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LIGURIAN EARTHQUAKE: SEISMIC AND TSUNAMI SCENARIO MODELING, FROM HAZARD TO RISK ASSESSMENT TOWARDS EVACUATIONS PLANNING

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The aim of the present study is to identify realistic and damaging scenarios of seismic and tsunami events on Nice city and to provide data relative to the resulting physical damages to the built environment, as well as to the network systems. We tried to reduce the gap between realistic scientific modeling, risk evaluation and mitigation: the results will be used by partners of the Franco-German Cooperation in Civil Security Research project “DSS EVAC” (Decision Support System for Large Scale Evacuation Logistics) for large-scale evacuation logistics of mid-size towns, as inputs for the development of a decision support system, hence covering the whole risk chain analysis. In the end, such scenarios shall bring two different components to the project: one is the disaster modeling point of view (input to the evacuation model), and the other is the decision chain involved in the evacuation plan (output expected from the DSS tool).

Context

The Alps and Ligurian See are part of the most active seismic areas in Western Europe. Seismicity is described as low to moderate although quite superficial and diffuse. Many historical seismic events were reported in this region, and some were quite damaging. Among them one can report the Ligurian earthquake of 1887 (Mw=6.9, Larroque et al., 2012), which triggered building collapses and an induced tsunami. In this study on Nice, the disaster scenario presented here will be based upon the Ligurian earthquake and tsunami, but translated towards the West along the Ligurian fault system in order to consider the “most damaging” hypothesis for Nice.

In doing so, the methodology required serial modeling, from the descriptions of the seismic event and tsunami features, to the rupture modeling, wave propagation simulation and impact on site, hence requiring the collaboration of multiple and various expertise.

Seismic event and ground motion estimation

First, a finite source model has been built for the Ligurian earthquake using source parameters from Larroque et al. (2012). A heterogeneous slip distribution has been generated according to the spatial random field model developed by Mai and Beroza (2002).

Then, in order to estimate ground motion deformation, a simulation of wave propagation from the seismic source to the target zone can be performed using some accurate three-dimensional (3D) models built from the available deep and surficial geological, geotechnical and geophysical data. In order for such simulations to be relevant, dispersion in the computed ground motion (e.g. amplitude, frequency content) is to be minimized, which implies to increase the spatial resolution, even at the

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regional scale, and hence, to have access to high-performance computation codes, with accurate numerical methods. For that purpose, some 3D elastic Spectral-Element (SEM) simulations have been performed with EFISPEC3D, a software developed at BRGM (de Martin, 2011), in order to assess linear site effects at the regional scale, using a mesh grid valid up to 3 Hz. With such a refined model, we observe that the whole region is affected by heterogeneous ground motion.

Ground deformation maps are then translated into Peak Ground Acceleration (PGA) and thereafter into macroseismic intensity map to be included in the risk scenario. Several empirical relationships have been used in this study to transform PGA into intensity: Faenza and Michelini (2010), Faccioli and Cauzzi (2006), Atkinson and Kaka (2007), Tselentis and Danciu (2007), Marin et al. (2004) and Atkinson and Sonley (2000). The lithological site effect has been also considered, considering the lithological site effect map from RISK-UE European project (2004).

Seismic events acceleration maps have also been produced, i.-e. using attenuation relationships such as Akkar and Bommer's (2007) which rely on a simple description of the source from few parameters (magnitude, depth, epicentre) to estimate ground motion. The objective was to show at the end the potential differences in terms of computed seismic risk between two resolution methods, namely a "simplified method" mostly used in practice and accurate numerical simulations.

Vulnerability assessment and damage scenario

The current building vulnerability results have been mostly obtained from previous projects led by BRGM team in Nice city (e.g. RISK-UE 2004). Due the size of the city and the number of buildings (estimated around 36,000), it was not possible to compile a systematic and exhaustive inventory of the built environment. It was therefore essential to call upon statistical sampling techniques. In this study, new census data from 2008 (INSEE, French Stat Data Institute) has been incorporated in order to update the former vulnerability and risk assessment analyses.

Here, results have been focused on two main outputs, keeping in mind the final evacuation tool to be developed:

i. The heavy structural damages to buildings which may have impact on the evacuation process in terms of blocked road/streets blocked by (amounts of debris);
ii. The number of people without shelter, during winter (low tourist season) and summer (high tourist season)

The damage functions, as a function of the vulnerability index and the macroseismic intensity, are integrated within the software Armagedom (Sedan et al., 2013). Results are calculated for urban units or in a regular grid in terms of total or percentage of buildings or dwellings per EMS-98 (Grünthal, 1998) damage state (from D0, no damage state, to D5, total collapse). Armagedom calculates also the total number of "without shelter" people as the total number of population living within buildings in damages states D3, D4 and D5.

Very strong differences appear in the results in terms of damages to building stock between the two simulations (simplified and SEM). EFISPEC3D results give very strong soil accelerations in Nice city and consequently very important intensities (VIII to IX in EMS-98) which cause strong damages to building stock. This interval of intensities is quite coherent however with the intensities observed in Imperia city in 1887, close to the historical epicenter (Sisfrance, www.sisfrance.net). On the other side, the attenuation relationships lead to much lower intensity and damage values (VII-VIII in EMS-98 scale). The comparison shown in this study are interesting, as they highlight the crucial influence of different hazard parameters on seismic risk scenarios outcomes.

Tsunami modeling

In parallel to the seismic chain analysis, a tsunami scenario has been modeled, from generation due to the earthquake source rupture and wave propagation to the inundation along the coasts.

In order to model the generation of an earthquake-triggered tsunami, we have applied a widely adopted methodology based on Okada (1985) for calculating the coseismic distribution of sea bottom deformation resulting from the rupture of a finite fault during an earthquake. Vertical displacement of the sea bottom is then transmitted instantaneously to the free surface as initial condition for tsunami generation.

Tsunami wave propagation is then modeled using a new version of a fully nonlinear Boussinesq wave model (FUNWAVE-TVD, Shi et al., 2012), which presents theorical and numerical improvements with respect to former versions. The tsunami propagation has been calculated using two regular nested grids, with resolution of respectively 25m for the large scale grid and 5m for the grid close to Nice. To simulate the flooding at a high resolution, a Digital Elevation Model (DEM) of Nice city, considering buildings and walls, has been built and added to the finest grid.The simulation results show no significant submersion of the city, even for a high tide, the maximum induced water surface elevation being around 0.6m close to the shore.

Conclusion

Regarding seismic risk scenario, very strong differences appear locally in the resulting damages, when using a finite fault 3D numerical model or empirical attenuation relationships. In this study, we show that refined earthquake modelling can improve risk assessment and therefore may be applied as input to evacuation models. However, spatial heterogeneities still need to be understood and strongly linked to ad hoc specifications (e. g. geological or seismotectonic context, source directivity, numerical methodology…) using detailed parametric analyses. As for the tsunami scenario considered in this study, very few consequences are to be expected in Nice city.

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