Comparative analysis between elastic response spectra of different European Codes

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ABSTRACT
A comparative analysis between the elastic response spectra defined by different European seismic codes is presented in this paper. The following normatives are analyzed: Spanish building code NCSE-02, Eurocode 8 (EC-8), Italian building code NTC-08 and National Annex to EC-8 for Portugal and France. The study is carried out in the frame of a project aimed at defining the Spanish National Annex to EC-8, and the results provide us with some criteria for establishing the spectral shapes and the soil coefficients to be used in the Spanish National Annex to EC-8 as well as in a new revision of the NCSE-02.

Keywords: "Response spectra", " European Seismic codes ", "Eurocode".

1. INTRODUCTION

The main purpose of the present paper is compile information which will make the definition of the elastic response spectra for the Spanish National Annex to Eurocode 8 (SNA-EC8). With this aim the specific objectives are: 1) To summarize the criteria for establishing response spectra of different European normatives 2) To compare the results obtained through the application of these normatives, and 3) To reach conclusions which provide criteria for the definition of such spectra in the SNA-EC8 . In addition to the Spanish Normative, *Norma de la Contrucción Sismorresistente Española* (NCSE-02), the other analyzed codes have been: Eurocode EC-8 (2004), Portugal National Annex to EC-08 (PNA-EC8, Draft ,*Campos Costa Personal communication*), Italian Building Code (NTC-08) and French National Annex to EC-08 (FNA-EC8, Draft, Pecker *Personal communication*) .

The work is structured in three parts: 1) Summary of aspects concerning the response spectra given by different codes, 2) Comparison of the response spectra given by the Spanish code NCSE-02 with the other ones anchored with similar acceleration on rock site, and 3) comparison of the response spectra in populations close to the Portugal-Spain and France-Spain boundaries using all the parameters defined (including acceleration) by the respective codes. Finally some conclusions are extracted.

2. SUMMARY OF THE ASPECTS REGARDING THE RESPONSE SPECTRA ACCORDING TO THE ANALYZED CODES.

All the analyzed codes consider a hazard map on rock, with the exception of the Spanish normative NCSE-02, whose hazard map corresponds to a firm soil and gives a basic acceleration a_b . The mean soil factor for converting the a_b values to rock accelerations a_{gR} is 0.8. The spectra present two basic bands, one with constant spectral acceleration, S_{am}, and another with constant spectral velocity, S_{vm}. The cut-off period between both bands is called T_C (in EC-8) y T_B (in NCSE-02).

The EC-8 defines 2 types of spectra, type 1 for countries where earthquakes may reach magnitudes $M > 5.5$ and Type 2 where the earthquakes with highest contribution to the hazard correspond to magnitudes $M \leq 5.5$. EC-8 recommends two series of coefficients, C and S for taking into account soil conditions. The plateau of the spectral shapes in both types takes a value of 2.5.

The Portuguese National Annex to EC8 (PNA-EC8, draft) considers two zonation maps for scenarios of Interplate earthquakes (Azores-Gibraltar) and Intraplate (continental) shocks, respectively. The first is identified with the action of long distance and high magnitude ($M > 5.5$) shocks and the second with short distance and moderate magnitude events ($M \leq 5.5$).The corresponding response spectra are built with similar equations for the spectral shapes of EC-8 Type 1 in the first case and Type 2 in the second one, but with different cut-off periods. In general, the plateau is wider in the PNA-EC8 than in EC-08. On the other hand, a similar soil classification is adopted with factors, in general, higher in PNA-EC8 than in EC8.

The Italian Normative NTC-08 does not use the concept of seismic zones and defines the response spectra in each point of a network covering the entire Italian Territory. NTC-08 provides the following parameters defined for each point (in rock) and for 9 return periods: a_g horizontal acceleration, F_o amplification factor for reaching the plateau and T_C* cut-off period for beginning the constant-velocity part of the spectrum . The spectral shapes are built with equations similar to the ones given by EC-8, but S and T_C* are estimated by their own procedures.

