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Influence of Neotectonics on seismic hazard for critical facilities

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ABSTRACT: Most of the neotectonic and paleoseismicity studies in the whole Spain have been undertaken recently and are still in a preliminary stage. Nuclear Power Plants and other critical facilities were built though about 20 to 10 years ago. In that times seismic hazard assesment was carried out without these studies. In low to moderate seismicity areas it is difficult to give numerical values to the seismic potential of a fault or another kind of seismic source in order to be introduced in the numerical assesment methods.The influence of neotectonic studies in seismic hazard assesment is discussed on this communication by meas of an example. Its corresponds to Alentejo-Plasencia fault in western Spain, where some preliminary neotectonic studies show a new understanding of the fault's seismic potential.

1 INTRODUCTION

Since the 60's seismic hazard studies have been carried out in Spain in order to build large dams and Nuclear Power Plants, and more recently for Civil Protection purposes. Most of this facilities are located in moderate sesimicity areas, such as the Betic Cordillera (SE Spain) or in Cataluña on the NE of Spain. On low seismicity areas, on the stable interior of Iberian peninsula, only nuclear related facilities, such as Nuclear Power Plants and, eventually future Radiactive Waste Disposal have an operating life long enough to be affected by the seismic hazard.

Maximum historically felt intensity is IX MSK for the Pyrenees, and eastern and southeastern Spain; VII for the Cataluña area and about IV for the Iberian peninsula interior. New seismic hazard maps published by the IGN (1991) and used for the new Seismic Code (NCS-93) show MSK intensities of > VIII for SE and E Spain, VIII for NE Spain and less than VII for the rest of the country for a 1000 yr return period. These results were obtained mainly from the seismic catalogue using Cornell (1968) methodology based probabilistic approaches (Martin, 1984; IGN, 1991).

Although neotectonic and active faulting studies started about 20 years ago, traditionally centered on areas of higher seismicity of the Iberian peninsula such as the Betic Cordillera and NE Spain (Bousquet, 1979; Sanz de Galdeano, 1983; Santanach et al, 1980; Capote & De Vicente, 1989), studies that relate paleosesimicity with slip rates of active faults have just begun a few years ago (Silva et al , 1992; Martinez Diaz & Hernandez Enrile, 1996; Massana, 1996). At the central and western part of the Iberian peninsula these sort of studies are even scarcer (Cabral, 1989; Dias & Cabral, 1991; Villamor et al, 1996; Giner & De Vicente; 1995)

The most important problem on seismic hazard assesment is the introduction of geological active faulting and neotectonics data on the calculations, mainly when large earthquake occurrence return periods in low seismicity areas are taken into account. In this case, the historical and instrumental earthquake catalogue do not expand to the time interval of interest.

2 SEISMIC HAZARD STUDIES IN SPAIN

A study on the influence of different parameters on seismic hazard assesment in Spain (Villamor,1994; González DE Vallejo, 1994) compiled 16 seismic hazard projects (9 dams; 2 nuclear power plants; 1 low-life radioactive waste disposal, 1 ore mine and 1 regional study for Civil protection purposes) and studied the importance given to the geological parameters on the seismic hazard assesment on each case (fig.1). Regarding the geological information obtained by the project makers in order to asses the seismic hazard of the corresponding sites and the way it was used for this assesment, some results connected with the present communication are shown next (Table I):

-Seismogenetic sources are mainly defined as seismogenetic areas, due to the lack of detailed studies on recent movements of specific structures such as faults or folds.

- There is a lack of detailed studies on the size and cinematics of specific potentially active structures for seismic hazard assesment. Fault size, segmentation,

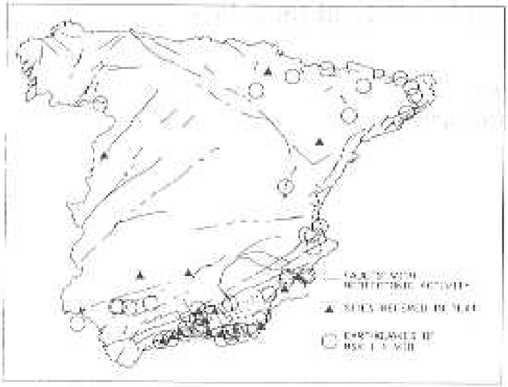

Figure 1. Location of the 16 sites studied in Villamor (1994) and González de Vallejo (1994).

Table I. Use of tectonic data for seismic hazard studies in Spain (Villamor, 1994).

