Parametric spectral inversion for North-eastern Italy

Contribution to Session 30 – Seismic site response: case studies, issues and new challenges

Cataldi Laura - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Division of the Seismological Research Center, Cussignacco (Udine), Italy, e-mail: lcataldi@ogs.it

Poggi Valerio - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Division of the Seismological Research Center, Cussignacco (Udine), Italy, e-mail: vpoggi@ogs.it

Costa Giovanni - University of Trieste, Department of Mathematics and Geosciences, Trieste, Italy, e-mail: costa@units.it

Parolai Stefano - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Division of the Seismological Research Center, Cussignacco (Udine), Italy, e-mail: sparolai@ogs.it

Edwards Benjamin - University of Liverpool, Department of Earth, Ocean and Ecological Sciences, Liverpool, United Kingdom, email: Ben.Edwards@liverpool.ac.uk

Abstract: Strong motion prediction holds great interest for engineering seismology, as it is strictly related to vulnerability and risk assessment. In the case of areas of low or moderate seismicity with little strong motion records, such as North-eastern Italy, models obtained for other regions can be calibrated for application to the area of interest with the help of precise information on site-specific amplification and regional attenuation. The aim of this study is to provide high-quality estimates for seismological parameters for a trans-frontier study area in NE Italy by using parametric spectral inversion. The Fourier amplitude spectral model is built based on region-specific literature with the addition of uncertainty estimators. Frequency dependent site response functions are extracted using residual analysis. Results are in good agreement with available literature and provide a complementary empirical description of site response that can be directly applied into site-specific hazard assessment.

Keywords: Waveform inversion; Fourier analysis; Site response; Source parameters

1. Introduction

Engineering seismology greatly benefits from precise knowledge on seismological properties; for example, information on site response can be directly integrated inside site-specific hazard assessment. Reliable characterisation of attenuation and site effects is crucial also in areas of low to moderate seismicity, where direct formulation of strong ground motion prediction equations is not feasible and models obtained for different regions have to be re-calibrated before application.

The aim of this study is to provide high quality estimates for site effects, attenuation, and source parameters for a case study area in North-eastern Italy. A parametric approach was adopted to separate source, path and site effects contributing to Fourier Amplitude Spectra (FAS). Previous parametric spectral analyses for the region include Castro et al. (1997), Malagnini et al. (2002) and Franceschina et al. (2006). The methodology was adapted from Bora et al. (2017), with the addition of uncertainty estimators and region-specific modelling choices. Frequency-dependent site amplifications were calculated through residual analysis. They will provide a detailed empirical description of site response complementary to the available Eurocode-8 site classification.

2. Regional seismotectonic setting

The study area used for spectral inversion was selected in Northeast Italy at the border with Slovenia and Austria. The region displays significant low-to-moderate seismic activity, with some major strong historical earthquakes originated in Idrija and Veneto regions.

