GEO-CHARACTERIZATION ACCORDING TO RECENT ADVANCES OF EUROCODE (EC8)

Savvaidis A.[*a], Margaris B.[a], Theodoulidis N.[a], Lekidis V.[a], Karakostas Ch.[a], Mangriotis M-D.[a], Kalogeras I.[b], Koutrakis S.[b], Vafidis A.[c], Steiakakis M.[c], Agioutantis Z.[c], Rozos D.[d], Loupasakis C[d]., Rondoyanni Th.[d], Tsangaratos P.[d], Dikmen U.[e], Papadopoulos N.[f], Sarris A.[f], Soupios P.[g], Kokkinou E.[g], Papadopoulos I.[g], Kouli M.[g], and Vallianatos F[g]

[a]Institute of Engineering Seismology and Earthquake Engineering (EPPO), Thessaloniki, Greece; [b]Geodynamic Institute, National Observatory of Athens, Greece; [c] Department of Mineral Resources Engineering, Technical University of Crete, Greece; [d]Laboratory of Engineering Geology and Hydrogeology, Department of Geological Sciences, School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece; [e] Department of Geophysics, Ankara University, Turkey; [f]Laboratory of Geophysical-Remote Sensing & Archaeoenvironment, Institute for Mediterranean Studies, Foundation for Research & Technology Hellas, Greece; [g]Laboratory of Geophysics and Seismology, Department of Natural Resources and Environment, Technological Educational Institute of Crete, Chania, Grete, Greece

ABSTRACT

For the seismic action estimation according to Eurocode (EC8) one has to characterize site conditions and suitably estimate soil amplification and corresponding peak ground motion for the site. For this reason, as specified, one has to define a design spectrum through the ground-type/soil-category (S), and the peak ground acceleration (PGA) of the reference return period (TNCR) for the corresponding seismic zone and for structural technical requirements chosen by the designer. Ground type is defined through geophysical/geotechnical parameters, i.e. (a) the average shear wave velocity up to 30 meters depth, (b) the Standard Penetration Test blow-count, and (c) the undrained shear strength of soil.

Through the "GEO-CHARACTERIZATION" THALIS-PROJECT we combine different geophysical and geotechnical methods in order to more accurately define the ground conditions in selected sites of the Hellenic Accelerometric Network (HAN) in the area of Crete Island. More specifically in the present efforts, geological information shear wave velocity and attenuation model calculated from seismic surface geophysical measurements is used. Additionally we utilize the ground acceleration recorded through HAN from intermediate depth earthquakes in the broader area of South Aegean Sea.

Using the recorded ground motion data and the procedure defined in EC8, the corresponding elastic response spectrum is calculated for selected sites. The resulting information are compared with the values defined for the corresponding EC8 spectrum for the seismic zone comprising the island of Crete.

As a final outcome of this work we intend to propose regional normalized elastic spectra for seismic design of structures and urban development planning and compare them with Eurocode.

Keywords: Natural Hazards, Earthquake Risk, Eurocode, Environmental protection, Crete.

1. INTRODUCTION

Given the impact on human losses, built environment and socioeconomic destruction from strong ground shaking, seismic risk mitigation is a primary objective of research activities in the fields of seismology and earthquake engineering. Well-known examples such as Mexico City in 1985, Northridge 1994, Athens 1999, Izmit and Duzce in 1999, among others, have been extensively cited to illustrate that surface geology can drastically exacerbate damage. The

* alexandros@itsak.gr; phone +3023100476081; fax +302310476085; www.itsak.gr

First International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2013), edited by Diofantos G. Hadjimitsis, Kyriacos Themistocleous, Silas Michaelides, George Papadavid, Proc. of SPIE Vol. 8795, 879513 · © 2013 SPIE · CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2028456

so-called site effects, depend on geological conditions, both lithological and geomorphological, and may produce strong modification in amplitude level, spectral content and time duration of earthquake ground motion. Since site effects may drastically increase seismic hazard level even in areas with moderate seismicity, their assessment becomes a major concern in seismic risk mitigation.

The methods which are generally considered as the most reliable for site effect estimation are site-specific and follow either an empirical or a numerical approach; (i) The instrumental approach, originally proposed by Borcherdt (1970), compares the spectral contents of the earthquake recordings obtained at the site of interest with a corresponding obtained at a nearby rock station called as reference site, using the so called Standard Spectral Ratio (SSR) and (ii) The numerical approach provides ground motion prediction based on a geophysical model of the site.