		NOT CONSIDERED	CONSIDERED, BUT NOT USED IN THE ASSESMENT	USED IN THE ASSESMENT
Fault parameters (length, area, depth, type of movement...)		52 %	48 %	-
Active faulting map		43 %	-	57 %
Fault segmentation		100%	-	-
Recent movements	Field	65 %	35 %	-
	Literature	42 %	58 %	-
Current Tectonic Regime definition in the area		35 %	-	65 %
Division into seismogenetic sources		12 %	-	30 %
Absolute dating tecniques		88 %	-	12 %

current tectonic regime, absolute dating, etc, are poorly described.

- Most of the reports do not define different levels of seismic activity on different structures.

This generalised lack of detailed neotectonic studies or, if existing, not used for the hazard assesment, on the 16 reports has several causes: a) there is no social memory of large events causing disasters (the last large one took place 112 years ago close to Granada city , SE Spain) that could encourage the administration to promote more detailed studies; b) the Earthquake Catalogue comprises 2,000 years of recording events and is the most important input parameter source for the currently used seismic hazard methodologies; c) Neotectonics and paleoseismicity studies in moderate-low to low seismicity areas imply a great scientific and economic effort to obtain few results in many cases, which is not usually considered on a standard seismic hazard assesment.

If seismic hazard studies are undertaken for non critical facilities, the existing information in Spain from its 2,000-year earthquake catalogue can be considered appropiate for these purposes, if we take into account that these facilities have lifes shorter than 200 years. New neotectonic knowledge will probably not modify much the expected magnitudes for different short return periods, but can redefine the shape and location of seismogentic sources in which this studies are based.

If seismic hazard studies are carried out for critical facilities in low seismicity areas detailed neotectonic and paleoseismicity studies must guide to an assesment of the activity of the seismogenetic structure, expected earthquake magnitude of events caused by the geological structure, and return period of these events. Active faults and other active structures in low to moderate-low seismicity areas have return periods of 10,000 to 100,000 years. These would influence long-life facilities that can be affected by long return period events, such as nuclear waste repositories.

Only few efforts to introduce the existing geological knowledge into seismic hazard assesment have been made in Spain (Litehiser & Marrone,1991).

An example of improving the seismic potential knowledge of low to moderate-low seismicity regions after neotectonic studies will be discussed next.

3 TECTONIC ACTIVITY AND SEISMICITY OF ALENTEJO-PLASENCIA FAULT.

Alentejo-Plasencia Fault is a very long sinistral strike-slip fault (about 500 Km on land) that runs from the north of the Spanish Central System (Avila province) right through Extremadura in western Spain, across the portugish Alentejo province and into the sea, where it is supposed to connect with th Azores-Gibraltar transform fault. The sinitral displacement shown by the fault is only 3 Km.The fault is associated to a large basic dyke that runs along its whole trace. This is a 100-m-wide doleritic dyke of jurassic age related to the extension of the Atlantic Ocean during the Mesozoic (Schemmerhorn et al, 1978). Alentejo-Plasencia fault was been traditionally considered as a latehercynian fault (Arthaud & Matte, 1975). The roll of this fault during the alpine times has been considered either a pasive element (Vegas, et al, 1990) or an active structure (De Vicente et al, 1994). Some recent studies assign a neotectonic activity to the fault (Carrasco et al, 1991; Cabral, 1995). The presence of this great basic dyke shows the crustal importance of the fault. This latter and the fact that its continuation into Portugal and into the offshore connecting the large Azores-Gibraltar transform fault has been associated to seismic events, draws the interest of the scientific and engineering community on the fault. This fault has not got though associated macroseismicity in the spanish sector (fig 2) but seismicity on the Portugish offshore has traditionally being related to it.

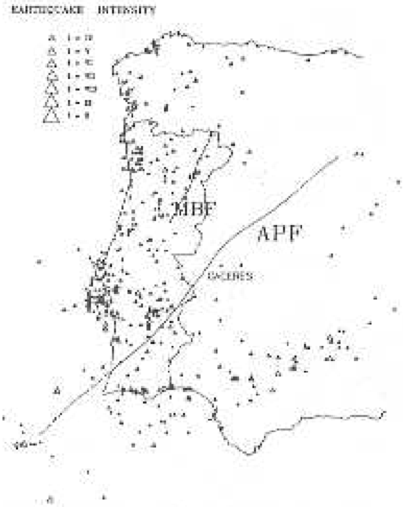

Figure 2. Epicentre distribution in West and Central Iberian peninsula. APF, Alentejo-Plasencia Fault. MBF, Manteigas-Bragança Fault.