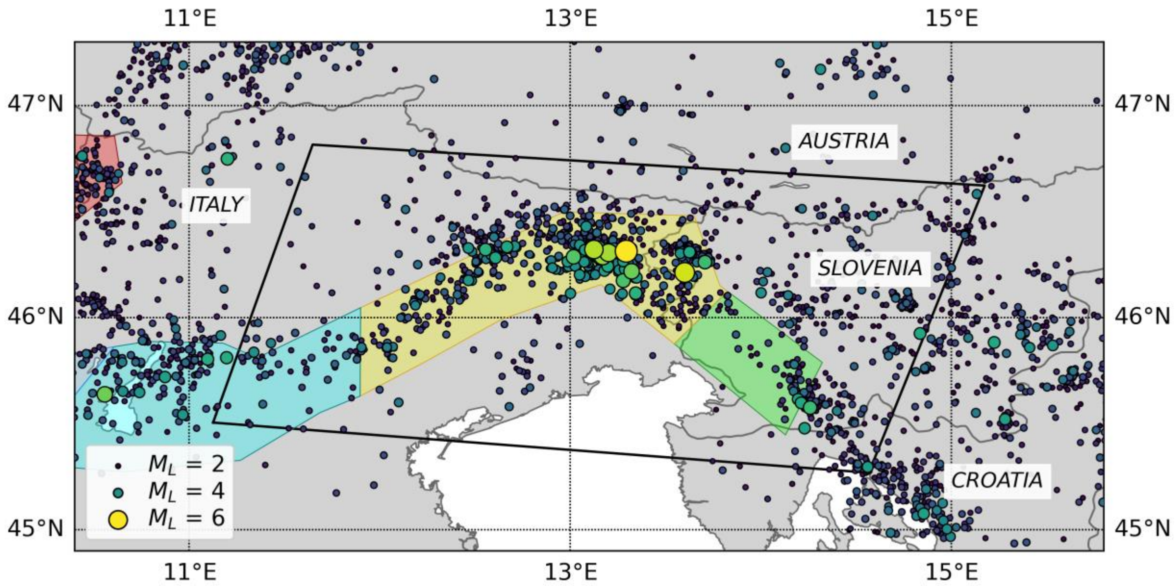

Figure 1 - Seismicity of the study area (black line polygon) in the period 1976-2017 (colored circles). The main seismogenic sources populating the area are also pictured in the form of *ZS9* seismogenic zones (colored polygons).

Associated hypocentral depths are usually below 20 km, with predominant compressive faulting style for the Alpine area (Bressan et al. 2003). The main seismogenic sources are displayed in Figure 1 as described by the *Zonazione Sismogenetica ZS9* model (Meletti and Valensise 2004), together with the seismic activity in the period 1976-2017 as given by the reviewed International Seismological Centre bulletin (ISC 2020).

3. Dataset

The study area was defined to include as many main regional seismogenic features and recording stations as possible. The prime localization proposed by the revised ISC bulletin was used to ensure homogeneity of the event localizations. The revised waveform database available from SeisRaM group at the University of Trieste was used, which relies on the trans-frontier European network CE3RN (Bragato et al. 2014) and gathers data from all the main networks (Italian, Croatian, Slovenian, and Austrian) that monitor the region.

Waveform data was processed following the methodology proposed by Edwards et al. (2008). The processed dataset consisted of 234 3-component records corresponding to 23 events and 24 recording stations. All events are shallow crustal events with moderate magnitudes ($2.3 \leq M_L \leq 4.5$) and hypocentral distances are below 200 km.

4. Methodology

In a general way, the velocity FAS of ground motion observed at a station j, originating from an earthquake i, for any frequency point k can be modelled as:

$$FAS_{ijk}(r_{ij}, f_k) = 2\pi f_k\, \Omega_i(f_k)\, D_{ij}(r_{ij}, f_k)\, S_j(f_k)\, I_j(f_k)\,, \tag{1}$$

where r_{ij} is the hypocentral distance and the building blocks are a source (Ω), a propagation (D), and a site (S) term. The instrument response term (I) can be discarded if the signal is corrected for the seismograph response prior to the inversion.

Each building block was modelled using a set of dedicated parameters. We used a simple Brune far field source spectrum and fixed the geometrical spreading terms from Malagnini et al. (2002). The model was kept as simple as possible; attenuation parameters were treated as frequency-independent and the network average rock site was used as amplitude reference. An additional set of parameters was introduced to estimate the model capacity to describe the epistemic uncertainty related to each building block.

A non-linear quasi-Newton inversion was applied and available *a priori* information was implemented in the minimization process through fixed parameters. After the inversion, frequency-dependent site amplification functions were reconstructed as the log-space geometric mean of the factorial residuals (observed/modelled data) for each site over all (N_i) events:

$$\log(a_j(f_k)) = \frac{1}{N_i}\left\{\sum_{i=1}^{N_i} \log\left(\frac{FAS^{o}_{ijk}}{FAS^{m}_{ijk}}\right)\right\} \tag{2}$$

5. Results and conclusions

Comparison between inverted and database source parameters for the used dataset shows a good agreement of the results. Inverted seismic moments range between 1.4×10^{13} and 2.6×10^{15} Nm and corner frequencies range between 1.8 and 12.5 Hz.

Inverted attenuation parameters are in line with regional estimates available in literature.

Frequency-dependent site amplification functions were calculated from the inversion residual, together with the associated geometric standard deviation. Based on comparison with available results obtained using different methodologies (e.g., Figure 2), they appear to correctly retrieve both the position and the amplitude of the amplification peaks.

