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A Comparative Analysis between the Spanish and Portuguese Seismic Codes: Application to a Border RC Primary School

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Abstract: The Iberian Peninsula is close to the Eurasia-Africa plate boundary resulting in a considerable seismic hazard. In fact, the southwestern Iberian Peninsula is affected by far away earthquakes of long-return period with large-very large magnitude. A project named PERSISTAH (Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva, in Portuguese) aims to cooperatively assess the seismic vulnerability of primary schools located in the Algarve (Portugal) and Huelva (Spain). Primary schools have been selected due to the considerable amount of similar buildings and their seismic vulnerability. In Portugal, the Decreto Lei 235/83 (RSAEEP) is mandatory while in Spain, the mandatory code is the Seismic Building Code (NCSE-02). In both countries, the Eurocode-8 (EC-8) is recommended. Despite the fact that both regions would be equally affected by an earthquake, both seismic codes are significantly different. This research compares the seismic action of Ayamonte (Huelva) and Vila Real de Santo António (Portugal). Both towns are very close and located at both sides of the border. Moreover, they share the same geology. This analysis has been applied considering a reinforced concrete (RC) primary school building located in Huelva. To do so, the performance-based method has been used. The seismic action and the damage levels are compared and analysed. The results have shown considerable differences in the seismic actions designation, in the performance point values and in the damage levels. The values considered in the Portuguese code are significantly more unfavourable. An agreement between codes should be made for border regions.

Key words: Performance-based method, seismic code, seismic behaviour, nonlinear analysis, Iberian Peninsula, RC building.

1. Introduction

The Iberian Peninsula (IP) is close to the Eurasia-Africa plate boundary. This results in a considerable seismic hazard for the southern IP. In fact, the southwestern IP is affected by far away earthquakes of long-return period and large-very large magnitude [1]. Buildings in this area have been severely damaged in the past by relevant events such as the 1344, 1531, 1722, 1755, 1859 and 1909 earthquakes [2].

A project named PERSISTAH (Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva, in Portuguese) aims to cooperatively assess the seismic vulnerability of primary schools located in the Algarve (Portugal) and Huelva (Spain) [3]. Primary schools have been selected due to their vulnerability [4], to the amount of buildings sharing a similar configuration and to the seismic hazard of the region. Moreover, a major part of them were constructed in the 1970s. That is, no seismic considerations were taken into account in their design or, if considered, the requirements were not very restrictive.

Despite the fact that both regions would be equally affected by an earthquake, the seismic codes of

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Portugal and Spain are significantly different [5]. In Portugal, the Decreto Lei 235/83 (RSAEEP) [6] is mandatory. Whereas in Spain, the Seismic Building Code (NCSE02) [7] must be fulfilled. In both countries, the Eurocode-8 (EC8) [8] is recommended. The most outstanding difference between codes is the seismic action level. Some other specifications such as the ductility requirements and the limit states are very similar.

The European Union promoted a homogenization of the design rules for earthquake resistant structures through the EC8 [9]. However, the determination of the basic parameters such as the seismic action must be provided by the National Annexes. Moreover, the seismic hazard analyses implemented in these seismic codes are outdated. In fact, as pointed out in Ref. [10], further research must be performed on the definition of the ground motions including attenuation laws and scenario features.

A few studies focused on the seismic codes provisions analysis. In Ref. [9], the authors performed a comparative study of the seismic hazard assessments in European national seismic codes. They obtained considerable differences in each seismic code. Hence, they concluded that inter-country cooperation would improve the earthquake catalogue and the criteria defining the seismogenic zones. In Ref. [11], the seismic design criteria and ground motion selection methods from five different world regions were compared. They demonstrated that despite the incentive for harmonization, obvious differences could be mainly found on the response spectra definitions.

In this context, this research compares the seismic action of Ayamonte (Huelva) and Vila Real de Santo António (Portugal). Both towns are very close and located at both sides of the border. Moreover, they share the same geology. This analysis has been applied considering a reinforced concrete (RC) primary school building located in Huelva. To do so, a comprehensive analysis of the seismic action level provisions of each code has been performed. The performance-based method has been used and nonlinear static analyses have been carried out. The seismic action and the damage levels are compared and analyzed.

2. Method

2.1 Seismic Action Specific Provisions

In this section, a comprehensive analysis of the seismic action level provisions of each code has been performed. As in Ref. [9], Table 1 summarizes the principal parameters analysed and their correspondent values.