The instrumental approach requires a large number of recording events on both site and reference stations with a distance between stations negligible compared to epicentral one. This approach is not suitable where number of data is limited, especially for low seismicity areas. The numerical approach requires extensive site surveys to provide a detailed soil model as a function of depth in order to constrain numerical results within the frequency range of engineering importance. The duration and cost of such extensive surveys are limitations for intensive application. As an alternative to assess site effect, the physical characterization of a site might be used as a proxy for site effect because it is easier to extend to a large area and it does not need earthquake recordings.

The European and American seismic codes regulation (Eurocode 8, EC8 and National Earthquake Hazards Reduction Program, NEHRP) include consideration of site effects through a simple site classification based on time-averaged velocity of the first 30 m, $V_{S,30}$, and associated spectral shapes. However, despite $V_{S,30}$ wide use as a proxy to actual site conditions and site effects, it is often criticized as it does not seem fully relevant to the main physics of site amplification (Castellaro et al. 2008; Assimaki et al. 2008). Indeed the response spectrum is the amplitude level at a given frequency and $V_{S,30}$ alone does not carry any frequency information. However, the simplicity of this $V_{S,30}$ site classification and the relative low cost of the background site survey made the $V_{S,30}$-based approach very popular, in particular because no alternative combining cost effectiveness, simplicity, and physical relevance to the underlying phenomena has been proposed.

For seismic action estimation according to EC8 one has to characterize site conditions and suitably estimate soil amplification and corresponding peak ground motion for the site. For this reason, one has to define a design spectrum through the ground-type/soil-category (S), the peak ground acceleration (PGA) of the reference return period (TNCR), for the corresponding seismic zone and parameters of earthquake resistant requirements chosen by the designer. Ground type is defined through geophysical/geotechnical parameters.

Taking into account that seismic provisions may provide average design values covering nationwide needs, it is often under discussion whether regional specific seismic actions could more realistically represent seismic hazard and its associated risk reduction. For instance, variation in seismotectonic environment may significantly affect spectral content of ground motion resulting in turn to elastic design spectra that differ from corresponding seismic provisions' values. Such a deviation may come mainly from luck of recorded data in the statistical set used to propose seismic action in code provisions. On the other hand, site characterization depends on geotechnical/geophysical methods used leading to results that sometimes are hardly associated with classification of soil type presented in seismic code.

For the aforementioned reasons, it becomes mandatory to investigate and test seismic code design spectral values over region that are exhibited to a specific seismotectonic environment based either on actual regional seismic recordings or/and new results of improved geophysical/geotechnical approaches for site characterization.

In this study, using recorded ground motion data from intermediate depth events in Crete and surrounding area and the procedure defined in EC8, the corresponding elastic response spectrum is calculated for selected sites. These values are compared with those defined for the corresponding EC8 design spectrum for the seismic zone comprising the island of Crete. As a final outcome of this work we intend to propose regional normalized elastic spectra for seismic design of structures and urban development planning, to compare them with Eurocode provisions and pinpoint differences that could be taken into account for improving seismic design actions in southern Aegean area.

2. DATA AND METHODS USED

2.1 Geo-characterization in Crete Island

In order to accomplish the aforementioned actions to provide the site characterization in the strong motion sites of the Hellenic Accelerometric Network (HAN), complementary geotechnical field work took place (preparing engineering-geological maps of the areas under investigation). Moreover, the existing geotechnical and engineering geological data in the literature and other available resources (e.g. geotechnical companies, administrative authorities) were collected, evaluated and used to improve our knowledge for the study area.

After the geological/engineering mapping, geophysical measurements were acquired very close to selected stations. The geophysical methods of MASW and SASW were applied to provide information about the 1D and 2D $V_{S,30}$ velocity and the attenuation (Q_S) model for the areas under investigation.

From the available geophysical and geotechnical data, the subsurface model for the selected sites where permanent accelerometers of HAN are installed on Crete (Figure 1), was constructed and used as input information for a theoretical and experimental evaluation of the site effects.

