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Integrating physics-based numerical scenarios into PSHA in large urban areas

Roberto Paolucci (1), Marco Stupazzini (2), Ilario Mazzieri (3), Ali Güney Özcebe (4), Chiara Smerzini (5), and Maria Infantino (6)

(1) Department of Civil and Environmental Engineering, Politecnico di Milano, Italy (roberto.paolucci@polimi.it), (2) Munich RE, Germany (MStupazzini@munichre.com), (3) Laboratory for Modeling and Scientific Computing, Department of Mathematics, Politecnico di Milano, Italy (ilario.mazzieri@polimi.it), (4) Department of Civil and Environmental Engineering, Politecnico di Milano, Italy (ozcebeag@gmail.com), (5) Department of Civil and Environmental Engineering, Politecnico di Milano, Italy (chiara.smerzini@polimi.it), (6) MSc student, Politecnico di Milano (maria.infantino@mail.polimi.it)

In recent years, stimulated by the increasing availability of computational resources, forward physics-based numerical simulation of earthquake ground motion, including a full 3D seismic wave propagation model from the source to the site, has achieved a remarkable advancement, allowing, in certain conditions, the use of synthetic ground shaking scenarios as an alternative or complementary tool to more traditional approaches based on Ground Motion Prediction Equations (GMPEs). GMPEs suffer, in fact, of a series of intrinsic limitations, namely, (i) they are poorly constrained in those conditions of major potential interest for engineering applications, i.e., in the near field of strong earthquakes, (ii) they refer to generic site conditions, and (iii) they cannot reproduce the spatial variability of ground motion in a realistic way, which is crucial for seismic risk studies at territorial scale.

In the perspective of promoting tools for an advanced seismic hazard characterization, Munich Re funded a research activity with Politecnico di Milano, having a twofold objective: on one side, the release of a certified computer code to execute numerical simulations of seismic wave propagation in complex large-scale models, and, on the other side, the development of an advanced integrated probabilistic/deterministic procedure for seismic hazard assessment in large urban areas, making use of 3D physics-based ground shaking scenarios, referred to hereinafter as PBS.

In this contribution the application of such an integrated procedure to the Istanbul case study, selected as one of the areas with the highest seismic risk worldwide, is addressed. Massive numerical simulations of ground shaking have been performed through a 3D numerical model by spectral elements for the area of Istanbul, considering possible realizations of a characteristic earthquake breaking the North Anatolian Fault (NAF) segment facing Istanbul across the Marmara Sea. Overall, about 50 PBSs have been simulated with magnitude M_W ranging from 7 to 7.4 by varying the distribution of the coseismic slip, the hypocenter location and location of the rupture area. Numerical simulations are carried out using an innovative high-performance computer code called SPEED (http://speed.mox.polimi.it/), based on the Discontinuous Galerkin Spectral Elements Method (DGSEM), which is particularly useful in tackling multi-scale seismic wave propagation problems in highly heterogeneous media. Relying on a novel approach for generating broadband ground motions, based on Artificial Neural Networks (ANNs), PBSs are provided in the whole frequency range of interest of engineering applications (0-25 Hz), making it possible to preserve the full spatial correlation of ground motion.

Numerical results are discussed to shed light on the most important physical factors that affect ground motion estimates, such as the directivity effects, which turn out to play a major role to accurately estimate seismic hazard in the Istanbul area in case of large $M_W \geq 7.2$ earthquakes.

These PBSs are the basis to construct an integrated probabilistic/deterministic approach for enhanced probabilistic seismic hazard assessment studies, where important physical features of spatial variability of ground motion, as related to focal mechanism, near-source directivity/directionality effects, 3D seismic response of soft soil, can be taken into account.