In the case of Spain, the imperative seismic code is the NCSE-02 while the EC-8 is recommended. This code provides only requirements to prevent buildings collapse. Therefore, only static analyses are allowed and no damage thresholds are considered. The seismic hazard map followed a similar approach to the 1994 version of the code. The calculation was performed in terms of the European Macroseismic Scale (EMS-98) intensity scale based on a Poissonian approach. The data came from the Spanish Geographic Institute, "Instituto Geográfico Nacional, National Geographical Institute of Spain (NGIS)". A logarithmical correlation was implemented to determine the horizontal acceleration using the EMS scale. The spectrum is defined according to the C and K coefficients. The K coefficient takes into account the different contribution of the Gibraltar-Azores zone to the seismic hazard. The C coefficient considers the influence of the soil. The return period (T) and the exceedance probability (P) differ from the rest of the codes. The hazard is described by the seismic acceleration (a_c), which is calculated as the product of the soil amplification coefficient (S), the importance factor (ρ) and the basic acceleration value (a_b). The coefficient S is used to calibrate the value of a_b since it is expressed for soil-type II.

In 2012, an update of the Spanish seismic hazard maps was performed [12]. Its use is recommended but it is not mandatory. This catalogue carried out a

Table 1 Summary of the basic seismic action designation parameters of each code.

Parameter	Decreto Lei RSAEEP	ECEC-88	NCSE-02	Spanish update	EC8 Spanish annex	EC8 Portuguese annex
Date	1983	1998	2002	2012	2010	2010
Earthquake scale	Magnitude	-	Intensity	Magnitude	-	-
Earthquake estimation	Historical Attenuation laws Gumbel III	-	Historical	Historical Attenuation laws	-	-
Attenuation function	Acceleration	-	Macroseismic	Acceleration	-	-
Hazard assessment	Poissonian Gumbel I	-	Poissonian	Poissonian	-	-
Hazard descriptor	PGA	$a_g = a_{gR} \cdot \gamma_I$	$a_c = S \cdot \rho \cdot a_b$	PGA	$a_{gR} = 0.8a_b$	a_{gR}
Importance factor	-	$\gamma_I = 1$	$\rho = 1$	$\rho = 1$	$\gamma_I = 1.3$	$\gamma_{I\text{-}T1} = 1.45$ $\gamma_{I\text{-}T2} = 1.25$
Type of spectrum	Types 1 and 2	Types 1 and 2	Type 1	Type 1	Types1 and 2	Types 1 and 2
Non-collapse	T_{NCR} = 1,000 yrs	T_{NCR} = 475 yrs P_{NCR} = 10%	T_{NCR} = 500 yrs P_{NCR} = 2‰	T_{NCR} = 475 yrs P_{NCR} = 10%	T_{NCR} = 475 yrs P_{NCR} = 10%	T_{NCR} = 475 yrs P_{NCR} = 10%
Damage level	-	T_{DLR} = 95 yrs P_{DLR} = 10%	T_{DLR} = 95 yrs P_{DLR} = 10%	T_{DLR} = 95 yrs P_{DLR} = 10%	T_{DLR} = 95 yrs P_{DLR} = 10%	T_{DLR} = 95 yrs P_{DLR} = 10%
Hazard value	-	-	Ayamonte $a_c = 1.597$ m/s^2 $a_g = 1.428$ m/s^2	Ayamonte $a_c = 1.763$ m/s^2 $a_g = 1.5$ m/s^2	-	Vila real $a_{g\text{-}T1} = 2.2$ m/s^2 $a_{g\text{-}T2} = 2.1$ m/s^2

revision of earthquakes of other catalogues and specific studies. In addition, a homogenization process to convert all the events into moment magnitude (M_w) by applying different relations was performed. A total number of 6,999 events were implemented, ranging from M_w 3.5-8.5 and depth 0-65 km. A Probabilistic Seismic Hazard Analysis (PSHA) was implemented following a Poisson distribution to determine the probability of exceedance. T and P were considered similar to the EC8 values. The hazard was expressed as PGA on soil-type I.

In the Portuguese code RSAEEP (1983), the earthquake estimation implemented historical events, attenuation laws and the Gumbel III extreme distribution. The hazard assessment took into account a Poissonian approach as well as a Gumbel I distribution. As established by Oliveira et al. [10], the process of seismic occurrence was based on the Seismic Catalogue of the Iberian Peninsula taking into account a 2,000-year period of observation. The return period was considerably superior to the other codes. The response spectra were tabulated for each of the four seismic zones and the influence of the soil was taken into account by means of the α-coefficient.