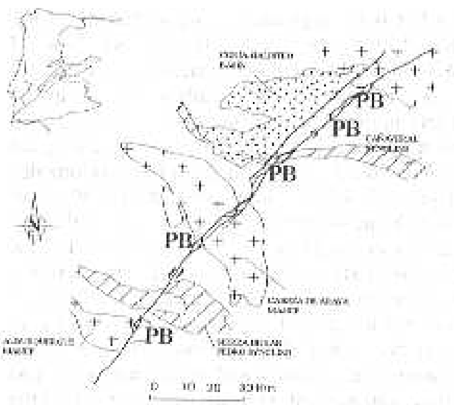

Figure 3. Location of Alentejo-Plasencia fault in the Iberian peninsula and geometry of its central sector. White, Precambrian terranes. Striped, Paleozoic terranes. Crosses, granitic bodies. Dots, Tertiary sediments. PB, pull-apart basins.

The authors have studied the activity of this large fault in order to establish its influence in seismic hazard assesment of this region (Capote et al , 1996; Villamor et al, 1996). This fault runs mainly through varsican terranes, with a pronunced geomorphological expression of the fault as a long 100-m-deep 1-Km-wide groove on the ground along the whole trace. The authors selected the westernmost spanish sector of the fault, because of the presence of small pull-apart basins along the trace, filled with cenozoic sediments and other age indicators.

The first steps that are needed when assesing the potential seismic activity of a fault with a long history, such as the Alentejo-Plasencia one are, on the one hand, to compile all the information about its reactivation history. Repeated reactivation along the history of the fault is an important point to be considered because a fault that has gone under repetead periods of reactivation is more prone to reactivate again (Skipp & Ambraseys, 1987). On the other hand, the establishment of the current tectonic regime (Skipp, 1984) of the region will give the clue to asses new movements on the fault. That is why its orientation on the current stress tensor is a very important feature.

Alentejo-Plasencia fault activity during the Alpine period was unknown before this study was undertaken . Some assumptions were made by other authors without a detailed approach to this subject. The first insight into the fault showed that it is not only a strike-slip Latehercynian fault. Most of the lateral displacement was subsequent to the intrusion of the jurassic dyke, in fact, the dyke is deformed by the fault and displaced about 2 Km; there were no latehercynian formations associated to it (similar to the latecarboniferous basin that are found in other Latehercynian faults); reference lines on different hercynian granitic bodies and fold traces are not displaced by the dyke but by the fault. All these facts show that even in the case that the jurassic dyke intrusion took place through a latehercynian fracture (or aligned fractures) the main lateral displacement on the fault is refered to post-dyke times. Alpine movements were studied through tertiary formations along the trace of the fault. A sinistral strike-slip regime during Miocene is expressed by releasing and restraining bends that form pull-apart basins a push-up structures (fig 3). Geomorphological expression of these basins and push-up is clear and the displaced erosional surfaces with associated weathering mantles have been also studied to asses the vertical displacement. Some signs of recent activity were found on Pliocene to Middle Pleistocene continental formations, such as a fault scarp in pliocene clastic formations, deformed Lower Pleistocene fluvial terraces and paleoseismicity structures on a Middle Pleistocene terrace. Although there is no absolute dating for this formations yet, the youngest deformed terrace have being considered of middle pleistocene age by geomorphological criteria.

The results of this study shows that Alentejo-Plasencia fault has been reactivated during different periods. The main movement took place during Miocene times, when strike-slip related structures and sediments were formed. It is, then, not an "old fault" The fault has behaved in different ways on different segments but only a preliminar segmentation of the faults has been considered. Due to the lack of macroseismicity and the scarce paleoseimicity of the fault, only microsesimicity studies will help to differentiate individual segments on it. Attending to the generalised concept that the stress regime in Spain has not changed since Late Miocene times (González de Vallejo et al, 1988 ; De Vicente et al, 1996), we accept that the neotectonic period starts after the late alpine movements, and that the current tectonic regime has the same stress orientation but less activity. Preliminar current displacement rates on the fault are 0.001mm/yr for vertical displacement and 0.01 to 0.05mm/yr for total displacement (Villamor et al, 1996).Taking these values and paleoseismicity field observations into account we understand then, that the fault is subjected to quaternary movements that could have an associated paloseismicity of magnitud 6.0 or more and returned periods between 10.000 and 100.000 years.

