SITE-SPECIFIC GROUND MOTION MODELS (GMM) FOR MENTA DAM SITE

MODELLI DI PREVISIONE DI INTENSITÀ SISMICA (GMM) PER IL SITO DELLA DIGA DEL MENTA

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Abstract

The paper presents the results of a study in which non-ergodic (or site-specific) Ground Motion Models (GMMs) are developed for a site located in the Aspromonte Mountains, Southern Italy. The seismic hazard in this area is due to both Apennine faults and Calabrian Arc subduction. The site hosts the Menta Dam, a strategic bituminous-faced rockfill dam designed in the Seventies for supplying drinking water to Reggio Calabria province.
The monitoring system of the dam includes three accelerometers which have been recording seismic signals of regional earthquakes since 2016. The recordings have been used to evaluate the applicability of ground motion models (GMMs), from which regional path coefficients have been developed. The adjusted GMMs are used to develop a mean site residual useful for estimation of mean visco-elastic site response. The adjusted models with the non-ergodic site term are then used for Probabilistic Seismic Hazard Analyses (PSHA) at the site.

Sommario

La nota riguarda lo sviluppo di modelli di previsione dell'intensità sismica non-ergodici (sito-specifici) per un sito localizzato nel massiccio dell'Aspromonte, in Calabria. Dal punto di vista della pericolosità sismica, il contesto della regione risulta piuttosto complesso, a motivo della presenza delle faglie appenniniche ma anche della subduzione dell'Arco Calabro. Presso la località in esame è situata la Diga del Menta, una diga in rockfill con manto bituminoso progettata negli anni '70 per l'approvvigionamento idrico della regione.
Nel complesso del sistema di monitoraggio della diga, nel 2016 sono stati installati tre accelerometri che registrano i segnali sismici degli eventi che si manifestano nella regione. Le registrazioni sono state impiegate per una valutazione di alcuni modelli di previsione dell'intensità sismica, o leggi di attenuazione (Ground Motion Models, GMMs), da cui sono stati desunti dei coefficienti correttivi specifici per la regione in esame. I modelli così corretti, che includono la correzione sito-specifica, sono utili per un successivo impiego nell'Analisi Probabilistica di Pericolosità Sismica (PSHA).

