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Empirical tsunami fragility modelling for hierarchical damage levels: application to damage data of the 2009 South Pacific tsunami

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Methodology:

A fragility model expresses the probability of exceeding certain damage levels for a given level of intensity for a specific class of buildings or infrastructure. An empirical tsunami fragility curve for a given damage level is derived based on observed pairs of data for the tsunami intensity measure and the corresponding damage level. Tsunami inundation depth and/or flow velocity are usually adopted as scalar intensity measures (they can also be employed together as a vector-valued intensity measure). Physical damage levels are usually defined in a hierarchical manner, implying discrete, mutually exclusive, and collectively exhaustive (MECE) damage states. This means that the fragility curves for consecutive hierarchical damage levels must not intersect. It is clear that by fitting empirical fragility curves to each single damage level, this condition is not automatically satisfied. To overcome this problem, ordered ("parallel") fragility models or partially ordered models have been adopted in the literature to derive fragility curves for MECE damage states. Empirical tsunami fragility curves are usually constructed using generalized linear regression models by adopting probit, logit, or the complementary loglog link functions. As far as model comparison and selection are concerned, established statistical approaches have been used in recent literature to identify the optimal link function among those mentioned above. Moreover, for estimating the uncertainty in the resulting empirical fragility curves, bootstrap resampling has been commonly used.

The present work proposes a simulation-based Bayesian method for inference and model class selection to perform ensemble modelling of the tsunami fragility curves for MECE damage states and the related uncertainties for a given class of buildings. The method uses adaptive Markov Chain Monte Carlo Simulation (MCMC), based on likelihood estimation using point-wise intensity values, to estimate the fragility model parameters and the uncertainties. Among the set of viable fragility models considered, Bayesian model class selection is used to identify the simplest model that fits the data best (i.e., is a parsimonious model). The proposed method provides consistent parameter estimation and confidence intervals for MECE the damage states and identifies the best fragility model class among the pool of viable models, based on a single set of simulation realizations. The whole procedure is provided as open-source software on the site of the European Tsunami Risk Service (https://eurotsunamirisk.org/software/) and is also available as a standalone docker application.

Application:

As the case-study application, the central South Pacific region-wide tsunami on September 29, 2009 is used. The tsunami was triggered by an unprecedented earthquake doublet (Mw 8.1 and Mw 8.0). The tsunami seriously impacted numerous locations in the central South Pacific. Herein, the damage data related to 120 brick masonry residential buildings associated with the reconnaissance survey sites of American Samoa and Samoa islands were utilized as a proof of concept. A six-tier damage scale is considered, and tsunami inundation depth has been used as the intensity measure.

Keywords: probabilistic tsunami risk analysis, tsunami fragility, Bayesian inference, model class selection