This result differs from what is obtained by other approaches. Although no macroseismicity is associated to the fault during the last 2,000 years, a seismic hazard assesment based on the earthquake catalogue of the seismicity on the neighbourhood of the fault was undertaken with the Cornell methodology. It is not a realistic seismic hazard assesment of the region because only seismicity occuring on the variscan Hesperian Massif was considered, with the aim of assesing the influence on the hazard of the earthquakes generated on the Hesperian Massif and historically recorded. This asssesment was based on a traditional seismogenetic source zonification, with no specific structures described as seismogenetic sources. Results for long return periods are shown on figure 4. For long periods the earthquake catalogue and the Cornell methodology would asses smaller movements for an area close to the fault. Regarding the fault sector located northwards of Cáceres, intensities for a 10.000 return period (figure 4) range from VI to V, and intensity isolines cross the fault. If we considered the fault as a seismogenetic source itself with an expected earthquake of magnitude 6.0 for a 10.000 year return period, the intensities assesed by the probabilistic approach will not only increased but also the shape of the intensity isolines will change. Even a deterministic approach based on the historical record would asses smaller earthquakes to the fault area, and can not help in dividing the fault into different activity segments because of the lack of historical earthquakes along it.

Only neotectonic and paleoseismicity studies can guide to a better understanding of the different segments of the fault and the activity on each of them.

It can be concluded that Alentejo-Plasencia fault is an intracontinental strike-slip fault with low activity. Its 0.01 to 0.05 mm/yr slip rate explains the lack of associated earthquakes on the historical and instrumental seismicity records, but the occurrence of

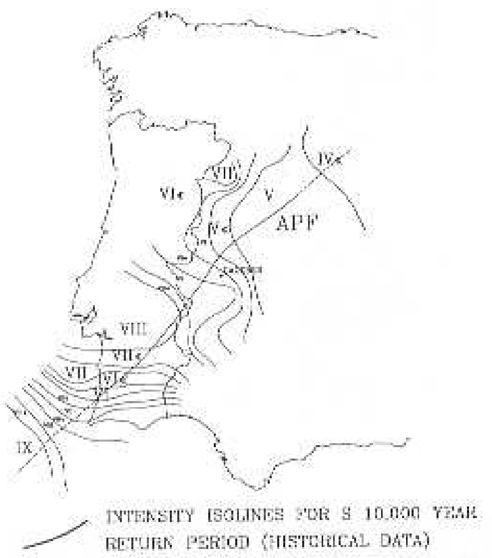

Figure 4. Seismic hazard map for the region along Alentejo-Plasencia fault. Only seismicity on the Hesperian Massif is considered

earthquakes of considerable magnitude of return periods of 10^4 or more. These values are different on other similar faults of the western part of Iberian Peninsula, such as the Manteigas-Bragança Fault (Cabral, 1989). This fault has a 0.5 mm/yr slip rate that explains its recorded associated seismicity. These characteristics of Alentejo-Plasencia fault require a good geological and neotectonic knowledge in order to carry out seismic hazard studies, which is obvious when the results are compared with the results based only on the recorded seismicity.

4 CONCLUSIONS

Taking the study of Alentejo-Plasencia fault as an example, several conclusions must be pointed out here. In traditionally considered intraplate stable areas, faults and other tectonic structures that would be considered as "inactive" and "aseismic" if we attend only to the recorded seismicity and return periods around 10^2 years, must be treated as potentially active if we consider return periods of 10^4 years or if we are dealing with critical facilities. Geological information and observed paleoseismicity are the main information source for these purposes. This information itself is very limited in stable areas and do not allow a segmentation of the fault. These stable area faults can be segmented through microseismicity studies, that combined with other geological data, can characterize the fault as a seismogenetic structure. The lack of macroseismicity during the instrumental and even historical period on these areas gives an incomplete approach of seismic hazard assesments based only on the earthquake catalogue, not only because they do not contributed to the identification of active faults but also because intensity isolines for long return periods do not reflect the sesimic activity associated to the fault itself.

Regarding the considered example in Spain it is stated that Alentejo-Plasencia fault represents a model of intracontinental strike-slip low activity fault, without associated recorded seismicity on the historical earthquake catalogue, but that geological and paleoseismicity information confirms its possible seismogenetic character for long return periods. Events of magnitude 6.0 are expected for 10.000 to 100.000 return periods. This fault represents a less active fault compared with other structrues on the variscian massif on western Iberian peninsula, such as the ones located on North Portugal.These latter have higher slip rates that confirm the presence of associated recorded seismicity. Although we do not ignore the great difficulty on a precise characterization of the seismic parameters of Alentejo-Plasencia fault, we justify the geological studies because they help to identify the seismogenetic structure in an area where is not possible to use traditional tecniques, and because they contribute to the assesment of the structure activity even only in an approximate way. This possibility contrasts with the lack of use of geological data of active structures on the sesimic hazard studies that have been carried out in Spain until the present. We consider it neccessary then to promote the realization of geological studies , specially on stable areas, such as the Iberian peninsula variscan massif, in order to avoid the lack of information on the seismic record typical of these kind of regions.

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