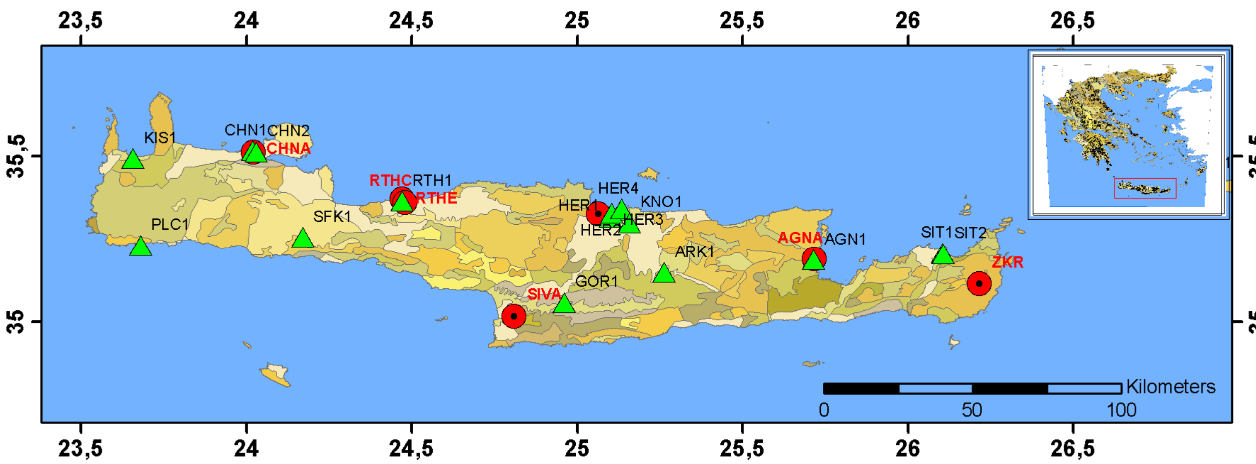

Figure 1. Geological map of Crete Island where the stations of HAN are presented with red circles and green triangles for EPPO-ITSAK and NOA-GI strong motion instruments, respectively.

2.2 Horizontal elastic response spectra defined in EC8

In EC8, seven ground types (A to E and two special types S_1 and S_2) are prescribed, to account for the influence of local ground conditions on the seismic action. The types are defined either through a qualitative description of the corresponding stratigraphic profile or through qualitative parameters, namely $V_{S,30}$ (average value of propagation velocity of *S* waves in the upper 30 m of the soil profile at shear strain of 10^{-6} or less) if available, otherwise through use of N_{SPT} (Standard Penetration Test blow count) or c_U (undrained shear strength of soil). For ground types S_1 and S_2 special studies for the definition of seismic action are required. For the other ground types (A to E) two types (Type-1 and Type-2) of elastic response spectra are in general prescribed (depending on if the earthquakes that contribute most to the seismic hazard defined for the site -for the purpose of probabilistic hazard assessment- have a surface-wave magnitude, M_s, greater or not than 5.5 respectively). It should be noted that Eurocodes allow a certain number of their clauses and parameters to be defined through a National Annex specific for each EU country state. Hence, for Greece only Type-1 spectra are applicable (as defined in the corresponding Greek National Annex). As seen in Figure 2a, the typical horizontal elastic response spectrum shape consists of four sequential branches whose range is defined by the periods T_B, T_C and T_D of a single-degree of freedom system. The first branch starts from a (seismic-zone dependent) design ground acceleration value of a_g (at T=0) and increases linearly up to a value of $2.5{*}S{*}\eta{*}a_g$, where S is a soil parameter whose value – along with the values of T_B, T_C and T_D – depends on the ground type, and η is a structural damping correction factor with reference value η=1 for 5% viscous damping. The second branch retains a constant value up to period T_C. The third branch decreases inversely linearly to the period up to a value of T_D. Finally, the last branch continues decreasing inversely to the square of the period up to T=4sec. The recommended in EC8 shapes of Type-1 elastic response spectra for ground types A to E can be seen in Figure 2b. The Greek National Annex adopts the values of T_B and T_C recommended in EC8, but prescribes a value of T_D=2.5 sec for all ground types (instead of the EC8-recommended value of T_D=2.0 sec).