Regarding the EC-8 provisions, a different approach is used to determine the response spectrum. Depending on the soil type, different values of fundamental periods are designated. The hazard is described as the design ground acceleration on Type A-ground (a_g). This is equal to the reference peak ground acceleration (a_{gR}) multiplied by the importance factor (γ_I). The values to be ascribed to a_{gR} can be found in the national annexes. In the Spanish annex, the a_b must be reduced 80% to obtain the a_{gR} since the a_b is expressed for the soil type II. Regarding the Portuguese annex, no reduction must be performed. Moreover, different values of the γ_I-factor are established in each annex for the schools' buildings (i.e. 1.3 in the Spanish annex and 1.45 and 1.25 in the Portuguese annex, when considering the response spectrum Types 1 and 2, respectively).

The EC-8 and the Portuguese code establish different response spectra types. According to the EC-8 designation, Type 1 (T1) is used if the earthquakes that contribute most to the seismic hazard are far-earthquakes of moderate-high magnitude (M_w >

5.5). Type 2 (T2) spectrum is implemented if the earthquakes are near-earthquakes of magnitude not larger than $M_w < 5.5$. Nevertheless, the NCSE-02 considers only the far-earthquake scenario.

Concerning the return periods and the probability of exceedance, they remained the same in the case of the EC-8 and the National Annexes for the non-collapse (NCR) and the damage level cases (DLR). However, in the case of the NCSE-02, the *T* and the *P* for the non-collapse case are different as well as the return period of the Portuguese code.

The response spectra determined according to each seismic code provision for the border region of Vila Real de Santo António-Ayamonte are shown in Fig. 1. The following codes have been considered: the Portuguese *Decreto Lei*; the NCSE-02 response spectrum considering Ayamonte and the values obtained by the 2012 update; and the EC-8 response spectrum considering these former values and the Portuguese seismic action provisions for Vila Real established in the National annex and in Ref. [13].

The soil type selected has been type III or C in the case of the national codes and European provisions, respectively. It should be noted that considerable differences could be found on the hazard value comparing the seismic codes. These values differ up to 60%.

2.2 Building's Configurations

A typical RC primary school has been selected. This is located in Ayamonte (Spain). However, this has been analysed as if it was located in Vila Real de Santo António (Portugal) and in Ayamonte (Spain). These two towns are placed at each side of the border between both countries (Fig. 2a). Hence, buildings in this area share the same geology and the seismic hazard should be similar. The building is composed of two storeys and it was constructed during the 1970s. Therefore, basic seismic requirements were considered during its design. The plan and the elevation of the building have been depicted in Fig. 2b.

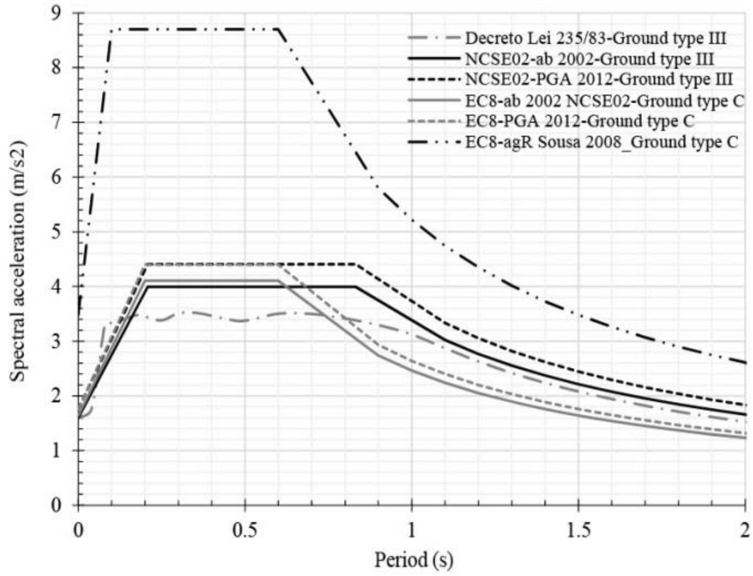
The building is composed of RC wide-beams, columns and ribbed slabs. The frames in the X direction are the load bearing frames. Load beams are designed as 60 × 30 cm, they have 5Ø16 mm of longitudinal rebar and Ø6 mm each 20 cm of transversal rebar. Tie beams are of 30 × 30 cm, they have 4Ø12 mm of longitudinal rebar and Ø6 mm each 20 cm of transversal rebar. Columns are of 30 × 30 cm, they have 4Ø12 mm of longitudinal rebar and Ø6 mm each 15 cm of transversal rebar. The RC compressive strength (f_{ck}) is 17.5 MPa while the steel yield stress (F_y) is 420 MPa. The modulus of elasticity (E_c) is 25,000 MPa and 200,000 MPa, for the RC and the steel, respectively.

