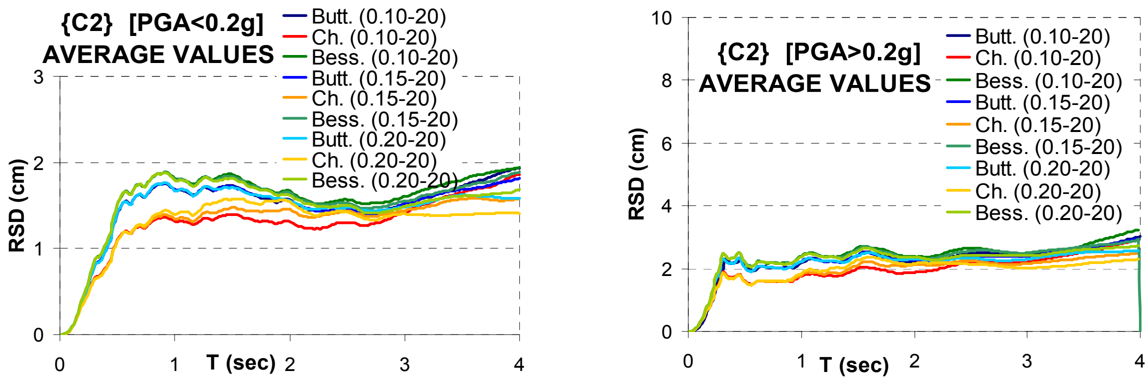

Figure 12. Soil class C_2 – Records: average values of absolute displacement response spectra

The choice of filters and cutoff frequencies applied on acceleration time histories are of major importance for the computed displacement response spectra. From the results of the strong motion recordings processing it is quite obvious that the choice of the filter type can be decisive especially in soil classes B_2, C_1, C_2, (Figures 10-12), for both levels of seismic excitation. The use of Bessel type of filter for all three combinations of cutoff frequencies tends to overestimate the computed displacement spectra compared to Butterworth filter type, while using Chebyshev type of filter leads to significantly lower displacement spectral values. Based on the extracted results, for period values $T_0<0.8$ sec, which is the range of fundamental period values for most structures, the choice of the high-cut frequency is critical, since it defines the cutoff of PSA values in high frequencies, leading in the reduction of the displacement spectral values. On the contrary, the choice of the low-cut frequency for reducing the long-period noise in accelerograms cause minor differentiations in estimated displacement response spectra, according to Boore, (2001). In addition, Boore and Bommer (2005), suggest that baselines can be used as a tool to remove at least part of the noise as means of recovering more physically plausible displacements and that the correct application of the chosen filter is much more important than the choice of a particular filter (causal or acausal filters).

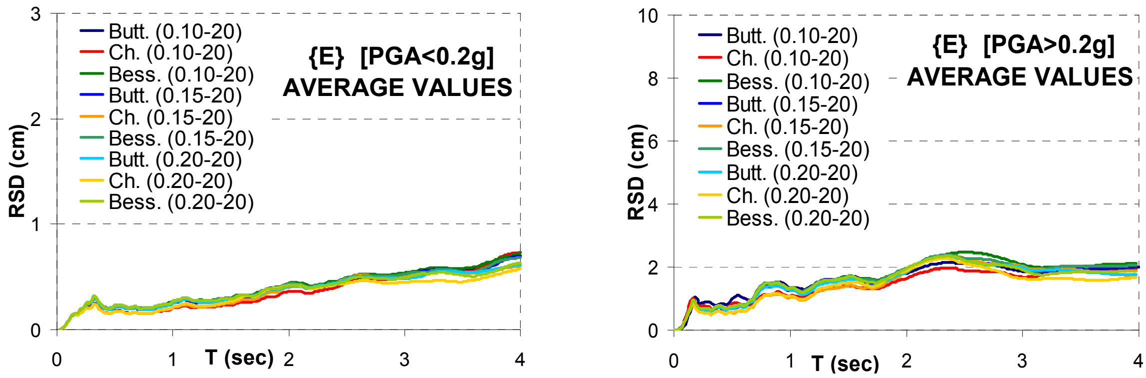

Figure 13. Soil class E – Records: average values of absolute displacement response spectra