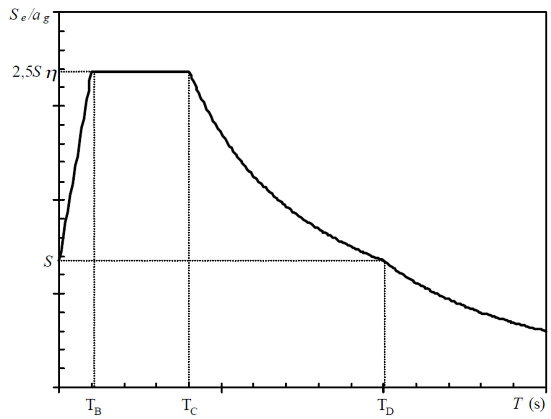

Figure 2a. Shape of the EC8 elastic response spectrum

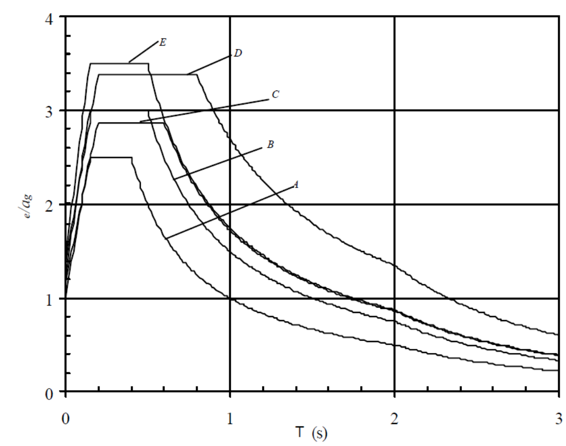

Figure 2b. Recommended Type-1 elastic response spectra for ground types A to E (EC8)

Finally, it should be noted that a vertical elastic response spectrum as well as corresponding design spectra for elastic analysis of structures are prescribed in EC8 (both based on similar concepts as those of the horizontal elastic response spectrum described above), but their detailed presentation falls beyond the scope of the present paper.

2.3 Geological & Geotechnical setting of the HER1 accelerometer foundation conditions

As an indicative example we hereby present geological/geotechnical setting for station HER1 of HAN situated at the Technical University of Crete (TEI) at Heraklion city. The HER1 accelerometer is founded on a Marly horizon of Neogene consisting of white, yellowish to light dark marls to sandy marls, fossiliferous, well bedded to laminate (Figure 3). They develop a weathering mantle of about 1 to 1.5m thick. Within the marls small size lenticular interferences of conglomerate, sandstones, sands or marly limestone can be found, the thickness of which does not appear to exceed 3 to 4m. These marls can be characterized as stiff formations with good geotechnical behavior and low permeability. The total thickness of the formation appears to reach several tens to a few hundred meters.

Considering the geotechnical characteristics of the marls (Tsiampaos, 1988) they present grate variation on their unconfined compressive strength ranging from 63 to 1106 KPa, (mean value 376KPa) with a water content of 17.3 to 43.3%. They are over-consolidated with an OCR less than 3. The compression index (Cc) value ranges from 0.083 to 0.250 with an initial void ratio (e_o) between 0.740 – 1.110. Concerning their swelling characteristics they contain high montmorillonite percentage, up to 25%, and they present relatively high swelling pressure values between 30 and 200KPa.

Besides the marls, within the limits of the narrow research area alluvial deposits also occur. Located in a small part of the northern entrance of TEI they consists of fine –grained silty sand with small amounts of clay and also with sparse fragments of quartz, carbonate or chert gravels. These deposits are loose or slightly coherent formation with moderate plasticity and increased permeability. The thickness of the formation is no more than 1 to 2m and they do not affect the foundation conditions of the HER1 accelerometer.

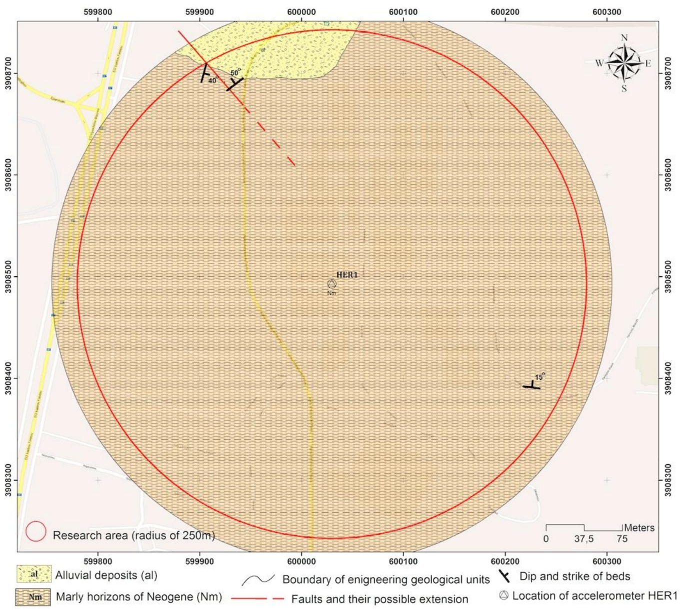

Figure 3. Geological and tectonic mapping adjacent to the Accelerometric Station of HER1.