The French National Annex to Eurocode 8 (FNA-EC8, draft) considers two zonation maps, one for the Metropolitan Territory and another for the Caribbean French Islands. The maps, coefficient of soils and spectral shapes are included in the French Building Code (Arreté JORF-127, 1997). The construction of response spectra in the first case uses the spectral shapes of EC-8 type 2 ($M \leq 5.5$), with different amplification factors and cut-off periods. The plateau of the FNA-EC8 for Metropolitan Territory is wider than the ones of EC-8 Type 2. For the scenarios of Caribbean Islands FNA-EC8 uses exactly the spectral shapes of EC-8 type 1 ($M > 5.5$), with similar amplification factors.

The Spanish Building Code NCSE-02 considers a hazard map (return period of 500 years) providing values of basic acceleration, a_b, in a class of hard soil, in such a way that a medium factor of 0.8 is required for converting values of a_b to rock accelerations a_{gR}. The plateau of the standard shapes is fixed in 2.5, similar to those of EC-8, PNA-EC8, FNA-EC8 and equal to the average values in the Italian Code NTC-08. The cut-off periods depend on two coefficients: C, identificator of the soil class, and K, which takes into account the influence of the long-distance earthquakes occurred in the Azores Gibraltar zone. Four classes of soil are considered with coefficient C taking values:

Class I. C = 1.0 I ($V_S > 750$ m/s); more or less equivalent to Class A in the other codes
Class II. C = 1.3 ($400 \leq V_S \leq 750$ m/s); equivalent to Class B
Class III. C =1.6 (200 m/s < V_S < 400 m/s); equivalent to Class C
Class III. C =1.8 or 2. (V_s< 200 m/s); equivalent to Class D

The soil amplification factor S depends on C and a_b through a non-linear function, taking values in the range (0,8-2.0). The contribution factor of long-distance shocks ranges between K=1 (no contribution) and K=1.3 (highest contribution, in places close to the Portugal-Spanish border). The role of the coefficient K is to widen the plateau in the response spectra on those places with $K > 1$.

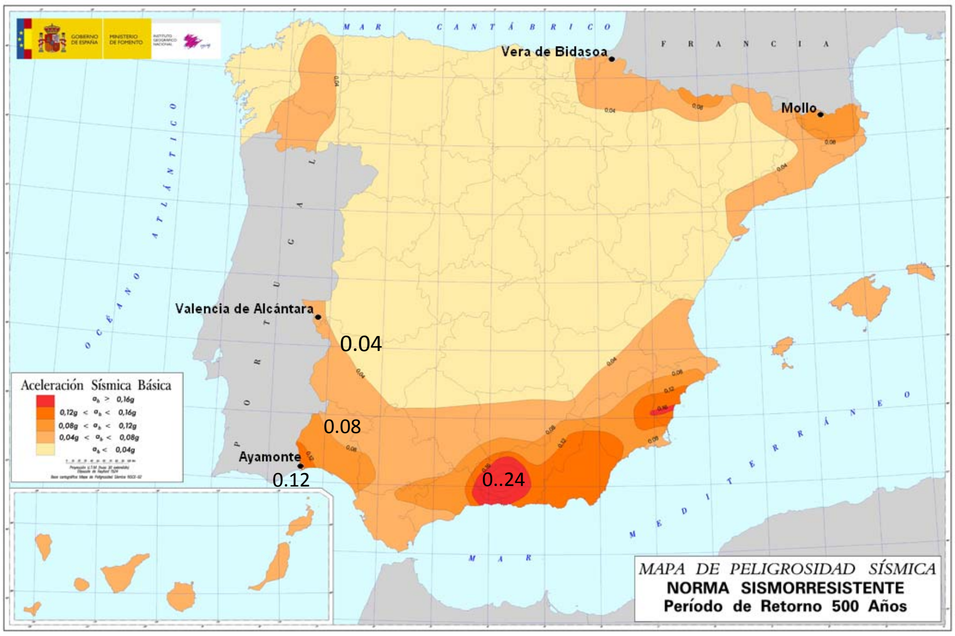

Figure 1. Hazard map of the Spanish Building Code NCSE-02 in terms of "basic acceleration", a_b (firm soil, in g) for a return period of 500 years. We also show the populations where a comparative analysis of response spectra given by the Portuguese, French and Spanish normatives will be done: Ayamonte and Valencia de Alcantara, in the Portugal-Spain boundary and Vera de Bidasoa and Molló in the France-Spain boundary.