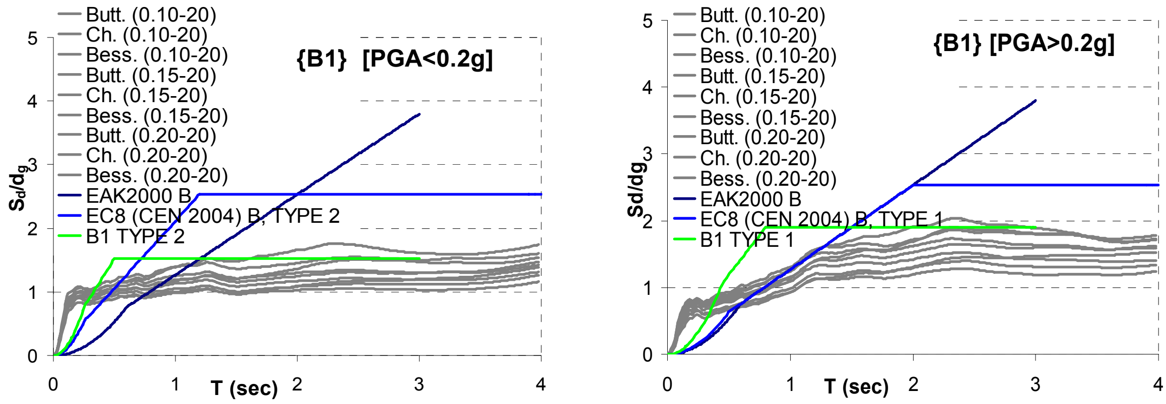

Figure 14. Soil class B_1 – Records: average values of normalized displacement response spectra (a) PGA<0.2g : 55 records, (b) PGA>0.2g : 35 records

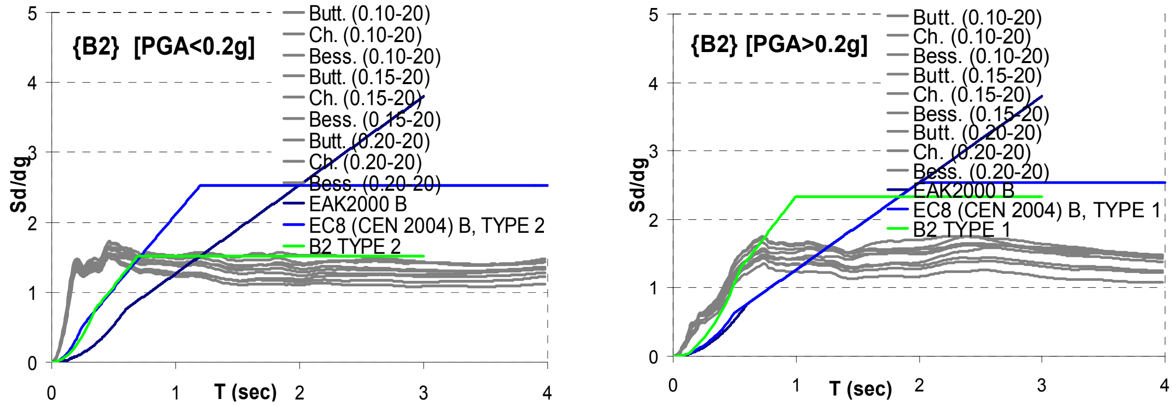

Figure 15. Soil class B_2 – Records: average values of normalized displacement response spectra (a) PGA<0.2g : 31 records, (b) PGA>0.2g : 22 records

