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Site-specific seismic hazard analysis for Calabrian dam site using regionally customized seismic source and ground motion models

Paolo Zimmaro*, Jonathan P. Stewart

Department of Civil and Environmental Engineering, University of California Los Angeles, 5731 Boelter Hall, Los Angeles, CA 90095-1593, USA

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ABSTRACT

Probabilistic seismic hazard analysis (PSHA) are performed for routine applications using source models and ground motion models (GMMs) recommended by a government agency (e.g., US Geological Survey) or an expert panel (e.g., SHARE project). For important projects, site-specific PSHA involves critical analysis of GMMs and sources for the application region. We adopt the latter approach for a dam site in Calabria (southern Italy), a high seismic hazard region. We consider area sources as well as fault sources coupled with background zones, tailoring a model developed in the SHARE project for the subject site. We identify several problems with assigned maximum magnitudes for fault and in-slab subduction sources. We also add two sources not previously considered – the crustal Lakes fault and the Calabrian arc subduction interface. We select GMMs that are better constrained in the hazard-controlling range of magnitudes and distances than those typically used in prior Italian applications. Short-period median spectral accelerations at the 2475-year return period exceed those from prior SHARE studies by about 10–15%, and those from the Italian building code by amounts ranging from 15% to 96%. Despite the site being located in a region with finite faults capable of generating large events, the 2475-year hazard is dominated by source zones that allow for earthquakes directly beneath the site.

1. Introduction

Probabilistic estimates of ground shaking from future earthquakes (i.e., Probabilistic Seismic Hazard Analysis, or PSHA) can be undertaken at three general levels of resolution: (1) using published hazard maps, possibly supplemented with site factors, (2) running PSHA with pre-established earthquake source models and ground motion models, and (3) supplementing the pre-established source and ground motion models with novel features relevant to the specific site of interest. The first and most common is to look up ground motion values on maps, such as the USGS seismic hazard maps [1] and maps produced for the Italian building code [2,3]. Such maps are based on ground motions computed from PSHA on a grid of points for a reference site condition (typically rock with a time-averaged shear wave velocity in the upper 30 m, V_{S30}=760 m/s). These maps are most commonly prepared for peak ground acceleration (PGA) and pseudo-response spectral ordinates (PSA) at 0.2 and 1.0 s oscillator periods. Ground motions computed through this sort of PSHA are not site-specific, because (1) hazard is not computed at the specific site location; (2) geotechnical site conditions are not considered in the hazard analysis, with the ground motions instead being modified with deterministic site factors that do not preserve the desired hazard level (e.g., [4]); and (3) ground motion intensity measures (IMs) other than mapped values are evaluated from various interpolation functions, not formal hazard analyses.

Site-specific PSHA overcomes these problems, but it too can be undertaken with varying levels of care with respect to local considerations in source and ground motion modeling. The second level of resolution consists of site-specific PSHA using computer programs (commercial or otherwise) with pre-established source models and a library of available ground motion models. Such source models are typically prepared by groups of experts (e.g., [5–7]), but typically do not include all known faults that might affect a site. The third, and highest, level of resolution in PSHA supplements pre-established source models with more careful consideration of sources in the vicinity of the site. Such analyses may also use ground motion models (GMMs) customized for site-specific conditions (non-ergodic) if local characterization of site response or path effects is available (e.g., [8–10]). In this paper, we apply the third type of PSHA for vital infrastructure in the Calabria region (southern Italy): the Farneto del Principe dam (Latitude: 39.6515°N - Longitude: 16.1627°E). This dam was chosen because: (1) it is the subject of investigation, in which the first author was engaged, to assess seismic vulnerability and possible retrofit (Ausilio et al. [11]) and (2) it is located in a particularly

* Corresponding author.
E-mail addresses: pzimmaro@ucla.edu (P. Zimmaro), jstewart@seas.ucla.edu (J.P. Stewart).

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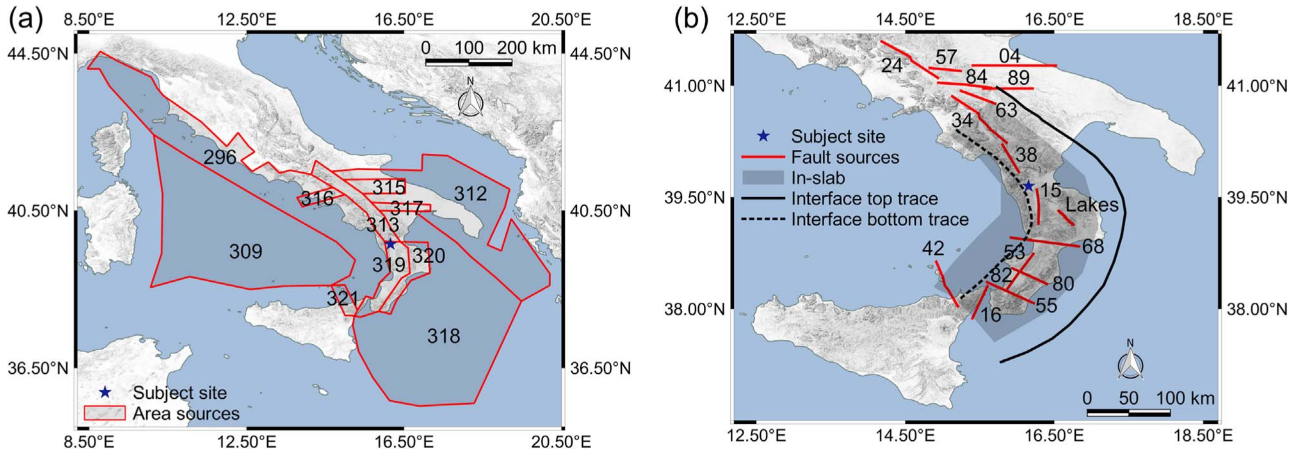