3 COMPARISON OF RESPONSE SPECTRA DERIVED FROM APPLICATION OF THE ANALYZED CODES ANCHORED TO SIMILAR VALUES OF a_{gR}

A comparison between the response spectra obtained by application of the procedures, equations and soil factors of the analyzed codes, all of them anchored to similar values of rock acceleration a_{gR} has been done. The values of a_b in the hazard map of NCSE-02 have been converted to a_{gR} using the corresponding S factor. We consider different combination of a_b, K and S values and represent the spectra given by NCSE-02 together with the ones derived from the others codes for equivalent a_{gR}.

Figure 2 shows the results for a case without influence of the long-distance Azores Gibraltar earthquakes (K=1) and two extreme values of a_b, 0.05 and 0.24 g. The last one is the maximum value included in the NCSE-02 hazard map for Granada province. The spectra are compared with the ones of EC-8, PNA-EC8 (Type 2, intraplate shocks), FNA-EC8 (Type 2, Metropolitan Territory) and two extreme cases of the NTC08.

Figure 3 shows the results for a case with maximum influence of the long-distance Azores Gibraltar earthquakes (K=1.3) in two classes of soil and a value of a_b, 0.15 g, the highest found in the hazard map for K= 1.3. The spectra are drawn together with the ones of EC-8 (Type 1) and PNA-EC8 (Type 1, interplate earthquakes).

