IMPROVING THE RESOLUTION OF SEISMIC HAZARD ESTIMATES FOR CRITICAL FACILITIES: THE DATABASE OF GREEK CRUSTAL SEISMOGENIC SOURCES IN THE FRAME OF THE SHARE PROJECT

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SHARE (Seismic Hazard Harmonization in Europe) European project aims at delivering measurable progress in all steps leading to a harmonized assessment of seismic hazard in Europe - in the definition of engineering requirements, in the collection and analysis of input data, in procedures for hazard assessment, and in engineering applications. In this frame, a database of the shallow (crustal) seismogenic sources for the broader Aegean Region is developed (Fig 1) as a contribution to the homogenized seismogenic source model. Indeed, such data collection, informatization and parameterization of the principal seismotectonic parameters is lacking for this area though it represents the very basics for any realistic seismic hazard assessment.

The Greek database focuses on three major goals: (i) the systematic collection of all available information concerning neotectonic, active and capable faults as well as broader seismogenic volumes; (ii) the critical analysis of the data and the quantification of the principal seismotectonic parameters of the various sources and the associated degree of uncertainty; (iii) to supply an integrated view of potentially damaging seismogenic sources for a better SHA in Greece. The informatic framework of the database follows that used for the Italian DISS. In this paper we present the state-of-the-art of the Composite Seismogenic Sources (CSS) for the broader Aegean region.

The Aegean Region is among the most tectonically active areas of the Mediterranean realm and has the highest seismicity both in terms of frequency of events and magnitudes. The tectonic regime is rather complex producing earthquakes with many different orientations of nodal planes and a large variety of fault types both in terms of dimension and kinematics.

It is not always straightforward to correlate seismicity with the causative fault(s). This is mainly due to two reasons: firstly, several crustal sectors of the Aegean, where historical or instrumental epicentres are located, are affected by a dense fault population bearing evidences of recent activity but with badly defined seismotectonic behaviour. Secondly, large sectors of the broader Aegean Region are covered by the sea, therefore lacking crucial field and direct observations. In the latter case, the typical geological approaches are generally replaced with geophysical and seismological investigations (detailed bathymetry, seismic profiles, microseismicity, focal mechanisms, *etc.*), which can be proved very useful.

A first attempt to create a similar database for the Greek territory was carried out during the EU project FAUST (2001), where *ca.* 50 earthquake-related sources have been included. In contrast, the most recent and the most complete map of capable faults in Greece and the broader Aegean Region has been compiled by Pavlides *et al.* (2007).

Other attempts have been performed in the past, but all of them were lacking in both fault and data completeness. For example, simple map compilations cannot provide much information except the geographical location and few geometrical characteristics of the faults, like length and dip direction. On the other hand, fault catalogues generally lack important additional data, like geometric, kinematic and seismological ones. In order to bypass the above problems and to make the database a continuously updatable open-file, the choice of a GIS-based software was crucial. For our purpos-

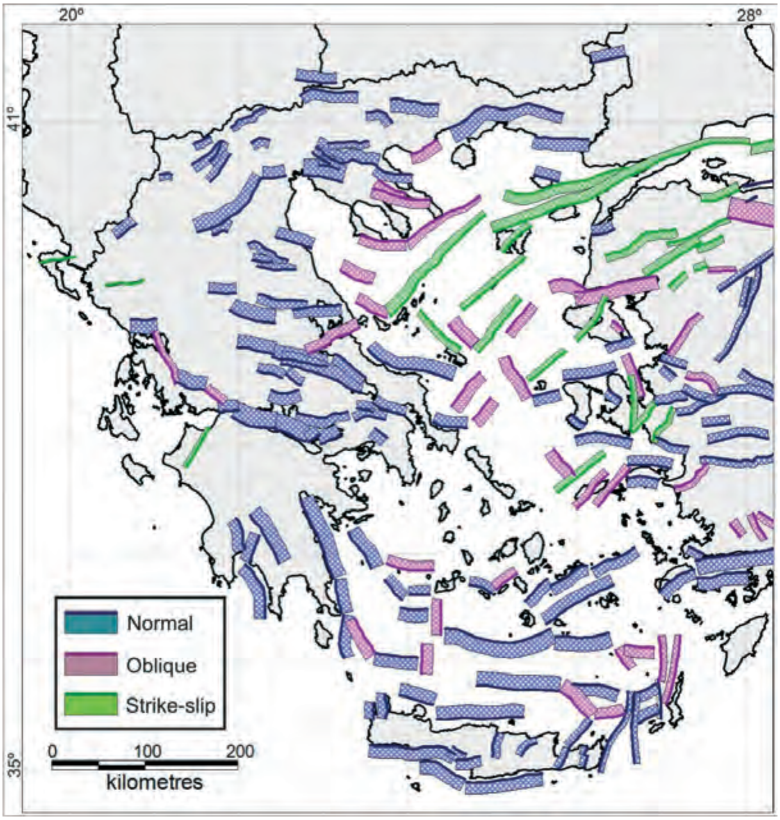

Fig. 1 - Geographic position of the studied area showing also the kinematic characteristics of the seismogenic sources of the area. The sources were divided into four principle faulting style based upon their value of average rake.

es we used the well tested, time-proof, worldwide acknowledged database structure and method proposed by INGV for the Italian DISS, which represents the result of almost twenty years research experience of its WG (Valensise and Pantosti, 2001). The DISS uses many basic levels of data that can be either independent or directly related. But for the needs of SHARE, we focus only on the CSSs (see Basili *et al.*, 2008).