2.4 Geophysical data and method used.

From the strong motion sites in Crete we hereby present the geophysical information that can conclude to the ground type, as needed, for EC8 for two stations, CHN1 and HER1, in Chania and Heraklion cities, respectively.

In December 2012, we performed a series of geophysical seismic tests including MASW (multichannel analysis of surface waves) and ReMi (refraction microtremor) methods (ex. Park, 1999; Louie, 2001) to determine the Vs (shear-wave velocity) and Qs (shear-wave Q factor) profiles at different stations those among which is HER1.

We used a 24-channel seismograph with 4.5Hz vertical geophones. Two different receiver spacing (dx) layouts were acquired at each location: 1m and 3m at HER1 and 1m and 2m at HER2. Different receiver spacings and various source-receiver offsets (0-40m) were attempted to assess the scale of any possible lateral heterogeneity and limitations due to S/N ratio. All seismic data was recorded with sampling rate (dt) of 2msec for a total record length of 4seconds and 20minutes for MASW and ReMi, respectively. A sledge hammer was used as the active seismic source for MASW.

For the MASW data, shot gathers with highest S/N ratio were selected and their corresponding f-k spectra were computed, using traces with minimum source-receiver distance of 20m to reduce near-field effects. For the ReMi data, the entire receiver array was processed for the f-k spectra computation. From visual inspection, the dispersion curve (Rayleigh wave phase velocity as a function of frequency) was picked for the fundamental mode. Figure 4 shows the picked dispersion curve for HER1 for the dx=3m array (the dx=1m array was not used as it contained too much lateral heterogeneity from shallow layers). The picked dispersion curve was roughly in the 5-38 Hz range. In order to assess the effect of different modeling algorithms and starting models in Vs inversion, two separate procedures were used: a) Neighborhood algorithm (Whatelet, 2005), b) Non-linear least squares Method (NL-LSM) (Xia et al., 1999). For method (a) the open source software geopsy (http://www.geopsy.org/) was used for two model scenarios: a two-layer plus half-space and three-layer plus half-space model, with minimum and maximum layer thickness set to 2m and 60m, respectively. For method (b) the software SeisImager/SW (http:// www.geometrics.com) was used to construct the initial model with number of 15 layers plus half space based on depth conversion results and only S-wave velocity was a free parameter throughout the inversion. This method uses 1.1 times the phase velocity for an estimate of S-wave velocity and the one-third wavelength approximation for an estimate of depth for the initial model construction. The inverted S-wave velocity profile obtained by operating non-linear least squares algorithm on common midpoint cross-correlation (CMP-CC) analysis (Hayashi and Suzuki, 2004). Figure 4 summarizes the Vs profiles from the two algorithms used in the inversion for HER1, and results from the (Mastrolorentzo, 2004) study for CHN1. As suggested from Table 1, although the two algorithms used in the HER1 inversion suggest different $V_{S,30}$ values, it is important to recognize that all models suggest HER1 be categorized as Ground Type B. This result complies with the geotechnical characterization provided in the previous section. Finally, for HER1, we attempted Qs inversion from Rayleigh wave attenuation curve (α_R as a function of frequency). The well-behaved frequency range for was 25-38Hz as computed from the dx=3m MASW data (dx=1m MASW data was too noisy for Qs inversion). Qs inversion was performed using Hermann's code 'Computer Programs in Seismology' (http://www.eas.slu.edu/eqc/eqccps.html) as an uncoupled inversion with assumed starting model (Table 2), for Qp=Qs and for fixed bottom and smoothness forced conditions. Due to the limited frequency range, the Qs penetration depth is in the order of 10m.

The Vs profile at station CHN1 was determined independently from a previous MASW study (Mastrolorentzo, 2004) and is provided in Figure 4.The $V_{S,30}$ value for CHN1 is 1132m/s, which categorizes the site as Ground Type A.

Table 1: $V_{S,30}$ values for HER1 station.