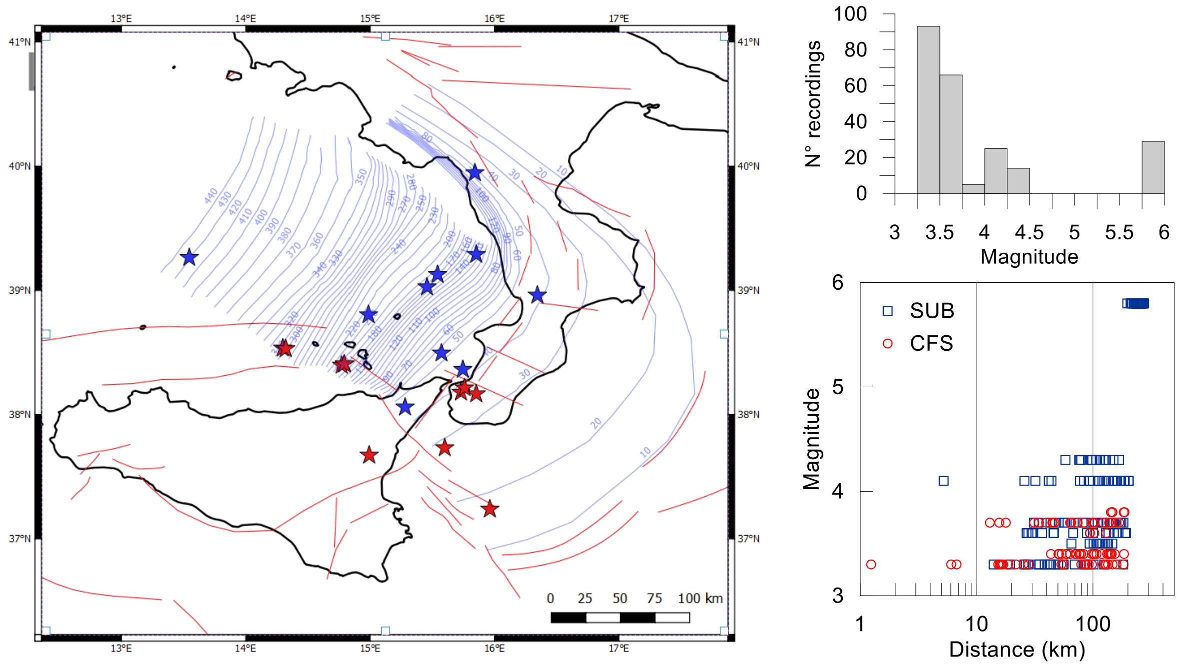
1. Framework of the study

The Menta Dam is a bituminous faced-rockfill dam designed in the 1970s and realized between 1987 and 2000. The dam, which is part of new waterworks that will supply drinking water to Reggio Calabria province, has been subjected to re-assessment according to recent NTD14. More specifically, the operational condition of the dam has been reviewed by analyzing monitoring data collected during the first impoundment phase and defining the interaction between the seepage flow and the embankment by means of in-situ verification and numerical simulations (Vecchietti et al. 2017a). Moreover, the assessment of the seismic behaviour of the embankment has been performed, with particular concern on the study of stability conditions and hydraulic safety of the facing (Vecchietti et al. 2017b, 2018). Seismic stability analyses using simplified pseudo-dynamic methods and time – history numerical analyses indicate a good performance of the dam in terms of residual displacements.
Semi-empirical Ground Motion Models (GMMs) are used for predicting seismic intensity measures. Those models are based on observations from multiple stations and seismic sources – even worldwide. Site-specific response will generally differ from the global average prediction given by the GMMs due to local conditions. In this paper, the applicability of source and path terms in two global GMMs, namely BSSA14 (Boore et. al 2014) and BCHydro16 (Abrahamson et al. 2016) are examined for use in the Southern Calabria region by validating model prediction with regional recordings.
Among the instruments included in the monitoring system of the dam, a set of accelerometers were installed in 2016 on the two abutments and along the southern slope of the reservoir. Recordings of earthquake at the site have been analysed, along with recordings from those same events at other sites, to develop a non-ergodic site term. That site term is used with the adjusted GMMs in Probabilistic Seismic Hazard Analysis (PSHA) for the Menta Dam site.

2. Application of GMMs

The site of interest is situated near to the Aspromonte Massif (Latitude 38.1234°N, Longitude 15.8998°E), in the municipality of Roccaforte del Greco (RC). Due to the complexity of the seismogenic processes taking place in Calabria, the geodynamics and tectonics of the area have been widely studied especially in the last 30 years (Carafa et al. 2018, Tiberti et al. 2017, Galli & Peronace, 2015, Presti et al. 2013, Monaco & Tortorici 2000, Valensise & Pantosti 1992, and references herein).
Calabrian Arc (Figure 1a) is a portion of the converging boundary of the Eurasian and African plates, and Calabria Region is situated on top of the subduction of the oceanic crust. Large normal faults have developed on the Tyrrhenian side of the upper plate, parallel to the Arc; these faults, together with strike-slip faults that dissect the extensional axis of the Calabrian Arc are responsible for large earthquakes (see DISS Database, http://diss.rm.ingv.it/diss/).
A total of 20 events occurred in the region between October 2016 and February 2018 have been considered in the present study. Records span from Magnitude 3.3 to Magnitude 5.8 and are located within a distance range 6 km < d < 350 km from the site of interest. These events belong to both crustal faults activity and deep in-slab subduction seismicity and have been recorded by on-site instruments as well as by other instruments installed in the same region and belonging to Italian Accelerometric Network managed by DPC (RAN-DPC). For each event-station couple, the epicentral distance, R_{epi}, the closest distance to the ground surface-fault projection, R_{JB}, and the hypocentral distance, R_{hypo}, were computed; each station has also been characterized with $V_{S,30}$[1] estimate. A total of 232 recordings compose the dataset for this work. Figure 1a-b shows the location of the events and magnitude – distance features of the dataset.