In order to compare the analytical curves which have derived from the strong ground motion processing with the design spectra of the current seismic codes, normalized displacement response spectra to the peak ground displacement value (PGD) of every displacement time history were computed successively, for each type of filter and cutoff frequency. Average values of the corresponding normalized displacement spectra were then computed, for two levels of seismic intensity PGA<0.2g and PGA>0.2g, for each combination of filter and cutoff frequency (nine + nine = eighteen mean values of normalized displacement response spectra), for every soil class. Finally, average values of the normalized displacement spectra were compared with the design displacement response spectra of the Greek seismic code – EAK2000, of EC8 (CEN 2004) (Type 1 and Type 2) and with the proposed new displacement response spectra by Pitilakis et al. (2004), for every soil class and for two levels of seismic excitation (PGA>0.2g and PGA<0.2g), as it is presented in Figures 14-18.

As Bommer and Pinho (2006) point out, a key issue on the elastic displacement response spectrum is the control period T_D that marks the start of the constant displacement plateau. The value of T_D in Eurocode 8 was fixed at 2sec for the Type 1 spectrum applicable in areas of high seismicity, based mainly on the work of Tolis and Faccioli (1999) that made use of the digital accelerograms from the 1995 Kobe earthquake, while for Type 2 spectrum for low seismicity cases, the value of T_D was fixed at 1.2sec. Judging, however, from the results of the strong motion processing for soil classes B_1 and B_2 it is evident that EC8 B displacement spectra for both cases of seismic excitation it is not at all compatible with the computed displacement spectra either regarding the value T_D nor the constant value of the plateau. In soil classes B_1, (Figure 14), the comparison between average values of the computed normalized displacement response spectra and the proposed design displacement spectra by Pitilakis et al. (2004) is quite satisfactory, especially for period values T_0>1.0sec. In soil class B_2 (Figure 15), for low seismic excitation, average computed and proposed displacement spectra are in the same range for period values T_0>0.8sec. For higher seismic intensity, the recorded spectral values

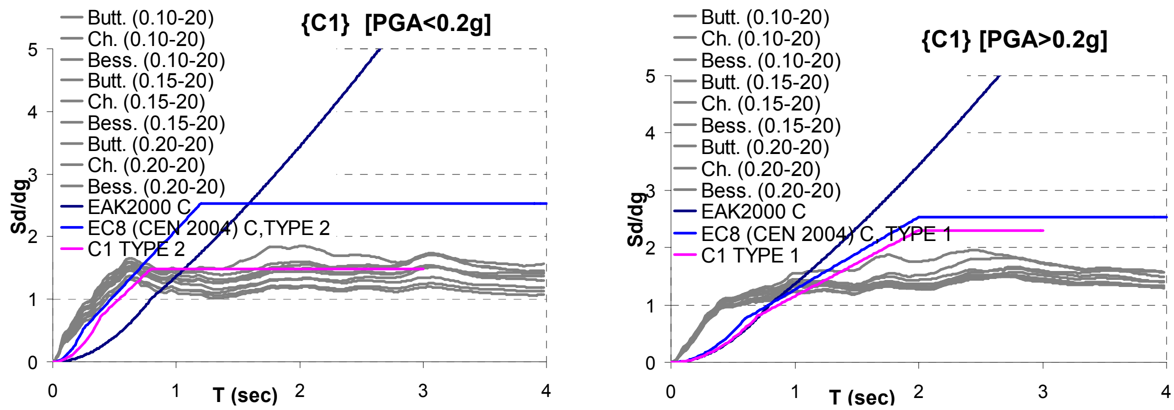

Figure 16. Soil class C_1 - Records: average values of normalized displacement response spectra (a) PGA<0.2g : 21 records, (b) PGA>0.2g : 17 records

