Geo-INQUIRE Transnational Access Project Report

Geo-INQUIRE installation: CYBER@PSHA - Probabilistic Seismic Hazard Analysis (TA2-541-10)

Project title: CyberShake physics-Based damage Evaluation for NorthEastern Italy CYBERNEI

Transnational access principal investigator: Dr. Chiara Scaini (and Dr. Elisa Zuccolo as deputy PI)

Project acronym: CYBERNEI

Project report ID: TA2-541-10-C1-4 (2nd Call)

Transnational access team: Dr. Natalia Zamora, Dr. Hazem Badreldin, Otilio Rojas, Dr. Josep de la Puente (Barcelona Supercomputing Center, Spain)

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Introduction

Rapid estimation of earthquake impacts in near real time is a key requirement for effective seismic risk management and civil protection response. However, such estimates strongly depend on assumptions about earthquake source characteristics, which are often poorly constrained during an ongoing emergency. This uncertainty propagates through ground-motion modeling and can significantly affect impact and damage estimates.

Within this context, the Geo-INQUIRE Transnational Access aimed to explore how physics-based seismic simulations can be integrated into impact and damage assessment workflows currently used for civil protection purposes in northeastern Italy.

In this study, we revisit the 1976 Friuli earthquake (Mw 6.5) — a well-documented but sparsely recorded event — as a case study to explore the implications of source modeling uncertainties for impact estimation. In particular, we aim at improving physics-based simulations by accounting for multiple sources, and using their results to assess the potential seismic impact of the 1976 Friuli earthquake.

Main phases of the study

The foundation of this work is to identify the relevant fault sources and generate a set of plausible rupture scenarios through numerical modeling. The resulting ground motions are then analyzed to evaluate their variability across the region. Finally, the outcomes are planned to be used to assess potential damage distributions and support seismic risk management in NE Italy. The study is therefore organized in three consequent phases.

In the first phase, we begin by identifying sources related to the Friuli 1976 earthquake, focusing on selecting 11 initial sources for simulations. The sources are chosen based on their proximity, fault characteristics, and relevance to the region's seismic activity. The ruptures generated through the simulation process are modeled using a set of well-established ground motion prediction equations and computational methods. Specifically, we use the finite difference method (FDM) to simulate the propagation of seismic waves across the region. This allows us to produce synthetic ground motion records, which can then be compared to actual observations from the Friuli 1976 event. One of the main challenges in this phase was defining accurate input parameters, such as fault geometry, stress drop, and material properties, which are essential for producing realistic simulations. The initial 11 source models provide a manageable starting point, though the aim is to scale this to over 200 sources in future work.

In the second phase, we compare the generated ground motion to observed records to assess its variability and overall quality. This involves statistical analysis of the differences in terms of peak ground acceleration (PGA), spectral response, and other key intensity measures / parameters. The aim is to quantify the differences between synthetic and real-world data to better understand the variability of ground motion in the region.

In the third and final phase, the synthetic ground motion is used as input for damage assessment at various sites affected by the 1976 earthquake. Challenges in this phase include the difficulty of site-specific calibration and the variability in building codes and construction standards across sites. This activity is currently under development.

Activities carried out during the Transnational Access

The Transnational Access at the Barcelona Supercomputing Center (BSC) supported the implementation of the study by providing a methodological framework, HPC resources, and hands-on training. In particular, during the Geo-INQUIRE Transnational Access at the Barcelona Supercomputing Center, we defined and tested a methodological framework for integrating physics-based seismic simulations into damage assessment workflows currently used by OGS for civil protection purposes in northeastern Italy.

Therefore, the transnational access supported the first and second step of the overall work plan. Within the Geoinquire transnational access, physics-based ground-motion simulations were performed for 11 potential seismic sources associated with r (Fig. 1)f the 1976 Friuli earthquake, as documented in the literature (DISS3.3.1, Diss Working Group 2025; ITACA v4.0, Felicetta et al., 2023: Aoudia et al., 2000) were prepared and run using the Cybershake tools (e.g. Callaghan et al 2024). The modeling outputs support the subsequent work to apply and test the damage assessment method for the same event, using historical exposure data from 1976 as well as current exposure data.

