Earth-Science Reviews 148 (2015) 94–120

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Comparison between *single-event effects* and *cumulative effects* for the purpose of seismic hazard assessment. A review from Greece

R. Caputo [a,b,*], S. Sboras [c], S. Pavlides [d,b], A. Chatzipetros [d,b]

[a] Department of Physics and Earth Sciences, University of Ferrara, Italy
[b] Research & Teaching Centre for Earthquake Geology, Tyrnavos, Greece
[c] National Centre for Environment and Sustainable Development, National Observatory of Athens, Greece
[d] Department of Geology, Aristotle University of Thessaloniki, Greece

ARTICLE INFO

Article history:
Received 26 February 2015
Accepted 8 May 2015
Available online 16 May 2015

Keywords:
Active faults
Morphotectonics
Seismotectonics
Sources of information
Earthquake geology

ABSTRACT

When compiling a database of active and capable faults, or more in general when collecting data for Seismic Hazard Assessment (SHA) purposes, the exploitation of the numerous and different *sources of information* represents a crucial issue. Also the understanding of their potential and limitations is essential. For example, using only information deriving from historically and/or instrumentally recorded earthquakes, as it has been commonly applied in the past, it is not sufficient and it could be, sometimes, even misleading in terms of SHA. In the present paper, the importance of using geological information for better defining the principal seismotectonic parameters of a seismogenic source is discussed and emphasized. In order to show this, four case studies of active faults recently reactivated by strong earthquakes have been selected from the Greek Database of Seismogenic Sources (GreDaSS). Each seismogenic source is analysed twice and separately for the two *sources of information*: firstly, on the basis of the *single-event effects* as mainly provided by historically or instrumentally recorded data, and secondly, on the basis of the *cumulative effects* consisting of any, mainly geological, evidence caused by multiple and repeated fault reactivations of the specific seismogenic source. The quality and accuracy of the produced results from both *sources of information* are then discussed in order to define the reliability of the outcomes and especially for calibrating the methodological approaches based on geological data, which have not only an intrinsically different degree of uncertainty and resolution, but also a greater potential in exploitability. As a matter of fact, an improved geological, in its broader sense, knowledge will help to fill in the gap of the geodetically and/or seismologically determined tectonic activity of hazardous regions. Moreover, including in a catalogue also the seismogenic sources that are not associated with historical and/or instrumental earthquakes will have a remarkable impact in future SHA analyses either probabilistic or deterministic ones.

Contents

* Corresponding author at: Department of Physics and Earth Sciences, University of Ferrara, via Saragat 1, 44122, Italy.
E-mail address: rcaputo@unife.it (R. Caputo).

http://dx.doi.org/10.1016/j.earscirev.2015.05.004
0012-8252/

1. Introduction

Large earthquakes often attract the interest of many researchers and consequently the literature corresponding to the causative faults becomes rich and abundant. Among the several reasons for this particular attention devoted by the scientific community there is the need of i) soon investigating the evanescent co-seismic ruptures and other secondary effects, ii) improving the SHA of the affected areas, iii) better understanding the reactivated tectonic structure and the broader geodynamic processes undergoing at a larger scale and iv) exporting the collected information to similar geological and tectonic settings. On the other hand, silent faults and/or minor earthquakes are much less analysed or they are generally investigated at a broad regional scale with different methodological approaches. This discrepancy has two effects on the collected information of potential seismogenic faults that have not been recently (viz. historically) reactivated: firstly, data are scattered and sometimes 'hidden' in various studies and hence difficult to be mined; secondly, data are sometimes inconsistent because of deriving from the application of not always proper investigation methods. On the other hand, consistency and uniformity of information represent a crucial issue for enabling the comparison between seismogenic sources at a regional scale and especially for SHA analyses.

The early efforts of systematic collection of seismogenic sources for Greece and surroundings were focused on faults that were related to either historically or instrumentally recorded earthquakes. For example, Ambraseys and Jackson (1998) have listed and analysed historical and instrumental events associated with surface faulting that occurred in the East Mediterranean, while Papazachos et al. (1999) compiled a map of 'rupture zones' representing seismogenic volumes responsible for the recent events affecting the broader Aegean Region. It is noteworthy that both papers were almost exclusively based on historical and instrumental seismological data.