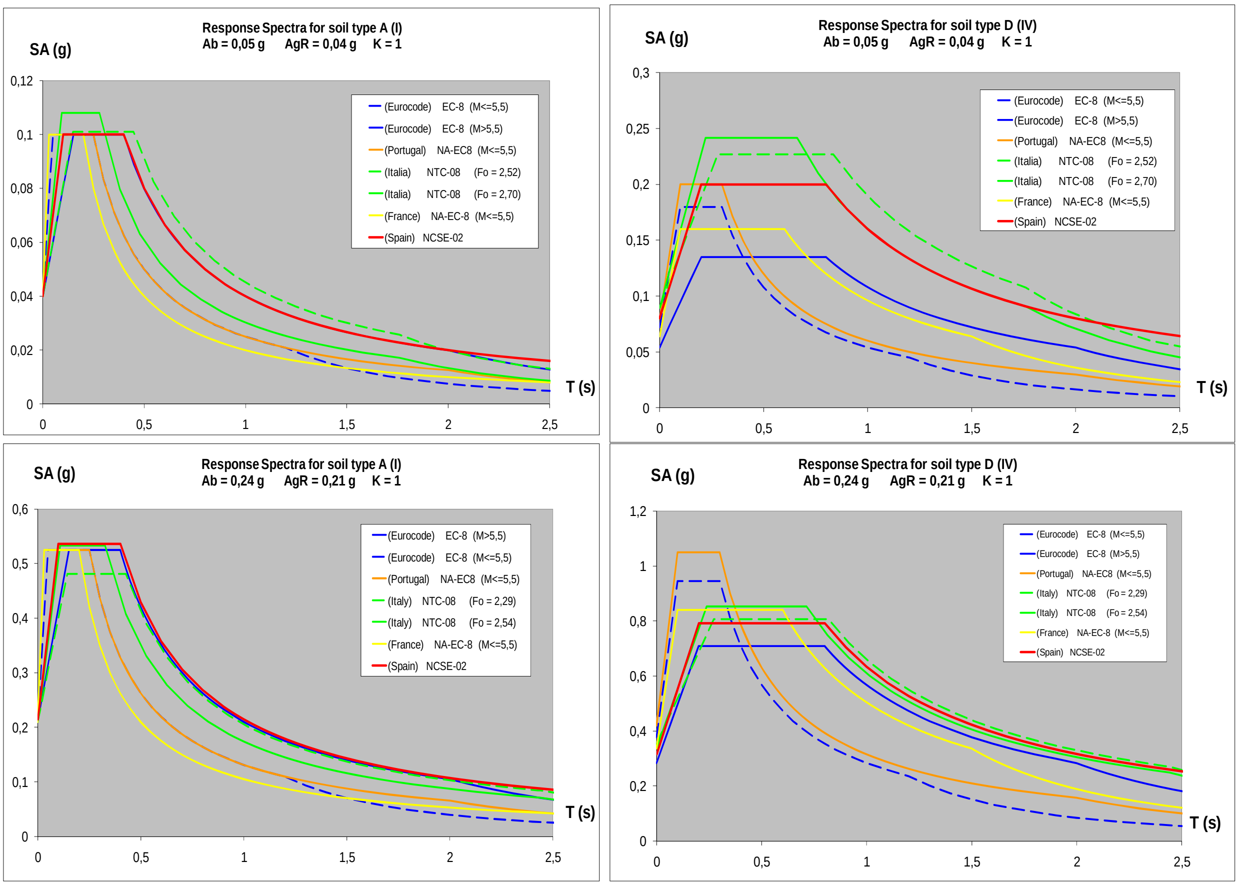

Figure 2. Comparison of response spetra given by the Spanish Building Code NCSE-02, for minimum influence of Azores-Gibraltar shocks (K=1) with the ones derived from the application of the National Annex of France and Portugal to EC-8, FNA-EC8 (Metropolitan Territory, Type 2) and PNA EC-8 (Intraplate earthquakes Type 2), the EC-8 and the Italian normative NTC-08 for two class of soil and two acceleration values a_{gR}.

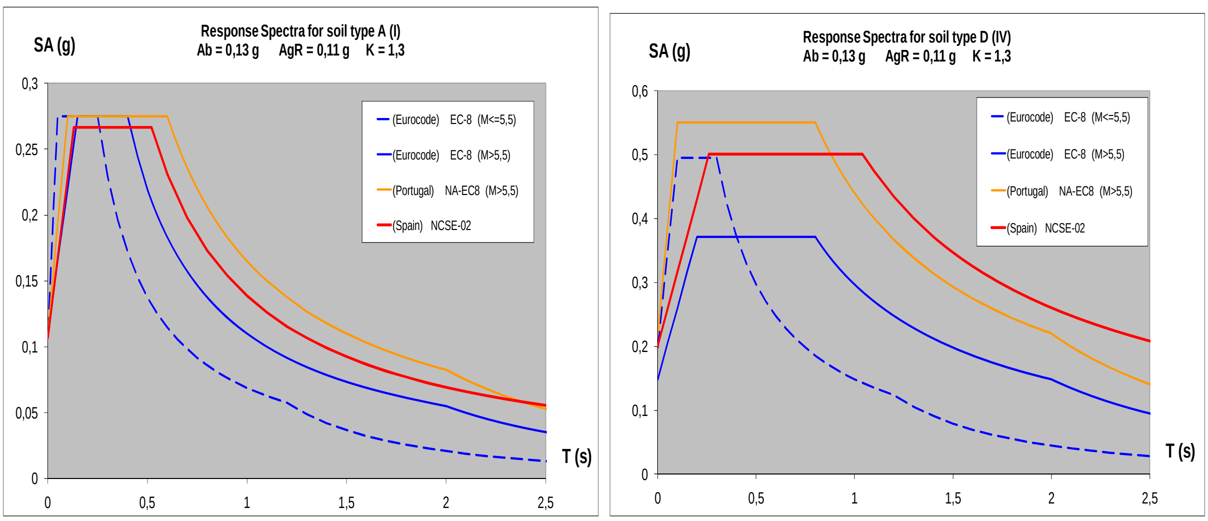

Figure 3. Comparison of response spectra given by the Spanish Building Code NCSE-02, for maximum influence of Azores-Gibraltar shocks (K=1.3), with those derived from the application of the Portuguese National Annex to EC-8, PNA EC-8 (Interplate earthquakes Type 1) and the EC-8 for two classes of soil.