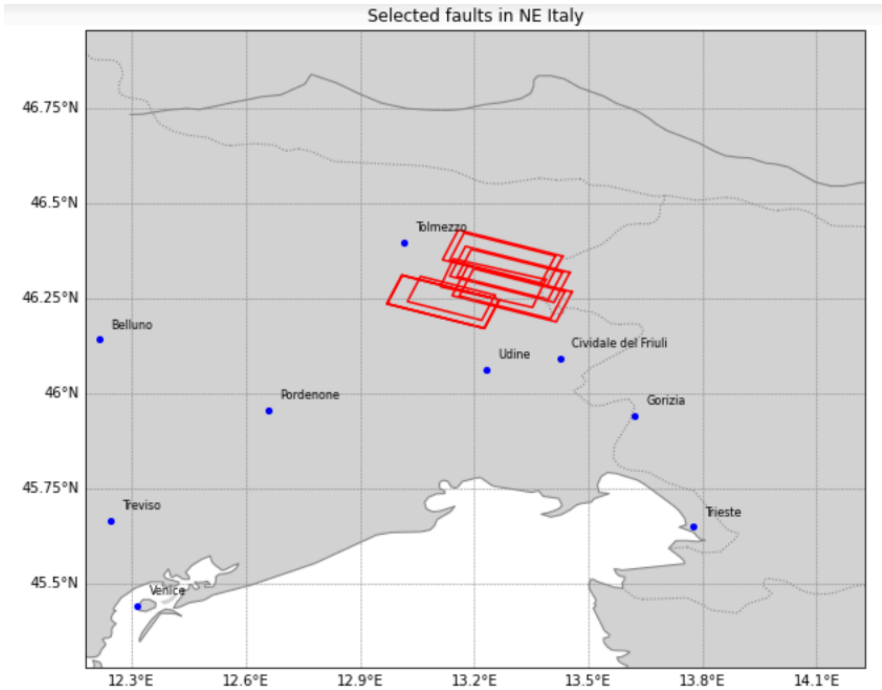

Fig. 1: Selected 11 rupture areas (DISS3.3.1, Diss Working Group 2025; ITACA v4.0, Felicetta et al., 2023: Aoudia et al., 2000) for the first version of this study, where a 1D velocity model is used to conduct numerical simulations with Cybershake platform.

A pipeline was defined together in order to simulate the selected scenario, produce synthetic seismograms and extract multiple intensity measures to be used for assessing the expected damage for each building typology in the study area (Fig. 2).

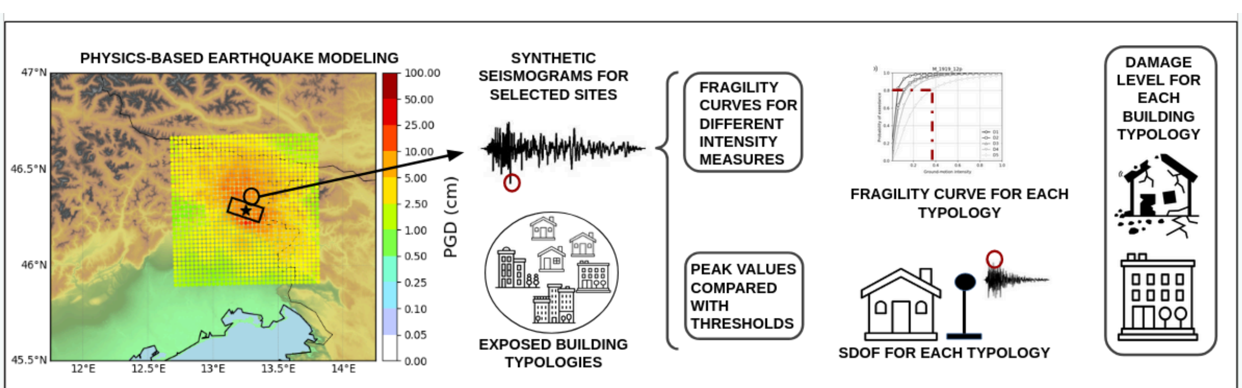

Fig. 2: Pipeline for the use of physics-based simulations outputs for damage assessment based on fragility curves for each exposed typology.