The gravitational loads considered in the analysis have been the self-weight of the elements and the permanent and variables loads. The first is automatically considered by the computer software used in the analysis. The dead loads are the sum of the weight of the ribbed slabs, the internal partitions, the ceiling and the ceramic flooring, which is in total 5.5 kPa. The variable load designated, corresponding to classrooms, is 3 kPa. This value is the same in both the Spanish and the Portuguese codes.

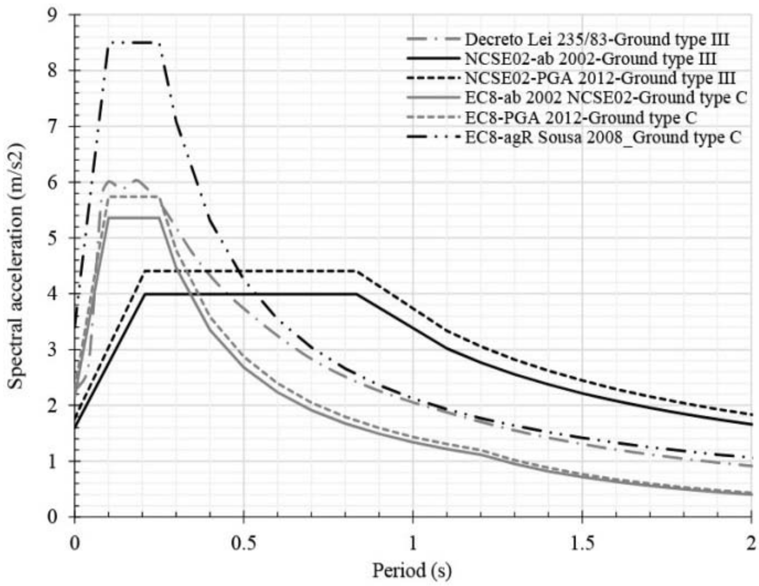
2.3 Performance-Based Method

The building's performance analysis depends on the capacity and the demand [14]. According to these parameters, it can obtain the so-called performance point of a building (displacement vs. basal shear force). The performance point is determined by the intersection of the capacity curve of the building and the inelastic response spectrum. This intersection can be performed by two methods: the capacity-demand spectrum method from the ACT-40 [15] and the N2-method [16].

In this work, the N2-method has been taken into account, which is the procedure implemented in the EC-8 to determine the target displacement. The construction of the theoretical bilinear curve has been carried out according to Ref. [17]. Different performance



(a)



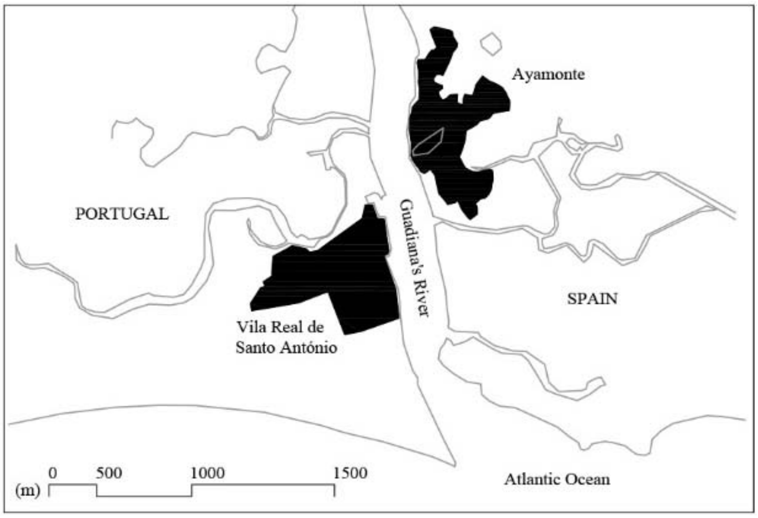
(b)

Fig. 1 Comparison of response spectra of each seismic code considered for: (a) a far-earthquake scenario (Type 1) and (b) a near-earthquake scenario (Type 2).