In order to proceed with the critical analysis and the filtering of all available data, we followed the fault classification suggested by Pavlides *et al.* (2007). The major criteria are based on the degree of activity of the tectonic structures, thus allowing to distinguish six fault types:

1. Seismic faults: faults associated with significant earthquakes;
2. Holocene active faults: with documented displacement during the last 10 ka and relatively high slip-rate;
3. Late Quaternary active faults: with documented displacement during the last 40 ka, corresponding to the maximum time interval possibly dated with the 14C method;
4. Quaternary active faults: with documented displacement during the Quaternary (2.6 Ma) and generally characterized by a low-to-medium slip-rate;
5. Capable faults of uncertain age with geometrical structure and kinematics favourably oriented in the frame of the present-day stress field, which could be possibly re-activated during a future earthquake.
6. Faults of uncertain activity: possibly inactive.

Regarding the qualitative part of the database, all available literature data for each seismogenic source are collected, and after being critically analyzed they are filtered and then parameterized before entering the information fields. Original investigations have been also carried out, and will be in the future, for structures with ambiguous or lacking data.

The principal criteria for evaluating the seismogenic potential of a fault are briefly listed in the following.

Geological and morphotectonic features: surface morphology can be strongly affected by active tectonics and hence many such features can be recognized and characterized based on field work and laboratory analyses. Among the most important and commonly used morphotectonic features are fault scarps, triangular facets and the tilting of Quaternary sediments. The age and type of stratigraphic unit(s) affected by a fault scarp or a fault trace are crucial for estimating and constraining the last re-activation of a tectonic structure. The incision and displacement of very recent sediments is a highly important indicator of recent activity. At this regard, the contribution of palaeoseismological investigations is essential (*e.g.* McCalpin, 1996). A less explicit indicator is the occurrence of a free-face developed in bedrock. In this case, it is not the age of the affected rocks, usually Palaeozoic or Mesozoic in the Greek territory, to be indicative of a recent activity, but the freshness of the morphological feature as well as the geometry and texture of the fault scarp. Steep, sleek and polished surfaces indicate a young fault. Even difference in colour can be a guideline for estimating successive co-seismic re-activations by linear morphogenic events (*e.g.* Caputo *et al.*, 2004; 2006). On the other hand, metamorphic rocks show poor evidence not only because of their greater erodibility, but also due to the internal fabric, like schistosity, that could generate by simple differential erosion morphological features similar to the tectonic ones. Additionally, with the aid of remote sensing analyses and dedicated software also many qualitative and quantitative morphometric parameters are generally considered, like the drainage pattern, stream orders, *etc.* (*e.g.* Goldsworthy and Jackson, 2000; Zovoili *et al.*, 2004).

Seismic activity: it can occur either as localised major earthquakes (moderate to strong) or diffuse microseismicity (*e.g.* Hatzfeld *et al.*, 1995; 2000; Kementzetzidou, 1996; Pavlides *et al.*, 2007). It is useful to separate the major events as historical or instrumental ones. The former start with the 550 BC event (*e.g.* Guidoboni *et al.*, 1994; Papazachos and Papazachou, 2003; Ambraseys, 2009) and can be used even for events from the 20th century. The completeness and precision of events before the 19th century is from poor to fair (Pavlides *et al.*, 2007) making often difficult the correlation between earthquakes and causative fault. The instrumental period for the Aegean Region is less than 100 years, but it probably starts to be sufficiently accurate only after the 1970s when the Greek seismographic network was definitely improved. A typical example is the 1954, Sophades earthquake which was produced by a NNE-NE dipping fault according to geological investigations (Ambraseys and Jackson, 1990; Caputo, 1995; Pavlides, 1993) and not by a N-S up to NW-SE trending plane as suggested by the focal mechanism proposed by McKenzie (1972).

Also *geophysical surveys* based on different methodological approaches (electrical resistivity tomographies, ground penetrating radar, high-resolution seismic profiles, *etc.*) can provide useful information and constraints for characterizing an active fault (*e.g.* Caputo *et al.*, 2003; Oliveto *et al.*, 2004; Karastathis *et al.*, 2007).

Regional geodynamic setting: the orientation of the fault plane with respect to the active stress field of the broader area is quite a strong evidence (Pavlides *et al.*, 2007). However, this approach could be somehow misleading in specific areas, since the tectonic regime is quite complex showing lateral variations or debated reconstructions by different authors. Areas like the northeastern Aegean or the Ionian Sea belong to this complex regime.

Concluding, in the Aegean Region, more than 160 CSSs have been recognized, characterized and parameterized (Fig. 1). Many of these structures have all metadata completed, while others are in an advanced progress state. All CSSs show evidences of Late Pleistocene-Holocene activity and sometimes also the occurrence of past 'linear morphogenic earthquakes' (Caputo, 2005) as inferred, for example, from palaeoseismological trenches, archaeoseismological investigations or detailed morphotectonic mapping. In some cases, a moderate to strong earthquake has occurred in the last few decades that allow investigating the re-activated fault with greater detail, based on modern scientific approaches.

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