[1] Following Scasserra et al. (2009), for those locations with no measures of $V_{S,30}$ the correlation with lithology proposed by Willis & Clahan (2006) has been used.



a) *b)*

Fig 1. a) Geodynamic and tectonic setting of Southern Italy. Crustal faults are represented in red. The NW ward dipping subducting slab of the African plate is represented by the blue iso-depth lines in the Tyrrhenian Sea. The stars represent the location of the events that compose the Dataset. b) Distance – Magnitude ranges from the Dataset used in this study, CFS: crustal fault source, SUB: subduction.

All the raw recordings have been pre-processed in order to remove high-frequency noise and late-triggered record in the time series (acceleration *vs.* time). The processing procedure is consistent with Boore & Bommer (2005) and PEER record processing procedure (Chiou et al. 2008). Finally, each pair of horizontal orthogonal component time series has been combined with the algorithm by Wang et al. (2018) in order to compute the 50th percentile rotated azimuth-dependent Pseudo-Spectral Acceleration spectrum (PSARot50) for the usable band of each event record.

2.1 Ground motion models (GMMs)

Ground Motion Models (GMMs), or Ground Motion Prediction Equations (GMPEs), are semi-empirical relations that allow estimation of seismic intensity measures (e.g. PSA, PGA, PSV) given a set of predictors related to characteristics of the event (e.g. magnitude, focal mechanism) and site (location and site parameters). These equations were developed by several authors from empirical regressions of observed amplitudes in available databases of recordings; these equations are applied in similar seismogenic contexts following the assumption that average source, path, and site effects from global databases may apply for any site (*ergodicity*). Typically, a GMM gives the mean of an intensity measure in log units $(\mu_{lnZ})_{ij}$ for an event i, at site j, as a function of addends, representing the source term ($F_{E,i}$), the path term ($F_{P,i}$) and the site term ($F_{S,i}$):

$$(\mu_{\ln Z})_{ij} = F_{E,i} + F_{P,ij} + F_{S,ij} \qquad (1)$$

as well as its standard deviation (σ). Among the GMMs proposed in the literature, the models selected for the present study are:

- Boore at al. (2014) BSSA14 model, which is based on NGA-West2 database records (Ancheta et al., 2014) and valid for active crustal regions; it has a regional correction term for Italy;
- Abrahamson et al. (2016) BCHydro16 model, which is the most recent model for subduction earthquakes with M > 5; it is worth to note that, although out of the validity range, this model was used applied also in case of M ≤ 5 events in the present work.

Those two models have been used to predict the PSA for the same conditions of the dataset and to compare model prediction and observed data and to analyse the residuals.

2.2 Analysis of residuals

The total residual (R_{ij}) is defined as:

$$R_{ij} = ln\, z_{ij} - \left(\mu_{ln\,Z}\right)_{ij} \tag{2}$$

where z_{ij}, is the observation of event i at station j and $(\mu_{lnZ})_{ij}$ is model prediction. The total residuals can be decomposed (Al Atik et al. 2010) into:

$$R_{ij} = \eta_{E,i} + \delta W_{ij} \tag{3}$$

where $\eta_{E,i}$ is the between-events residual (event-term), which corresponds to the average misfit of recordings of one particular earthquake (E) with respect to the median ground-motion model, and δW_{ij} is the within-event residual, which corresponds to the difference between the total residual and $\eta_{E,i}$. Recordings of multiple events for each station allow to further examine the within-event residuals to evaluate the site-term for each station, $\delta S2S_j$ (defined as the average δW_{ij} recorded at station j), i.e. the average misfit of recordings from one particular site with respect to the event-corrected median ground-motion. The quantity $\delta W_{0,ij}$ is the remaining residual after site- and event-terms are subtracted from total residuals:

