Computing Spatial Correlation of Ground Motion Intensities for ShakeMap

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Modeling the spatial correlation of ground motion intensity measures (IMs) caused by coherent contributions from earthquake source, path, and site, can provide valuable loss and hazard information, as well as a more realistic depiction of ground motions. Previous studies have developed for spatial correlation IM models as a function of site-to-site separation distance. Using ShakeMap grid distances, we simulate spatially-correlated random fields conditioned on seismic observations, where the random field converges to zero; they can then be added to a ShakeMap grid to obtain realizations of spatially correlated ground motions. Simulating the correlated fields is computationally expensive in terms of both time and memory. We explore two efficient algorithms to compute the correlated field: successive conditional simulation (SCS) and the Karhunen-Loeve Tranformation (KLT). Our ShakeMap-grid dependent SCS algorithm alleviates memory requires, enables parallelization and brings the computations closer to real-time. The ShakeMap-grid independent stochastic KLT algorithm utilizes the distance-dependent correlation function. Setting up the KLT is an offline/pre-computation process. The decay of the angular power spectrum in the KLT facilities reduction in stochastic dimensions for efficient online evaluation of the random field. To understand the impacts on potential losses, we apply the USGS PAGER system to estimate the fatalities and economic losses for realizations of the spatially correlated ground motions for several damaging earthquakes. Adding spatial correlation to the ground motion field constrained with observations does not significantly alter the distribution of loss estimates; however, for scenarios (or real-time events with few stations), the loss distribution noticeably changes with an increased mean and standard deviation. Further, we investigate the combined effects of directivity and spatial variability on the losses for a series of earthquake scenarios.

Spatial Distribution Model of Earthquake Strong-motion Amplitude and Frequency Variation on the Icelandic Strong-motion Array (ICEARRAY I) in South Iceland

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Iceland, the largest subaerial part of the Mid-Atlantic Ridge, is the most seismically region in northern Europe. The South Iceland Fracture Zone (SIFZ) is one of two major fracture zones where earthquake hazard is the highest. For the earthquake resistant design of structures in Iceland residential buildings are assumed to have relatively uniform form-factors for which site effects are typically assumed to be negligible. However, recent recordings data during and after the M_w6.3 Ölfus earthquake on May 2008 collected on twelve strong-motion stations of the ICEARRAY I in the town of Hveragerði provides the opportunity to quantify the spatial distribution of ground motion amplitudes and their frequency variation on lava rock. The data shows 100% difference in peak ground acceleration (PGA) during the mainshock and more than 1700 aftershocks. The local site conditions account for the strong spatial variation of ground motion peak parameters such as PGA and Spectral Acceleration (SA) as a function of oscillator period. The key peak-parameters are calculated for each record and their spatial variation in terms of amplitudes and frequency is quantified across the array. Furthermore, the data on PGA are modeled and analyzed using the Bayesian hierarchical framework to model physical phenomena and quantify uncertainty of the latent physical process. The spatial model includes event effects (moment magnitude, distance, source location, etc.) and site effects which are imposed on all of the parameters of the data density, to model the spatial variation of the underlying process. The new maps showing the spatial variation of PGA, SA, and Predominant frequency, HVSR-amplification obtained from Horizontal to Vertical Spectral Ratio (HVSR) approach have been produced. A new hazard estimate will enable a more optimal earthquake resistant design of structures as well as urban planning. The results are expected to apply in other urban areas in Iceland with similar geology.

Spatial Incoherency Analysis of Seismic Ground Motions from 2014-Argostoli Earthquake Dense Array

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In seismic soil-structure interaction studies, the common practice in Civil Engineering is to consider a uniform movement of free field at any point on the ground surface. However, that assumption is not completely realistic since the seismic ground motions can vary spatially due to wave passage effects, dispersions and reflections of wave propagating in the random heterogeneous media and site effects. Therefore, in order to increase the security of buildings and equipment, it is necessary to do the analyses of seismic soil-structure interactions in the most realistic way. This can be achieved by taking into account the spatial variability of seismic ground motions.

The spatial incoherence of seismic ground motions due to dispersions and reflections of waves can generally be modelled in such analysis by a coherency function in frequency domain. Several models of coherency function (empirical and semi-empirical) are presented and widely used in the literature. However, those coherency models cannot be applied to all different types of soil because they strongly depend on the properties of the sites where the seismic signals were recorded.

The work presented in this paper is the result of the statistical analysis of spatial variability of seismic ground motions from experimental data measured at Argostoli dense array (Kefalonia island, Greece) for the earthquakes in February 2014 (few days after a main shock of M_w=6.0). For such analysis, one hundred earthquake events were selected from several thousands of events recorded. The spatial coherencies for small separations (from 10m to 100m) were estimated from the strong motion window of earthquake signals and then compared to the existing coherency models in the literature to discuss their limitations in soil-structure interaction applications.

Magnitude, Region and Site-specific Spectral Value Correlations and Conditional Mean Spectra

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The observed correlation of total-residuals of horizontal peak spectral acceleration across spectral time periods is empirically modeled and used in estimating a conditional mean spectrum, in vector-valued PSHA, and in time history selection for dynamic analysis of structures. Although the total-residuals are known to be GMPE, dataset, region, distance and magnitude dependent, the total-residual correlation models were assumed not to be due to insufficient strong motion data to explore such dependencies. Using the RESORCE and NGA-West2 strong-motion datasets we review this ergodic assumption. Initially the between-event correlations are found to be magnitude dependent, which can be partially ascribed to differences between M<5.5 and M ≥ 5.5 events in terms of corner-frequency and role of high frequency attenuation. However the total-residual correlation model is controlled by the within-event correlations primarily because the within-event variance is much larger than the between-event variance, thus making it magnitude independent. To overcome this limitation we separate the between-station variance from the aleatory within-event variance and reduce it to an event-station corrected variance which is comparable in size to between-event variance. The resulting event-site corrected residuals and their correlations across spectral accelerations by construction are only path dependent, and are found to be region dependent possibly due to the regional differences in distance-decay of strong motion. As an example, the total-residual correlation models now estimated using the magnitude dependent between-event, region dependent event-station corrected correlations are used along with between-station residuals to derive a magnitude, region, and site-specific conditional mean spectra for 4 stations in Italy and Turkey.

Sensitivity of Annualized Earthquake Loss Estimates in California to Site Amplification

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