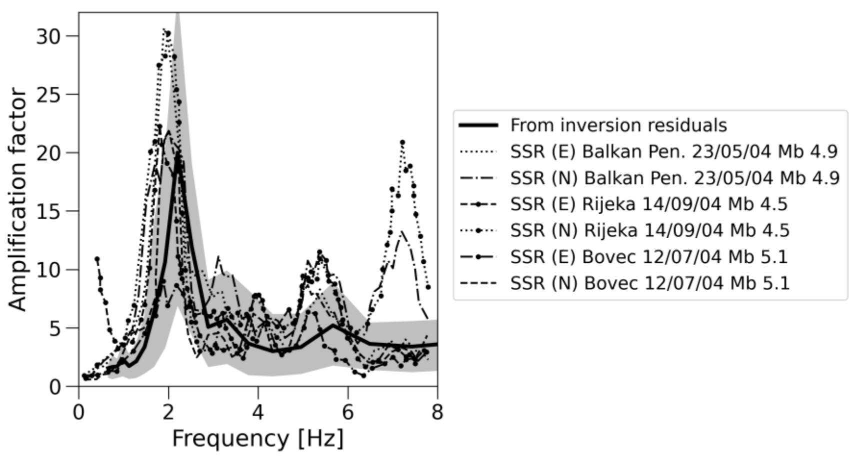

Figure 2 – Comparison for station CARC (Friuli-Venezia Giulia regional network). Solid black line is the site response function calculated in this study, with the associated standard deviation (shaded grey area). Dashed and dotted lines are results obtained by Fitzko et al. (2007) using Standard Spectral Ratio (SSR).

Complete site response functions will be built for each station by combining the frequency-dependent and the frequency-independent contributions and will be used to define a new regional reference set with a flat response over the frequency values of interest.

The results obtained in this study outline the capability of regional spectral parametric inversion to provide robust estimates of site response functions, even when simple modelling choices are made. Further complexity could be introduced in the parametrization and different models compared based on the behaviour of the uncertainty estimators.

References

- Bora S.S., Cotton F., Scherbaum F., Edwards B., Traversa P. (2017) Stochastic source, path and site attenuation parameters and associated variabilities for shallow crustal European earthquakes. B. Earthq. Eng., 15: 4531–4561, https://doi.org/10.1007/s10518-017-0167-x

- Bragato P.L., et al. (2014) The Central and Eastern European Earthquake Research Network-CE3RN. Geophys. Res. Abstracts, 16: 13911, https://doi.org/10.13140/RG.2.1.3507.7843

- Bressan G., Bragato P.L., Venturini C. (2003) Stress and strain tensors based on focal mechanisms in the seismotectonic framework of the Friuli-Venezia Giulia region (northeastern Italy). B. Seismol. Soc. Am., 93: 1280-1290, https://doi.org/10.1785/0120020058

- Castro R.R., Pacor F., Petrungaro C. (1997) Determination of S-wave energy release of earthquakes in the region of Friuli, Italy. Geophys. J. Int., 128: 399–408, https://doi.org/10.1111/j.1365-246X.1997.tb01563.x

- Edwards B., Rietbrock A., Bommer J.J., Baptie B. (2008) The Acquisition of Source, Path, and Site Effects from Microearthquake Recordings Using Q Tomography: Application to the United Kingdom. B. Seismol. Soc. Am., 98(4): 1915–1935, https://doi.org/10.1785/0120070127

- Fitzko F., Costa G., Delise A., Suhadolc P. (2007) Site Effects Analyses in the Old City Center of Trieste (NE Italy) Using Accelerometric Data. J. Earthq. Eng., 11: 33-48, https://doi.org/10.1080/13632460601123123

- Franceschina G., Kravanja S., Bressan G. (2006) Source parameters and scaling relationships in the Friuli-Venezia Giulia (Northeastern Italy) region. Phys. Earth Planet. In., 154(2): 48-167, https://doi.org/10.1016/j.pepi.2005.09.004

- International Seismological Centre (2020) On-line Bulletin, https://doi.org/10.31905/D808B830

- Malagnini L., Akinci A., Herrmann R., Pino N., Scognamiglio L. (2002) Characteristics of the Ground Motion in Northeastern Italy. B. Seismol. Soc. Am., 92: 2186-2204, https://doi.org/10.1785/0120010219

- Meletti C, Valensise G. (2004) Zonazione sismogenetica ZS9–App. 2 al rapporto conclusivo. Gruppo di Lavoro MPS (2004). Redazione della mappa di pericolosità sismica prevista dall'Ordinanza PCM 3274 (2004), http://zonesismiche.mi.ingv.it/documenti/App2.pdf