4. COMPARISON OF THE SEISMIC ACTION ON BOTH SIDES OF THE PORTUGAL-SPAIN AND FRANCE-SPAIN BOUNDARIES.

A direct comparison between the response spectra resulting on both sides of the boundaries by complete application of the corresponding codes (including acceleration values) has been developed for the 4 soil classes in the following situations (see map of figure 1):

- Response spectra of NCSE-02 in Ayamonte (a_b = 0,14 g, K = 1,3) and the spectra at the other side of the boundary with Portugal for the two scenarios defined by the PNA-EC8 (a_{gR} = 150 cm/s² in Type 1 and 170 cm/s² in Type 2).
- Response spectra of NCSE-02 in Valencia de Alcantara (a_b = 0,04 g, K = 1,2) and the spectra at the other side of the boundary with Portugal for the two scenarios defined by the PNA-EC8 (a_{gR} = 60 cm/s² in Type 1 and 110 cm/s² in Type 2).
- Response spectra of NCSE-02 in Vera de Bidasoa, Navarra (a_b = 0,04g, K = 1) and the spectra at the other side of the boundary with France according to the PNA-EC8 (a_{gR}=1,6 m/s²)
- Response spectra of NCSE-02 in Molló, Gerona (a_b = 0,11g, K=1) with the spectra at the other side of the boundary with France according the PNA-EC8 (a_{gR} = 1,6 m/s²)

The Figures 4 and 5 show the results of these comparisons at the borders with Portugal and France, respectively.

5. CONCLUSIONS

As main conclusions of the study we note:

- None of the analyzed European codes, PNA-EC8, FNA-EC8 and NTC08 adopt the parameters proposed by default in EC-8 for the construction of the elastic response spectra, changing the cut-off periods and soil factors in the case of PNA-EC8, FNA-EC8 and introducing a complete change of philosophy in the Italian Building Code NTC-08.
- The factor 2.5 defined in NCSE-02 as amplification factor of the plateau in the response spectra is used by almost all the analyzed normatives.
- The Spanish response spectra defined in NCSE-02 is, in general, conservative for long periods T > 1 s. The spectral ordinate SA(1s) in the case K=1.0 (no contribution of long-distance events) is defined in a similar range than Italian Normative NTC08 and is bigger to the values proposed in the other codes (reaching differences up 50%). In the case of K=1,3 (maximum contribution of long-distance events) the long period spectral ordinates in NCSE-02 are lower or higher than the ones in PNA-EC8 depending on soil conditions.

Regarding the comparison of response spectra given by the Spanish code NCSE-02 and the Portuguese and French codes in points located next to both sides of the corresponding boundaries with Spain, we can note:

- The response spectra on the Spanish side of the boundary with Portugal are lower (differences between 20 and 50 %) than those provided by PNA-EC8 for the interplate scenario (Type 1) on the Portuguese side. For the intraplate scenario (Type 2) of PNA-EC8 the differences are even bigger, the Portuguese spectra being up to 3 times bigger than the Spanish ones, in particular in short periods. The differences decrease for long periods, especially on the Northern side of the border, as can be seen in the case of Valencia de Alcántara. For long periods the spectra of NCSE-02 are equal or slightly bigger than those of the PNA-EC8.
- The spectral ordinates of NCSE-02 are much smaller than those of FNA-EC8 in almost all the cases, reaching on occasion differences by a factor of 4. In Mollo, in soils A, B, C and D, for periods longer than 0.5 s, the spectral ordinates are equal or slightly bigger than those given by FNA-EC8.