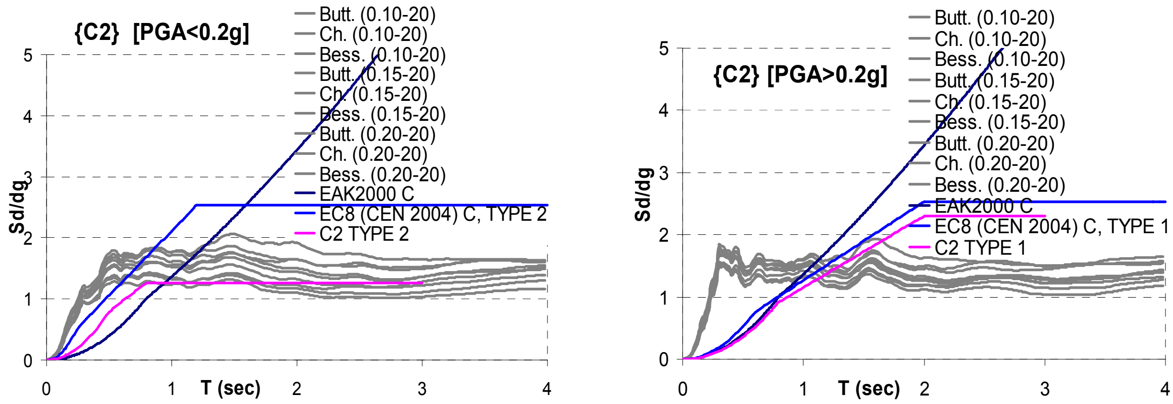

Figure 17. Soil class C_2 - Records: average values of normalized displacement response spectra (a) PGA<0.2g : 22 records, (b) PGA>0.2g : 10 records

for T_0<0.8sec are practically identical with the proposed analytical curves, while for T_0>1.0sec, where the constant displacement plateau starts, they are significantly lower.

Regarding soil classes C_1 and C_2, (Figures 16-17), EC8 C displacement spectral values for both cases of seismic intensity are quite overestimated compared to the average computed spectral values based on the strong motion processing. For PGA>0.2g, the value T_D at the proposed design displacement spectra by Pitilakis et al. (2004) is fixed at 2sec both in C_1 and C_2, as in EC8 C Type 1 displacement spectrum; as a result they are not at all compatible with the computed displacement response spectra. Faccioli et al. (2004) estimated average displacement response spectra based on the processing of strong K-net records (5.5<M<6.5) as a function of epicentral distance and site conditions; the value of

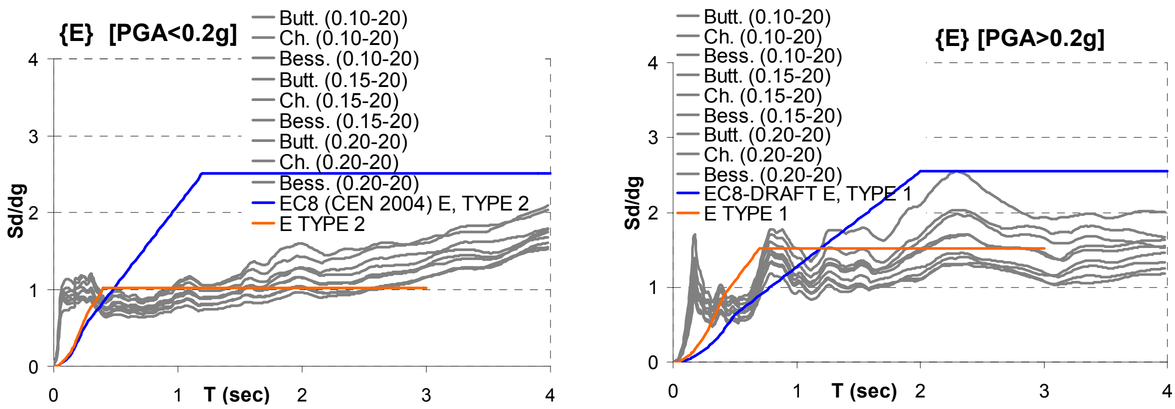

Figure 18. Soil class E – Records: average values of normalized displacement response spectra (a) PGA<0.2g : 28 records, (b) PGA>0.2g : 7 records