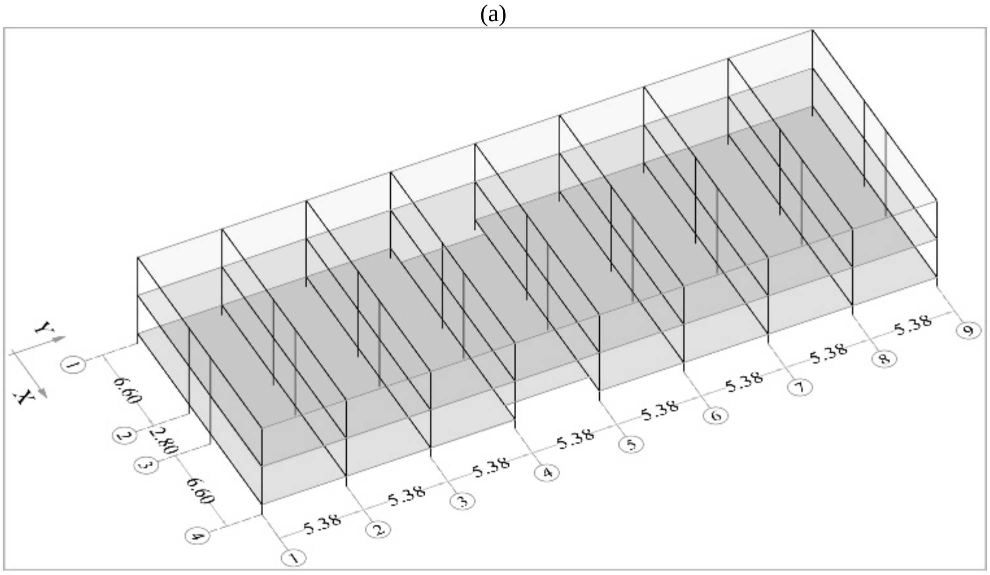
points have been obtained for each response spectrum defined in the previous section. These have expressed for a multi-degree-of-freedom (MDOF) system. Also, the non-collapse safety condition required $d_u^*/d_t^* > 1$ according to the EC-8 has been analysed and obtained for a single-degree-of-freedom (SDOF) system.

2.4 Nonlinear Static Analyses

Although more accurate results can be obtained by means of dynamic analyses, they require high computational efforts and time to model the structures [18]. Since this study aims to compare the general seismic performance of a building according to different seismic actions, nonlinear static analyses have been carried out (pushover analyses). They have been performed to determine the capacity curves in the two orthogonal directions of the building (X and Y) by means of the SAP2000 v.19 software [19].



(a)



(b)

Fig. 1 (a) Towns location and (b) building's configuration.

Two loads patterns have been considered as indicated in the EC-8. First, a triangular pattern based on lateral forces proportional to the height and the mass of each storey has been applied (mass). Then, a load pattern proportional to the displacement produced by the first mode of vibration has been considered (mode). Numerous works can be found on the simulation of the nonlinear behaviour of RC [20]. In the SAP2000 software, RC frames' nonlinear behaviour is simulated by means of the plastic hinges. Plastic hinges are added to all the RC frames. Two types of plastic hinges can be determined: default and manual. Manual plastic hinges determination takes considerable amount of time and the results do not differ from those obtained by the default designation [20]. Therefore, in this work, default plastic hinges have been defined according to the ASCE-41-13 [21] as implemented in Ref. [20]. PM2M3 plastic hinges have been added to columns whereas M3 hinges have been included in the beams. They have been included at both ends of the frames as established in the EC-8.

2.5 Damage Level Provisions

The fragility curves define the probability of reaching a damage state. In this work, these curves have been determined according to the RISK-UE lognormal distribution [22]. The damage probability for each state (no-damage, slight, moderate, severe and collapse) has been determined. In addition, a useful index named the mean damage grade has been obtained according to Ref. [23]. This index represents the most likely damage state that will suffer the structure according to the seismic action. This value will range from 0 to 4.

3. Results

This section presents the results obtained from the analyses carried out. Four capacity curves have been obtained, which are depicted in Fig. 3. These have been named as Ayamonte School (AS) followed by the direction studied (X or Y) and the load pattern (proportional to the mass or to the first mode of vibration). Similar curves have been determined for each load pattern in both directions of the building. Therefore, the most unfavourable curves will be taken into account when obtaining the rest of the results (i.e. AS_X_mode and AS_Y_mode).

Once the pushover curves have been obtained, the performance points for the MDOF system have been determined for each response spectrum considered. The performance points are plotted in Fig. 4.

In Fig. 5, the damage level probability is shown for each capacity curve selected. Only the results concerning the Type 1 response spectrum have been shown owing to the worse results obtained.

In Fig. 6, the mean damage index is depicted for each capacity curve selected considering both types of response spectra.

Table 2 summarizes the SDOF ultimate displacements (d_u*) and the inelastic target displacements (d_t*) for the most unfavorable capacity curves considering each response spectrum.