The relevant information for applying the pipeline were identified and prepared. The main building typologies in the 1976 building stock were unreinforced masonry constituted by either stone, pebbles or bricks and blocks, and pre- or low-code reinforced concrete. The current building stock was derived from the last comprehensive building census in Italy (Istat, 2011) and is mostly constituted by unreinforced or mixed masonry and reinforced concrete. Data sources related to damages suffered by buildings during the 1976 event were also gathered from past work (e.g. Grimaz et al., 2009).

Each building typology in the old and new exposure layer is associated with fragility curves from literature. Alternatively, for the building typologies for which thresholds are available (e.g. from Lagomarsino and Giovinazzi, 2006 or from ad-hoc building modeling), damage state can be assessed by comparing the relative displacement or average interstory drift in the building with the thresholds for different damage levels (e.g. Petrovic et al., 2023).

Main outcomes from the transnational access:

During the stay at BSC, colleagues from OGS have received training to use Cybershake. Training materials were prepared by BSC and shared with the visiting people, and multiple Q&A virtual sessions were accommodated in the following months. The visit also facilitated in-person knowledge transfer, iterative problem solving, and scientific discussions.

The first outcome is that the visiting researchers (Chiara Scaini and Elisa Zuccolo) were able to understand the wide range of potential applications of Cybershake and adapt the modeling strategy to their specific use case. In particular, they identified a simplified modeling strategy with selected sources and with 1D velocity profile, and a more sophisticated approach using more than 200 sources and a 3D velocity model.

An example of the results obtained during the first and second phase of the study are shown in Fig. 3, which presents the synthetic seismograms obtained at three selected stations from the simulation of two ruptures, using a 1D velocity model.

Part of these results will be submitted as an abstract for the European Geoscience Union EGU2026, and shared in the Simulation Data Lake.