Model Description	Method (a) 2layer+half-space	Method (a) 3layer+half-space	Method (b)
$V_{S,30}$ (m/s)	483	472	381

Table 2: Starting and inverted Qs model for HER1 station.

Thickness (m)	Assumed Vs (m/s)	Assumed Qs	Model Qs
5	268	15	20
2	407	20	36
3	407	20	38
5	407	20	29
Inf	569	20	20

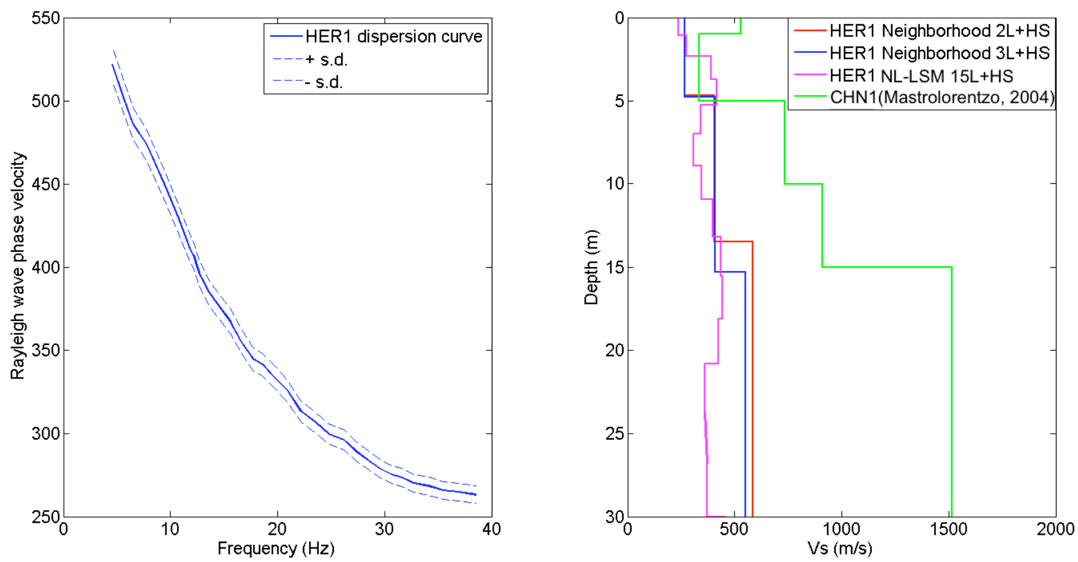

Figure 4: Picked Dispersion Curve for HER1 (left). Inverted Vs profiles for HER1 (current study) and CHN1 (Mastrolorentzo, 2004) (right).

3. COMPARISON OF SPECTRAL SHAPES

In the following, comparisons are made between elastic response spectra, according to EC 8 and observed spectral values which have been recorded by accelerographic instruments installed in the Chania and Heraklion sites, at the Crete Island. This instrumentation is part of the accelerographic network running from the Geodynamic Institute of the National Observatory in Athens (GEIN NOA) and the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) of the EPPO in Thessaloniki, covering the whole Hellenic territory, depicted for this study as HAN. The operation of this Network has started at the early of '70s in Greece from both institutions. In these comparisons the observed spectral values were derived from accelerograms which have been recorded by instruments triggered by strong intermediate depth earthquakes (hypocentral depths ≥ 50 km). In Table 3, the code station name (STA NAME), the origin of the instrument (ORIGIN), the geographical coordinates (STA LAT, STA LON) of the accelerographic stations the origin time of the earthquake event (ORIGIN TIME), the geographical coordinates (EPIC LAT, EPIC LON) of the earthquake hypocenter, the depth of the hypocenter (DEP), the earthquake magnitude (MAG), the epicentral (DIST) and hypocentral (HP DIST) distances are given.

Table 3. The accelerographic stations and the earthquake parameters of the strong motion records utilized for the calculation of observed spectral values. Groups with the same fill color denote the same earthquake event.