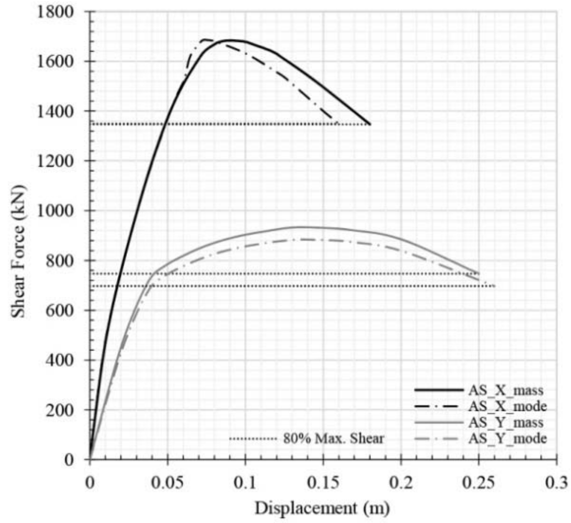
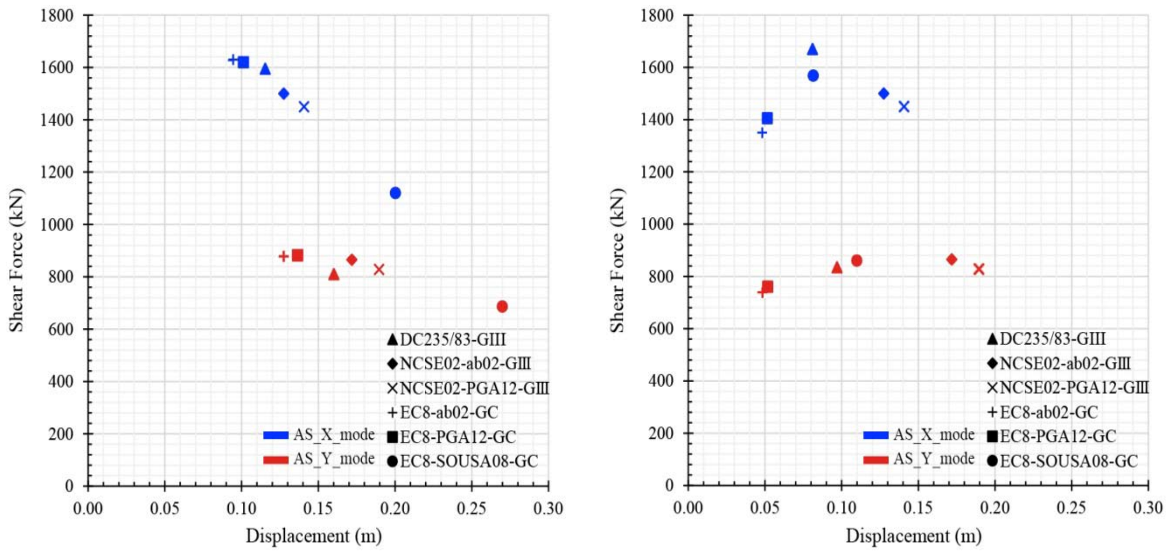
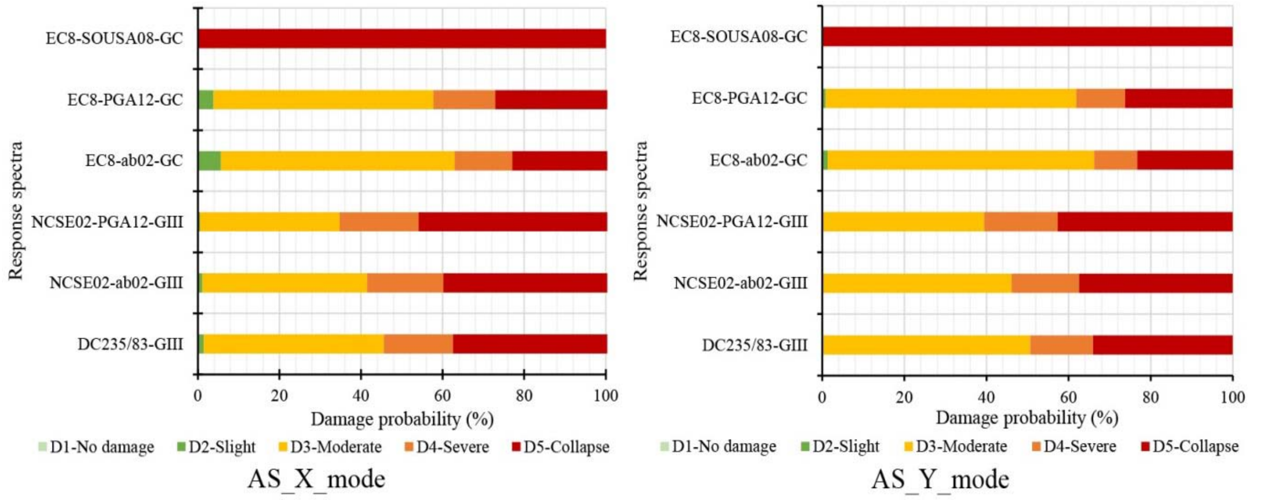


Fig. 2 Capacity curves in the X and the Y direction of the building.