$$\delta W_{ij} = \delta S2S_j + \delta W_{0,ij} \tag{4}$$

$\eta_{E,i}$ and $\delta S2S_j$ are zero mean random variables and their standard deviation, τ and ϕ_{S2S}, quantify the variability from event-to-event and site-to-site. The total single-station standard deviation σ_{SS} (Rodriguez-Marek et al. 2011) can be computed as:

$$\sigma_{SS} = \sqrt{\tau^2 + \phi_{SS}{}^2} \quad \text{and} \quad \phi_{SS} = \sqrt{\frac{\sum_j \sum_{i=1}^{NE_j} \delta W_{0,ij}{}^2}{\sum_j NE_j \quad -1}} \tag{5}$$

ϕ_{SS} is the event-corrected single-station standard deviation and NE_j is the total number of events recorded at station j.

Within-event residuals of PSA have been plotted as function of magnitude and distance (R_{JB} or R_{hypo} for crustal and subduction-inslab earthquakes respectively) for periods ranging from T = 0 (PGA) to T = 10s. Trends recognisable in the residuals suggested that GMMs are biased with respect to local recordings; in particular:

- residual for BSSA14 model, even if the correction coefficient for Italy was included, show a trend with distance;
- residual for BCHydro16 model are biased with respect to both distance and magnitude;

The selected GMMs have thus been better adapted to the regional recordings by introducing an additional period-independent correction term. More specifically, new coefficients were calibrated by performing a regression of the residuals with respect to the path functional term ($F_{P,i}$) for BSSA14 model, and to the magnitude-dependent term for BCHydro16 model.

The event- and site-corrected residuals δW_{ij} show that recordings are now well represented by regional-adjusted models (Figure 2). The standard deviations of the residual components (between-event τ, and site-corrected term ϕ_{SS}) is consistent with other studies performed in Italy (Luzi et al. 2014, Lanzano et al. 2017) and does not show a significant trend with magnitude (homoscedasticity).

2.3 Site response from the recordings

Regional-adjusted GMMs can now be used for evaluating non-ergodic site response at Menta Dam site: following Stewart et al. (2017), site mean amplification is represented by the bias of on-site recordings from suitable GMMs – regional GMMs in this case; more precisely, site response estimate is the sum of the residual at Menta Dam site (site term $\delta S2S_{Menta}$) and the ergodic site term for the site's $V_{S,30}$ given by the GMMs. As shown in Figure 3, site response is larger than the global average prediction of GMMs for period T lower than 0.4s. Uncertainty in the overall amplification level is represented by the standard error in the mean, which results much larger in the subduction model.

3. Concluding remarks

Regional-adjusted GMPEs for Southern Calabria have been obtained from available BSSA14 and BCHydro16 models in accordance with local database of recordings. These two models GMMs can now be implemented in the Probabilistic Seismic Hazard Analysis as non-ergodic GMMs. Finally, site-specific uniform hazard spectra will be obtained combining these Ground Motion Models with a source model which includes all the relevant seismic sources for the area.