STA NAM	ORIGIN	STA LAT	STA LON	ORIGIN TIME (YYMMDDHHMMSS)	EPIC LAT	EPIC LON	DEP	MAG	DIST	HP DIST
CHNA	GEIN NOA	35,5134	24,0217	940523064612	35,5409	24,6968	68	6,1	61,2	91,5
HER1	ITSAK	35,3177	25,1022	940523064612	35,5409	24,6968	68	6,1	44,3	81,2
CHN1	ITSAK	35,517	24,0208	940523064612	35,5409	24,6968	68	6,1	61,2	91,5
CHN1	ITSAK	35,517	24,0208	060108113455	36,1853	23,4037	67	6,7	92,8	114,5
HER2	ITSAK	35,3379	25,1356	060108113455	36,1853	23,4037	67	6,7	183	194,4
HER1	ITSAK	35,3177	25,1022	060108113455	36,1853	23,4037	67	6.7	184	195,0

In Figure 5 the acceleration response spectra from the aforementioned accelerograms (Table 3) are given calculated by 5%-damping and for the two horizontal components separately (L-longitudinal and T-Transverse) of seismic motion (depicted by colored lines). Those observed spectral values are compared to elastic response spectra scaled for various PGA's and for three different soil-categories (SC) according to EC8 (A, B and C: black continuous/dashed and grey thick lines) in all plots. The selected PGA values, where the EC8 elastic response spectra are anchored, correspond to the peak values of recorded accelerations in each station. For stations HER1 (Figure 5a) and CHN1 (Figure 5c) the ground-type (soil-category) defined through the present work is marked with an orange box.

In almost all cases the shapes of EC8 elastic response spectra are in good agreement with the corresponding observed spectral shapes in each accelerographic station. Exceptions are noticed for (i) HER1_STN comparison and especially for the recorded T-component of the accelerogram HER1 0601 of the Kythera earthquake 2006, M6.7 and hypocentral distance HP DIST: 195 km in a period range from 0.8 to 1.6 sec, and (ii) CHN1_STN comparison of the calculated elastic response spectra for soil-category A (defined through geophysical information) and the recorded accelerogram CHN1 9401 (for both T and L components) of the Cretan Sea earthquake 1994, M6.1 and hypocentral distance HP DIST: 91.5 km in a very short range of periods while the calculated elastic response spectra for soil category A do not sufficiently predict the observed spectral values of the accelerogram CHN1 0601 of the Kythera earthquake for a wide period range of 0.8 to 3.0 sec. In the former case the difference is mostly in the frequency range that corresponds to the descending, higher period (T>1 sec) branch of the spectrum and the accelerograms recorded by the Kythera 2006 earthquake seem to systematicaly deviate from the elastic response spectra recording to EC8 for a wide long period range, and in the later case both to the flat as well as to the descending branch of the spectrum.