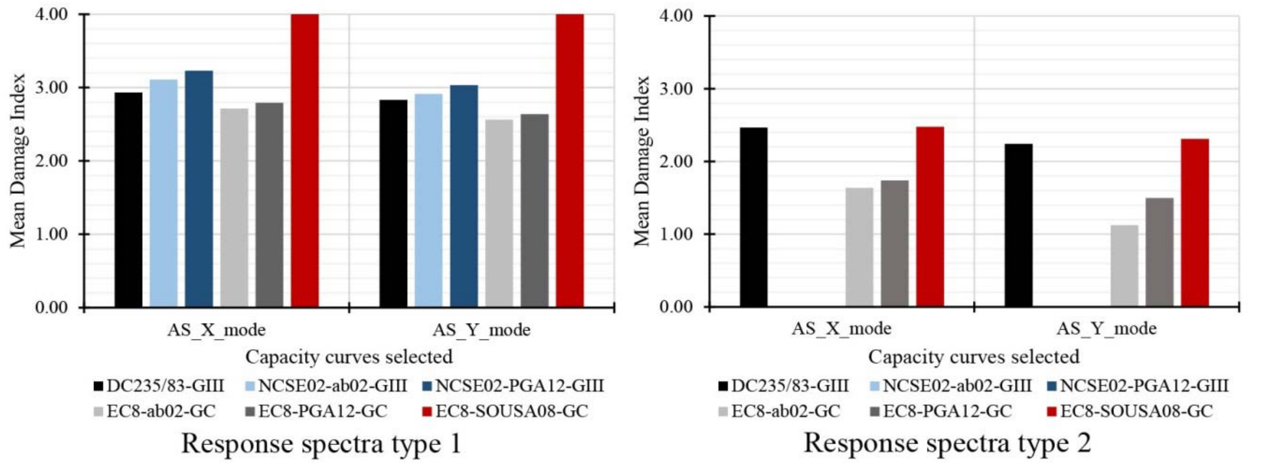
(a) (b)

Fig. 3 Performance points obtained for each unfavorable load pattern considering (a) Type 1 and (b) Type 2 response spectra.



(a) (b)

Fig. 4 Damage level probability for the capacity curves in the (a) X and (b) Y direction considering a load pattern based on the first vibration mode.



(a) (b)

Fig. 5 Mean damage index for each capacity curve considering (a) Type 1 and (b) Type 2 response spectra.

Table 2 SDOF ultimate and target displacements for each capacity curve and corresponding ratios of d_u*/d_t*.

Response spectrum	Type	Data	AS_X_mode	AS_Y_mode
Original building ultimate displacement		d_u* (m)	0.160	0.260
DC235/83-GIII	Type 1	d_t* (m)	0.098	0.135
		d_u*/d_t*	1.637	1.920
	Type 2	d_t* (m)	0.069	0.082
		d_u*/d_t*	2.332	3.171
NCSE02-ab02-GIII	Type 1	d_t* (m)	0.108	0.145
		d_u*/d_t*	1.482	1.789
	Type 2	d_t* (m)	-	-
		d_u*/d_t*	-	-
NCSE02-PGA12-GIII	Type 1	d_t* (m)	0.119	0.160
		d_u*/d_t*	1.343	1.622
	Type 2	d_t* (m)	-	-
		d_u*/d_t*	-	-

Table 2 to be continued

EC-8-ab02-GC	Type 1	d_t* (m)	0.080	0.108
		d_u*/d_t*	1.999	2.413
	Type 2	d_t* (m)	0.041	0.041
		d_u*/d_t*	3.923	6.363
EC-8-PGA12-GC	Type 1	d_t* (m)	0.086	0.115
		d_u*/d_t*	1.865	2.252
	Type 2	d_t* (m)	0.044	0.044
		d_u*/d_t*	3.661	5.939
EC-8-SOUSA08-GC	Type 1	d_t* (m)	0.170	0.228
		d_u*/d_t*	0.943	1.139
	Type 2	d_t* (m)	0.069	0.093
		d_u*/d_t*	2.317	2.798

3. Analysis of Results

The analysis of the specific provisions established in each seismic code has revealed considerable differences regarding the seismic action level designation. This is mainly due to the seismic hazard assessment of each code. The NCSE-02 considers a poissonian approach. This represents the probability of occurrence of an event in a time or spatial framework. The Portuguese seismic hazard assessment is based on a Gumbel distribution. Contrary to the poissonian approach, this represents a distribution of maximum values of events. This results in higher values of ground acceleration in the case of Portugal since only maximum values are considered in its hazard assessment.