During the same period, the first parametric databases of active faults were compiled for Italy (Valensise and Pantosti, 2001) and Southern Europe (FAUST, 2001), including *ca.* 50 sources for the Aegean Region. Although these were the first databases including all principal seismotectonic parameters, most seismogenic sources were associated with recently reactivated faults, with few exceptions where geological information was also considered.

A step forward in the direction of including also geological information is represented by the map of capable faults in Greece and the broader Aegean Region compiled by Pavlides et al. (2007), which includes all fault scarps and traces with a clear morphological expression meeting one or more of the criteria commonly used for identifying active faults (e.g. Burbank and Anderson, 2001; Bull, 2009; McCalpin, 2009). As an innovative result, most of the faults included in the map are not related with known earthquakes. However, a strong limitation of this map is the lack of any parametric information except for the geographical ones, which makes it of little use for SHA analyses.

More recently, Karakaisis et al. (2010) provide a re-assessment of previous seismologically-based compilations (Papazachos et al., 1999), whereas Mountrakis et al. (2006) using geological and seismological evidences present an interesting review of active faults though limited to a small sector of northern Greece (from Rhodope to West Macedonia). Additionally and like other similar 'local' compilations, these works are generally rather descriptive without quantitative parametric information.

In summary, past inventories of seismogenic sources for the Aegean Region either show the paucity of crucial seismotectonic information or are unsatisfactory in terms of completeness of seismogenic sources. On the one side, neotectonic maps do not contain any other parametric data except the geographic ones; on the other hand, the seismologically-based catalogues generally provide additional information relative to some geometric and kinematic parameters, but are largely deficient especially as concerns the number of recognized capable faults, which are probably the potential seismogenic sources of more concern for SHA analyses.

In order to carry out more realistic and reliable SHA analyses, the importance and the need of systematically parameterizing active and capable faults within Mediterranean and other European seismogenic regions were definitely realized during the last decade (e.g. DISS WG, 2010; Basili et al., 2013; Lunina et al., 2014). Similarly motivated is the GreDaSS (Greek Database of Seismogenic Sources) Project (Caputo and Pavlides, 2013) devoted to create a fully parametric repository of potential seismogenic sources ($M_w > 5.5$) for the broader Aegean Region (Fig. 1). Like all open-files of this kind, research activities in the frame of the GreDaSS Project are still in progress (Pavlides et al., 2010; Caputo et al., 2012; Sboras et al., 2013).

The principal aim of this paper is not to present and describe GreDaSS or its rationale, neither its informatic structure kindly provided by the DISS WG (see Basili et al. (2008) and references therein), but to focus on some crucial methodological issues and problems which are commonly coped with during such compilation works including GreDaSS.

For the purpose of this paper, firstly, we review the different *sources of information* that could potentially provide a useful input for this kind of databases and, secondly, we present and discuss four case studies from GreDaSS (Fig. 1). In particular, we will focus on four *individual seismogenic sources* (ISSs) which are characterized by a full set of geometric (geographic fault location, strike, dip, length, width, minimum and maximum depth), kinematic (rake and slip-per-event), dynamic (maximum expected magnitude) and chronological parameters (date of last major earthquake, slip-rate and mean recurrence interval) (Fig. 2 and Table 1). ISSs are implicitly assumed to behave according to a characteristic earthquake model (Schwartz and Coppersmith, 1984), though it can be seldom documented to be the real case for Mediterranean active faults. In order to overcome this problem, whose discussion is however well beyond the goals of this paper, since several years the *composite seismogenic sources*, CSSs, have been introduced in databases like GreDaSS (Caputo and Pavlides, 2013), DISS (DISS WG, 2010) and EDSF (Basili et al., 2013). The latter represent generally broader tectonic structures which are not assumed to be capable of a specific-size earthquake, but their seismic potential (viz. maximum expected magnitude) can be estimated from existing earthquake catalogues or based on geological and seismotectonic considerations. The introduction of the CSSs effectively enhanced the completeness of potential seismogenic sources included in these databases, although this may imply a smaller accuracy in their description.

2. Two different *sources of information*

It is worth mentioning that the creation of a parametric database of potential seismogenic sources like GreDaSS (Caputo and Pavlides, 2013), essentially stands on the systematic collection and critical analysis of all available information which could enable to quantify the