Fig. 1. Source models used in this study, along with their identification number. (a) Area sources (b) Fault sources.

interesting tectonic environment involving both shallow crustal faults and deep subduction features that facilitate illustration of several source modeling issues of broad importance in southern Italy.

We build upon the SHARE source modeling in the OpenQuake hazard computation platform [12] by critically evaluating current implementations and supplementing the available fault source models. We review available GMMs to identify suites that allow for consideration of epistemic uncertainty while capturing local conditions. The GMMs are applied in an ergodic form due to lack of information on site-specific site and path effects. Results are compared to those obtained using the Italian building code and with application of the generic SHARE model.

Some previous site-specific PSHA studies for sites in Italy have been presented by Sabetta et al. [13], Pace et al. [14], Akinci et al. [15], Faccioli and Villani [16], Rebez et al. [17], and Faccioli et al. [18] for sites in the Apennine mountain range, Po plain or Calabria. The Sabetta et al. [13] study focused on the sensitivity of hazard results to alternate GMMs. The remaining studies focused on improving source characterization models by moving beyond areal sources, which have traditionally dominated Italian PSHA (e.g. [3]), to increasing use of fault sources of various types or smoothed seismicity. Most of these studies have used either European GMMs that are now out of date or Italy-specific GMMs that are poorly constrained at large magnitude (among other problems). Exceptions are Sabetta et al. [13], which was a GMM sensitivity study, and Faccioli and Villani [16], which used global GMMs.

The present work is differentiated from prior published site-specific PSHAs for Italian sites in four principle respects: (1) we take a relatively global view in the GMM selection process, with the intent of selecting models that are well constrained over the parameter range of engineering interest, while also capturing region-specific path effects, and seeking to have a range of models to capture epistemic uncertainties; (2) we introduce the Calabrian arc subduction interface as a seismic source for PSHA as well as a smaller crustal fault source; (3) we consider epistemic uncertainties associated with source characterization and ground motion models with the intent of computing confidence intervals on hazard and evaluating the relative contributions of each type of uncertainty; and (4) we compare results with hazard computed using more approximate methods and evaluate causes of the differences.

2. Source models

Our approach for source modeling is to build upon the SHARE model [19] as implemented in the OpenQuake computational platform (SHARE_OQ_input.zip Version 6.1, obtained from www.efehr.org, last accessed October 2015). The SHARE model includes logic tree branches associated with observed seismicity (both kernel smoothed and area sources) and fault models (e.g., [19,20]). The SHARE model places most of the logic tree weight on the seismicity-based models. The SHARE model is well documented by Woessner et al. [19], to which we refer interested readers for details. The following subsections summarize key aspects of this model that affect epistemic uncertainties, critique certain details of the model as currently formulated that could introduce bias to PSHA results, and describe two fault sources added to the SHARE model for the present application.

2.1. Attributes of SHARE source models and present application

The SHARE model includes two logic tree branches for alternate characterizations of observed seismicity and a third branch for fault models and background zones. The observational data considered in seismicity-based branches is a combination of earthquakes from the instrumental era (approximately the past 35 years in Italy) and historic earthquakes documented from their effects (going back as far as 1000 years).

Area sources are the most frequently adopted source type for European national and regional PSHA and comprise the logic tree branch with the largest weight (0.5) in the SHARE model. Fig. 1(a) shows the site location relative to local area sources. Both crustal seismogenic zones and subduction intra-slab zones are modelled using area sources. Area sources are implemented following a modified Gutenberg-Richter (G-R) model, as shown in Fig. 2, with a minimum magnitude ($\mathbf{M}_{min}$) set at 4.6 and an effective largest magnitude ($\mathbf{M}_{obs}$)

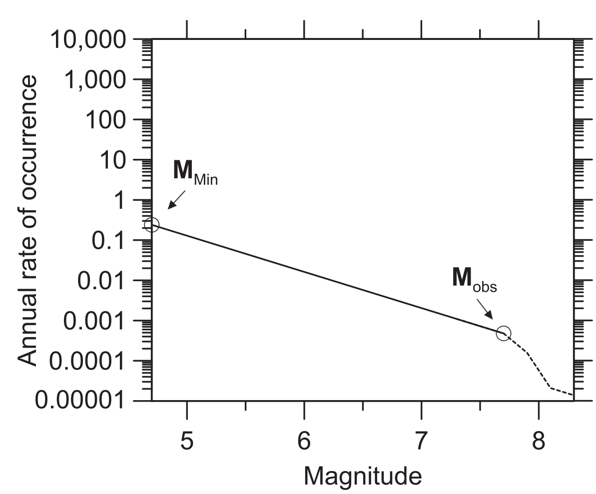

Fig. 2. Rate of occurrence for area source 319 as implemented in the SHARE model.