Moreover, the importance factor of school buildings varies its value for each code. The values in each code can differ from each other up to 30%. This also leads to higher values of ground acceleration in the Portuguese codes.

The nonlinear static analyses have resulted in similar capacity curves obtained for each load pattern considered in the X and Y direction. The most unfavourable curves have been those proportional to the first vibration mode of the structure. The MDOF performance point values obtained for the X direction have been considerably higher than those obtained for the Y direction. Differences of up to 200% can be found comparing both types of response spectra. Furthermore, the performance points have considerably differed from each response spectrum type. The displacement obtained for the Type 2-spectra have been lower than those obtained for the Type 1.

Regarding the damage level probability, lower values of damage have been obtained in the X direction of the building. This is due to the higher structural capacity of the building in this direction. Considering the response spectra, higher values of damage have been obtained for the response spectra designed according to the NCSE-02.

In the case of the mean damage level, the damage state D3—severe damage (value of 3) has been exceeded by the models that considered the NCSE-02 response spectrum. However, the worst value has been obtained for the consideration of the Portuguese seismic values. In the case of the Type 2 response spectra, the D3 limit has not been reached.

Regarding the safety requirement $d_u*/d_t* > 1$, higher ratio values have been obtained for the Type 2 response spectra. Moreover, higher values of this ratio have been obtained for the Y direction. This is due to the higher ductility that the building presents in this direction.

It should be highlighted that in the case of the Type 1-response spectra, the worst performance point has been obtained for the EC-8-designed spectrum considering the Portuguese seismic action values. Moreover, the target displacement has been higher than the ultimate displacement. Consequently, this resulted in the collapse of the structure as the damage probability has shown. Furthermore, the EC-8 safety requirement $d_u^*/d_t^* > 1$ has not been accomplished.

4. Conclusions

The Algarve-Huelva is located at the southwestern Iberian Peninsula, close to the Eurasia-Africa plate boundary. This results in a considerable seismic hazard. In fact, this region is affected by far away earthquakes of long-return period with large-very large magnitude. Despite the fact that both regions would be equally affected by an earthquake, the mandatory seismic codes of each country are significantly different. In this work, the seismic action of Ayamonte (Huelva) and Vila Real de Santo António (Portugal) have been compared. Both towns are very close and located at both sides of the border. Moreover, they share the same geology. This analysis has been applied considering an RC primary school building located in Huelva. Primary school buildings have been selected to be analysed owing to the considerable amount of similar buildings and the seismic vulnerability of this typology.

Nonlinear static analyses have been carried out to determine the performance point and the damage level of the building considering different response spectra definitions: the Portuguese *Decreto Lei*; the NCSE-02 response spectrum considering the Ayamonte seismic hazard values and those obtained by the update of 2012; and the EC-8 response spectrum considering these former values and the Portuguese seismic action provisions for Vila Real established in the National annex and in Ref. [13].

This work has concluded that considerable differences can be found on each seismic code provision particularly in the definition of the response spectra. This is due to the seismic hazard approaches followed in each code (i.e. average event distribution in the Spanish code and maximum values distribution in the Portuguese code). Moreover, the impact factor that amplifies the ground acceleration value differs from each other. Despite the fact that the EC-8 was proposed as a homogenization tool, the seismic action is obtained from the national annexes whose values considerably differ from each other. Therefore, although the buildings are close and share a similar geology, different values of ground acceleration are obtained when considering the different codes.

The nonlinear static analyses have shown that the worst seismic performance is obtained when considering the Portuguese seismic action updated. In fact, the EC-8 safety requirement has not been accomplished for this seismic action. This is due to the unfavourable values considered in the Portuguese code. Moreover, higher values of damage have been obtained when considering the NCSE-02 response spectrum. This is due to the reduction of the Ayamonte ground acceleration value established in the 2012 Spanish update. This study leads to the conclusion that safety provisions may not be fulfilled if a less restrictive seismic code is taken into account. Therefore, as pointed out in numerous works, an agreement between codes should be made for border regions.

Acknowledgements

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