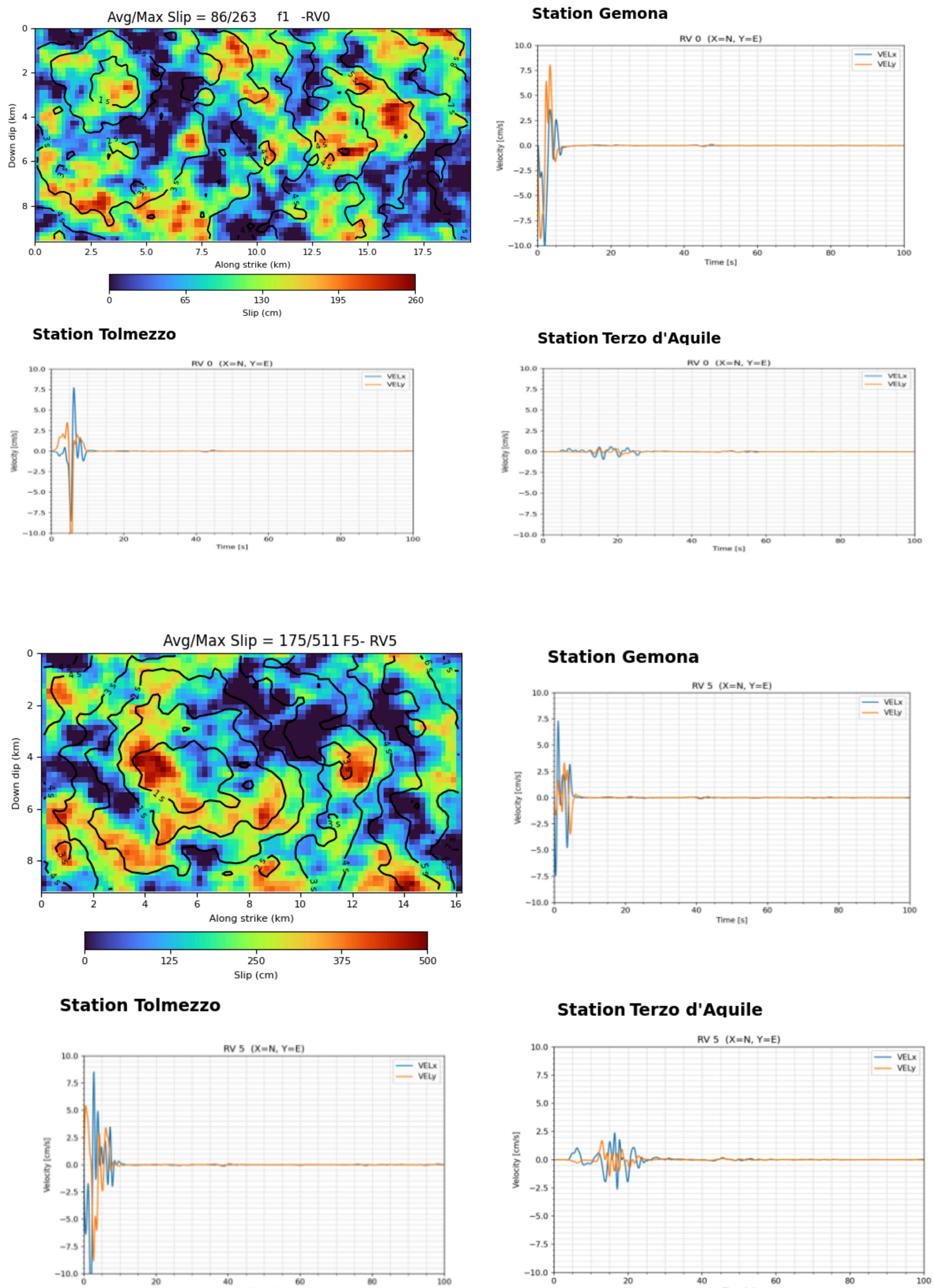

Fig. 3. Examples of outcomes for two selected faults and saved at three stations.

Future work: from ground shaking to damage

The results of the simulations with 1D velocity model will be compared to simulations with a 3D velocity model. Simulation results obtained with the Cybershake tools will be also compared with those obtained with Urgentshake, currently in use at OGS (Zuccolo et al., 2025).

Simulation results obtained with the Cybershake tools will be then used for physics-based damage assessment using existing information on exposure and fragility, and following the pipeline in Fig. 2. Building on an existing damage assessment approach based on intensity measures derived from shakemaps (Bragato et al., 2021; Poggi et al., 2021), future activities will be focused on adapting this method to ingest outputs from physics-based simulations and carry out damage assessment for different building typologies in the study area using the pipeline in Fig. 1.

The developed pipeline is general and accommodates the use of one or more damage assessment methods, separately or in combination. In particular, future directions for implementation are the combined use of multiple damage assessment approaches that make use of the entire seismogram (e.g. Scaini et al., 2021; Petrovic et al. 2022, 2023) and the use of updated building-by-building exposure datasets currently under development (Badreldin et al., 2025).

Conclusive remarks

The Geo-INQUIRE Transnational Access enabled the methodological setup and proof-of-concept needed to integrate physics-based seismic simulations into damage assessment workflows relevant for civil protection. Using the 1976 Friuli earthquake as a test case, the study highlighted how uncertainties in source modeling affect ground-motion variability and impact estimates, with direct implications for near real-time seismic risk assessment.

The Transnational Access supported the implementation of a simplified Cybershake modeling strategy based on selected sources and a 1D velocity model, allowing effective testing of model functionalities and generation of ready-to-use simulation outputs. At the same time, it laid the groundwork for future developments based on more advanced configurations, including larger source ensembles and 3D velocity models.

The in-person visit and direct interaction with BSC experts proved essential not only for rapid knowledge transfer and iterative problem solving, but also for fostering scientific exchange beyond technological implementation, creating opportunities for new joint research activities.

Overall, this activity represents a foundational step toward the operational use of physics-based simulations for seismic risk assessment, strengthening the capacity of OGS to exploit HPC tools and bridging advanced modeling, decision support, and societal impact.

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