A unified numerical model for the simulation of the seismic cycle for normal and reverse fault earthquakes in Italy

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Earthquakes are the result of the strain accumulation in the earth's crust over a variable decade to millennial period, i.e., the interseismic stage, followed by a sudden stress release at a crustal discontinuity, i.e., the coseismic stage, finally evolving in a postseismic stage. Commonly, the seismic cycle is modelled with analytical and numerical approaches. Analytical methods simulate the interseismic, coseismic and postseismic phases independently. These models impose the slip of single or multiple planar sources to infer fault geometry, slip distribution and regional deformations to fit the available geodetic or seismological measurements, often regardless of the magnitude and orientation of the interseismic gravitational and tectonic forces. Numerical approaches allow simulating complex geometries in heterogeneous media and at different modelling scales, assuming various constitutive laws. Such models often impose the slip on the fault plane to simulate the observed coseismic dislocation or the propagation of the seismic waves, or they adopt ad-hoc boundary conditions to investigate the interseismic stress accumulation or the postseismic relaxation for specific cases.

We contribute to the understanding of the seismic cycle associated to a single fault by developing a numerical model to simulate the long-term crustal interseismic deformation, the coseismic brittle episodic dislocation, and the postseismic relaxation of the upper crust within a unified environment for both normal and reverse fault earthquakes in Italy, including the forces acting during the interseismic period, i.e., the lithostatic load and the horizontal stress field, the latter simulated with the application of a shear traction at the model's base. We adjusted the setup of our model to simulate the interseismic, coseismic and postseismic phases for two seismic events: the $M_w 6.1$ L'Aquila 2009 normal fault earthquake and the $M_w 5.9$ Emilia-Romagna 2012 reverse fault earthquake.

The simulation results show that the applied basal shear traction is fundamental to model the large-scale interseismic pattern since it allows for a first-order simulation of the ongoing crustal interseismic extension of the Central Apennines and compression of the Adriatic foreland and the north-eastern part of the Italian territory. The action of shear tractions and lithostatic forces
generates a local concentration of stresses and strains in the presence of local heterogeneities or discontinuities, i.e., at the transition between the brittle locked fault and the ductile unlocked slipping fault during the interseismic stage. Such an interseismic strain partitioning provides maximum horizontal stress sufficient to exceed the friction on the locked brittle part of the fault, with the subsequent collapse of the hangingwall in case of extensional earthquakes or the expulsion of the hangingwall in case of compressional earthquakes. The instantaneous slip of the hangingwall perturbs the crustal pore fluid pressures, triggering groundwater flow in the postseismic phase from regions of higher pore pressures, which further compress, to regions of lower pore pressures, which further dilate. As a result, displacements gradually accumulate in the postseismic phase, according to the dissipation of pore pressure excess. Once the postseismic phase terminates, a new cycle of interseismic loading can start again.