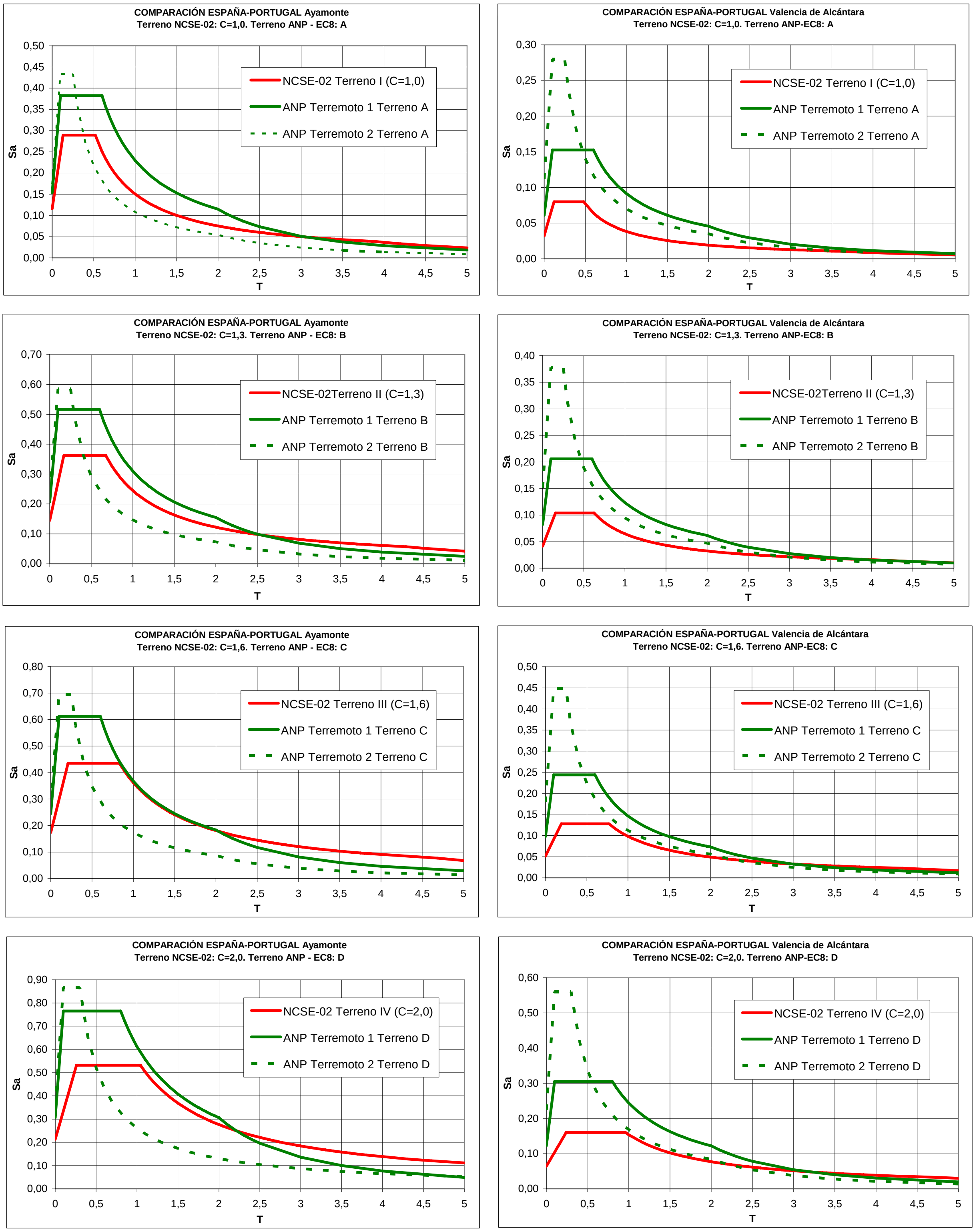

Figure 4. Comparison of response spectra in both sides of the Spain-Portugal boundary according to the parameters defined in NCSE-02 and PNA-EC8 (Type 1 and 2) for different soil conditions. (SA in g; T in s)

Left) Ayamonte ; Right) Valencia de Alcantara (see map of Figure 1)