T_D in computed spectral values classified in soil class C for epicentral distance 30-50 km was fixed at 2sec, while for epicentral distance 10-30 km was fixed at 1sec. The epicentral distance of the strong motion records with high seismic excitation used in this study for soil class C_1 is relatively small (<30km), while in soil class C_2 is in the range of 50-100km. Therefore, the influence of epicentral distance as a factor could possibly account for the total incompatibility between the computed average displacement spectra and the proposed analytical curves, corresponding to Type 1 displacement spectra, for soil classes C_1 and C_2. The exact opposite applies for PGA<0.2g; in soil class C_1, average values of the normalized displacement spectra are practically identical with the proposed design displacement spectra not only regarding the value T_D but also the constant value of the plateau, while in soil class C_2, average recorded and proposed design displacement spectral values are also in very good agreement.

Finally, in soil class E (Figure 18), the average normalized displacement spectra are in the same range of values with the proposed design displacement spectra, regarding the value T_D and the constant displacement plateau, for both defined levels of seismic intensity. It should be pointed out, however, that for PGA>0.2g the records sample is relatively small.

CONCLUSIONS

In the present study, the aim is to estimate reliable displacement response spectra by processing a large sample of strong ground motion records and performing a large number of theoretical analyses. The results show that computed average displacement spectra based both on theoretical analyses and strong motion records processing are generally in good agreement with the proposed design displacement spectra by Pitilakis et al., (2004), while they present some relatively important differences with the EC8 (CEN 2004) design displacement spectra. Further research is required, both theoretical and experimental, especially in the soil classes with limited information and records. Moreover, the database of strong ground motion records should be enriched from other countries, (e.g. U.S.A., Taiwan) especially in the soil subclasses C1, C2 and E with PGA>0.2g, where there is generally lack of good quality earthquake records. Moreover, the key issue on the strong ground motion processing is the selection of the proper correction procedure (application of filters and cutoff frequencies) in order to compute realistic displacement response spectra. In addition to that, a possible re-evaluation of T_D period values, which defines the start of the constant displacement plateau in design displacement spectra, should be further examined by taking into consideration the influence of the epicentral distance, especially in the case of soft soil conditions (soil classes C1 and C2). Finally, displacement spectra must be well correlated with the respective acceleration spectra and the two spectra should be fully consistent. Further research is required towards this direction.

REFERENCES

Bommer JJ and Elnashai AS, "Displacement spectra for seismic design", Journal of Earthquake Engineering, 3, Issue 1, 1-32, 1999

Bommer JJ and Pinho R, “Adapting earthquake actions in Eurocode 8 for performance-based seismic design”, Earthquake Engineering and Structural Dynamics, 35, 39-55, 2006

Boore DM. "Effect of baseline corrections on displacements and response spectra for several recordings of the 1999 Chi-Chi, Taiwan earthquake", Bulletin of the Seismological Society of America, 91, 1199-1211, 2001

Boore DM and Bommer JJ, “Processing of strong-motion accelerograms: needs, options and consequences”, Soil Dynamics and Earthquake Engineering, 25, 93-115, 2005

CEN (Comité Européen de Normalisation), "Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings (EN 1998-1)", Brussels, May 2004.

Cyberquake, H. Modaressi, BRGM, 1998

EAK2000, Greek Seismic Code, Organization of Seismic Planning and Protection, 2000

Faccioli E, Paolucci R and Rey J, "Displacement spectra for long periods", Earthquake Spectra, 20, 347-376, 2004

Pitilakis K, Gazepis C and Anastasiadis A, "Design response spectra and soil classification for seismic code provisions", Proc. of 13th World Conference on Earthquake Engineering, Paper No 2904, 2004

Seismosignal, Version 3.1.0, Seismosoft, 2006

Tolis SV and Faccioli E, "Displacement design spectra", Journal of Earthquake Engineering, 3, Issue 1, 107-125, 1999