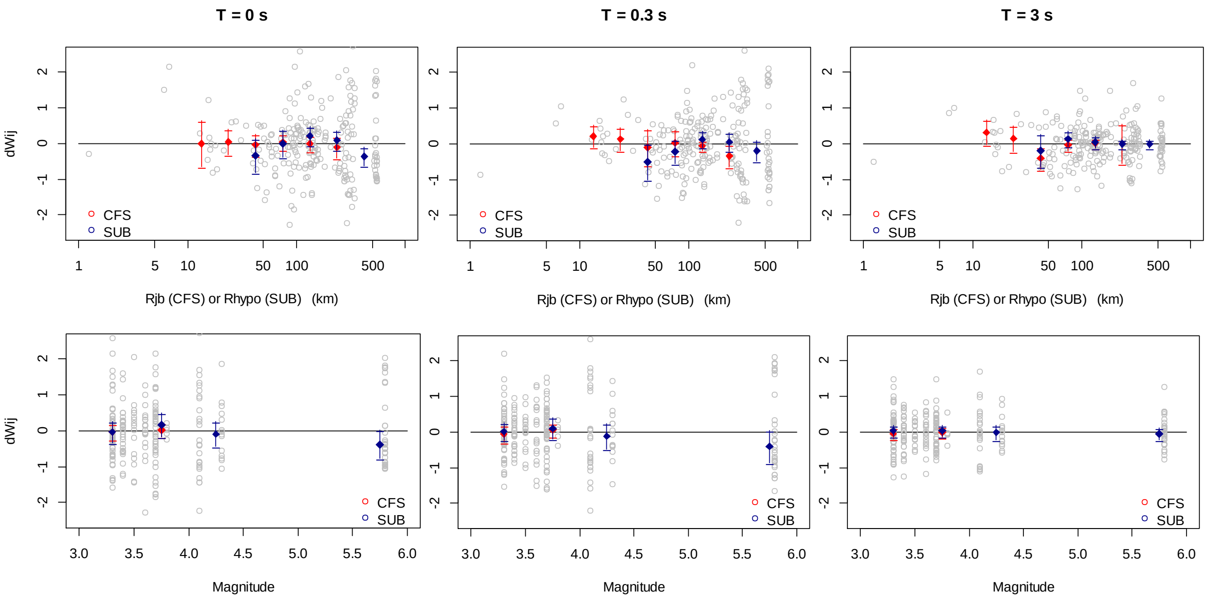


Fig 2. Event- and site-corrected residuals δW_{ij} as function of Distance (R_{JB} or R_{hypo} for crustal and subduction seismic recordings) and Magnitude for example periods T= 0 (PGA), 0.3s, 3s for the regional-adjusted models. The diamond symbols represent the mean and the bars represent ±95% confidence level for binned data, CFS: crustal fault source, SUB: subduction.

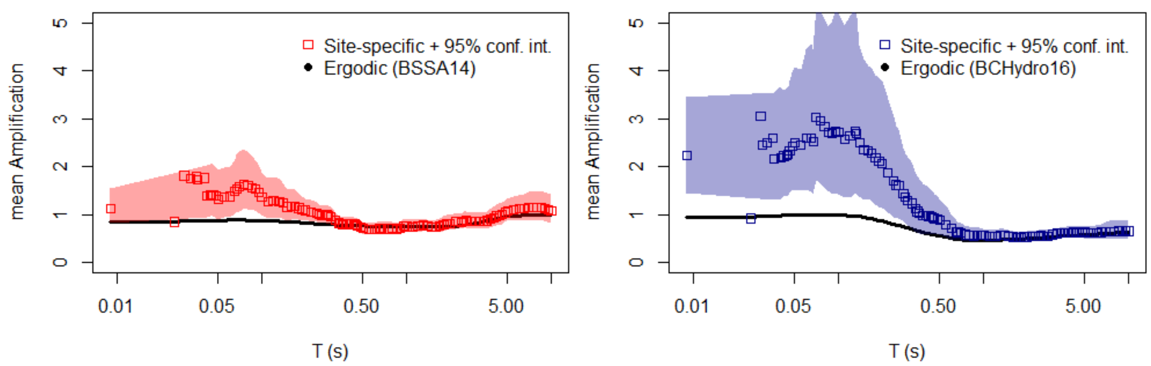


Fig 3. BSSA14 and BCHydro16 regional-adjusted model predictions (ergodic) relative to site-specific (non-ergodic) linear site amplification term of the GMMs to be used in a site-specific PSHA. Red plot: crustal fault source (CFS), Blue plot: subduction (SUB).

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