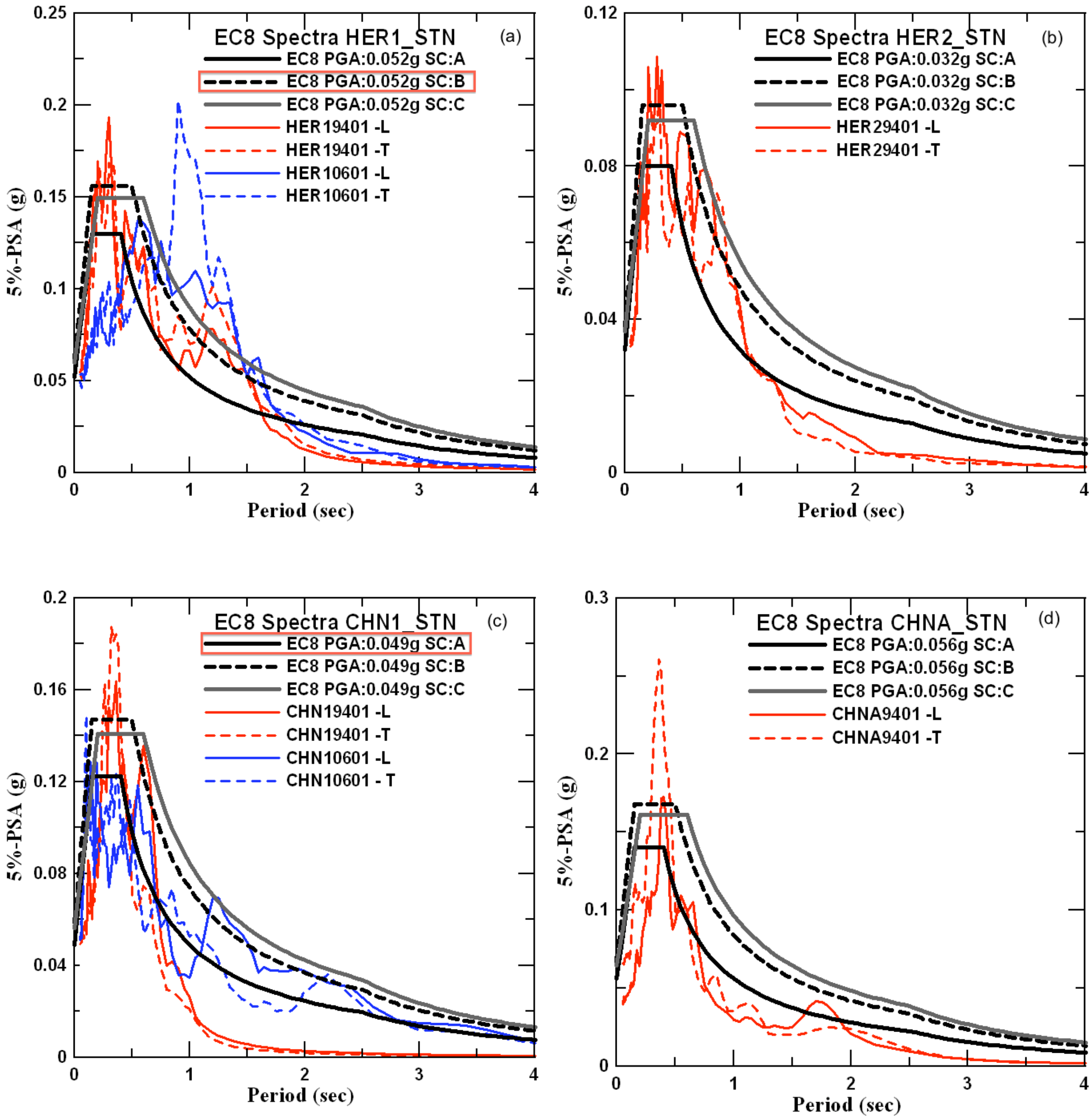

Figure 5. Observed and calculated acceleration response spectra for stations: (a) HER1, (b) HER2, (c) CHN1, (d) CHNA. The observed data are denoted with different color for independent earthquake events and with continuous and dashed line for Longitudinal and Transverse components of the same event, respectively. The theoretical elastic spectrum prescribed in EC8 (PGA-scaled) is presented for different ground type conditions, A, B and C, denoted with black line, dashed black line and grey line, respectively. For stations HER1 and CHN1 the ground-type (soil-category) defined is marked with an orange box.

For the use of the EC8 spectra and for the design especially of tall structures, it becomes obvious that the case of intermediate-depth earthquakes (like the Kythera 2006 earthquake, which was the first of its type to be recorded by the Hellenic Accelerometric Network) should be examined properly, taking into account the above remark, since the EC8 spectral shape does not seem to envelop in a satisfactory degree the much richer in the medium range (0.5 sec<T<1.5 sec) content that characterizes this type of earthquakes. Definite conclusions will be able to be reached when a sufficient number of recordings of intermediate-depth earthquakes in Greece will be available since such data probably have not been included during the composition of EC8.

4. CONCLUSIONS

Through our current work we present the steps for the calibration of the elastic spectrum prescribed in EC8 based on site geo-characterization defined by geological, geotechnical and geophysical data. It is of high value to be able to properly define the ground type at each site in order to be able to suitably calibrate the corresponding code prescribed spectra and propose appropriate modifications to spectral shapes in EC8 for the improvement of seismic design actions.

In to this aspect geological, geotechnical and geophysical investigations should be used jointly to provide accurately, or even with its corresponding uncertainty, the ground type. In the current work we focus on the shape, rather than the absolute values of EC8-prescribed spectra, and the conclusions derived herein should be viewed in this context. More specific quantitive comparisons with the EC8 elastic spectral shapes prescribed for the sites under examination will be possible when recordings from stronger earthquake events will be available. Additionally, before any robust conclusion is carried out, more sites of the Hellenic Accelerometric Network need to be investigated and geo-characterized in order to increase the number of comparative evaluation between seismic code seismic actions and observed acceleration spectra. Following this approach regional condition for the area of Crete Island might apply. These results will better define the urban planning in the seismically active zone of the South Aegean.

ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: **THALES**. Investing in knowledge society through the European Social Fund. More specifically the work presented is part of the Project with title “GEOTECHNICAL CHARACTERIZATION OF SELECTED AREAS IN CRETE USING GEOPHYSICAL AND GEOTECHNICAL METHODS”.

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