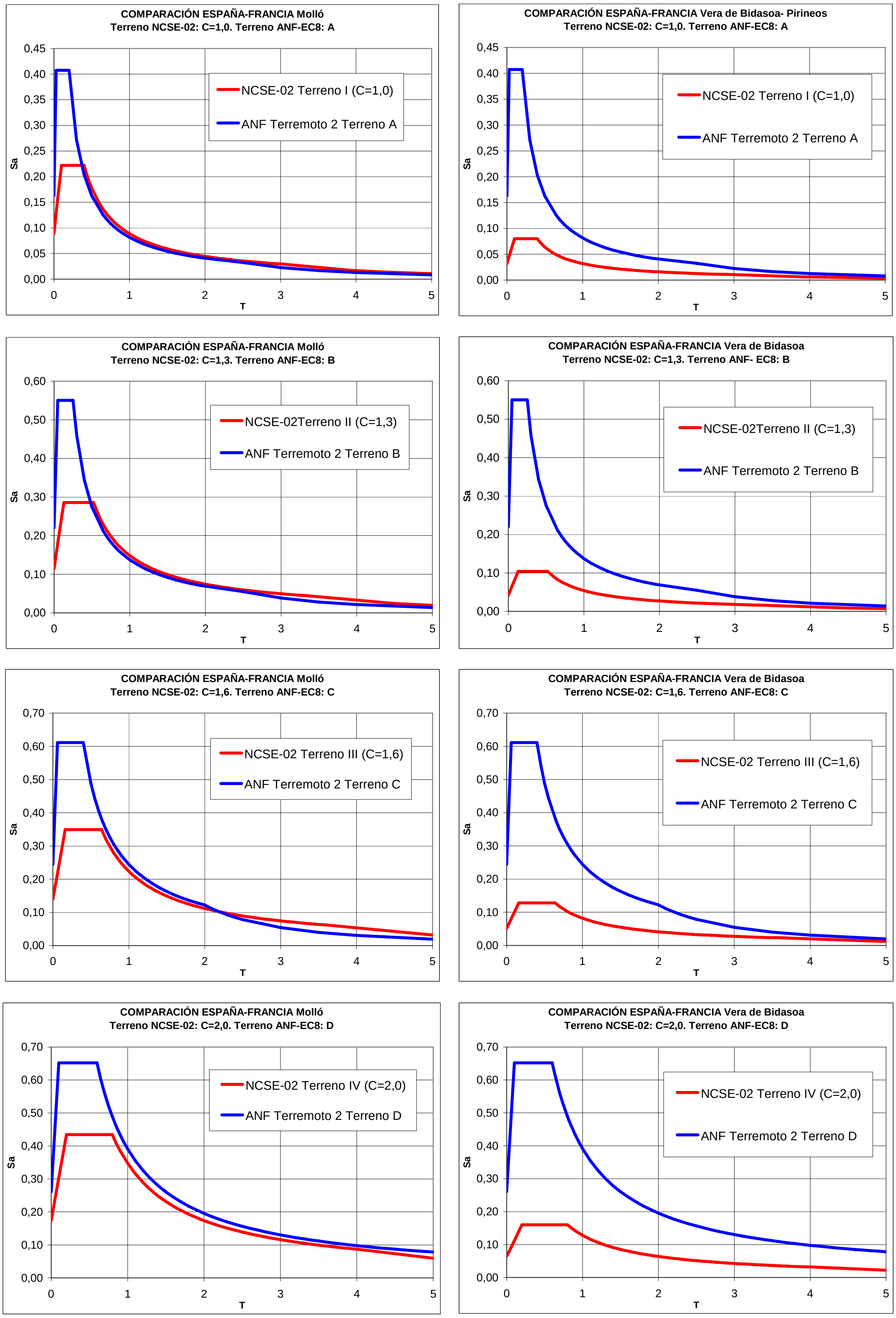

Figure 5. Comparison of response spectra in both sides of the Spain-France boundary according to the parameters defined in NCSE-02 and FNA-EC8 (Type 2) for different soil conditions. (SA in g; T in s)

Left) Molló; Right) Vera de Bidasoa (see map of Figure 1)

The analyzed codes use a similar formulation for the construction of the elastic response spectra but differ in the coefficient values involved in the computation. The result is an important dispersion in the resulting spectral ordinates. The procedure followed by the Italian Normative seems, in our opinion, the most advisable for fitting the response spectra in the Spanish National Annex.

The great differences found in this work on both sides of the boundaries between Portugal, Spain and France, depending on the respective codes, are only an example of what can be found in other European countries under scope of EC-8. This fact contradicts the very philosophy of the EC-8, which tries to harmonize the seismic design rules in European countries. It would be useful if the committees responsible for seismic hazard in bordering countries had more interaction in order to avoid discontinuities in the respective borders as those revealed in this paper.

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