A preliminary study on

The influence of building clusters on the variability of the ground motion during earthquakes

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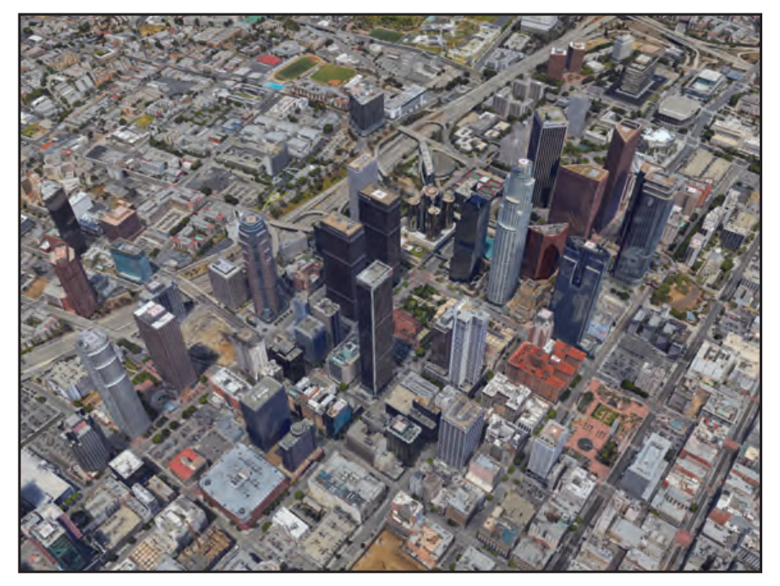
Abstract

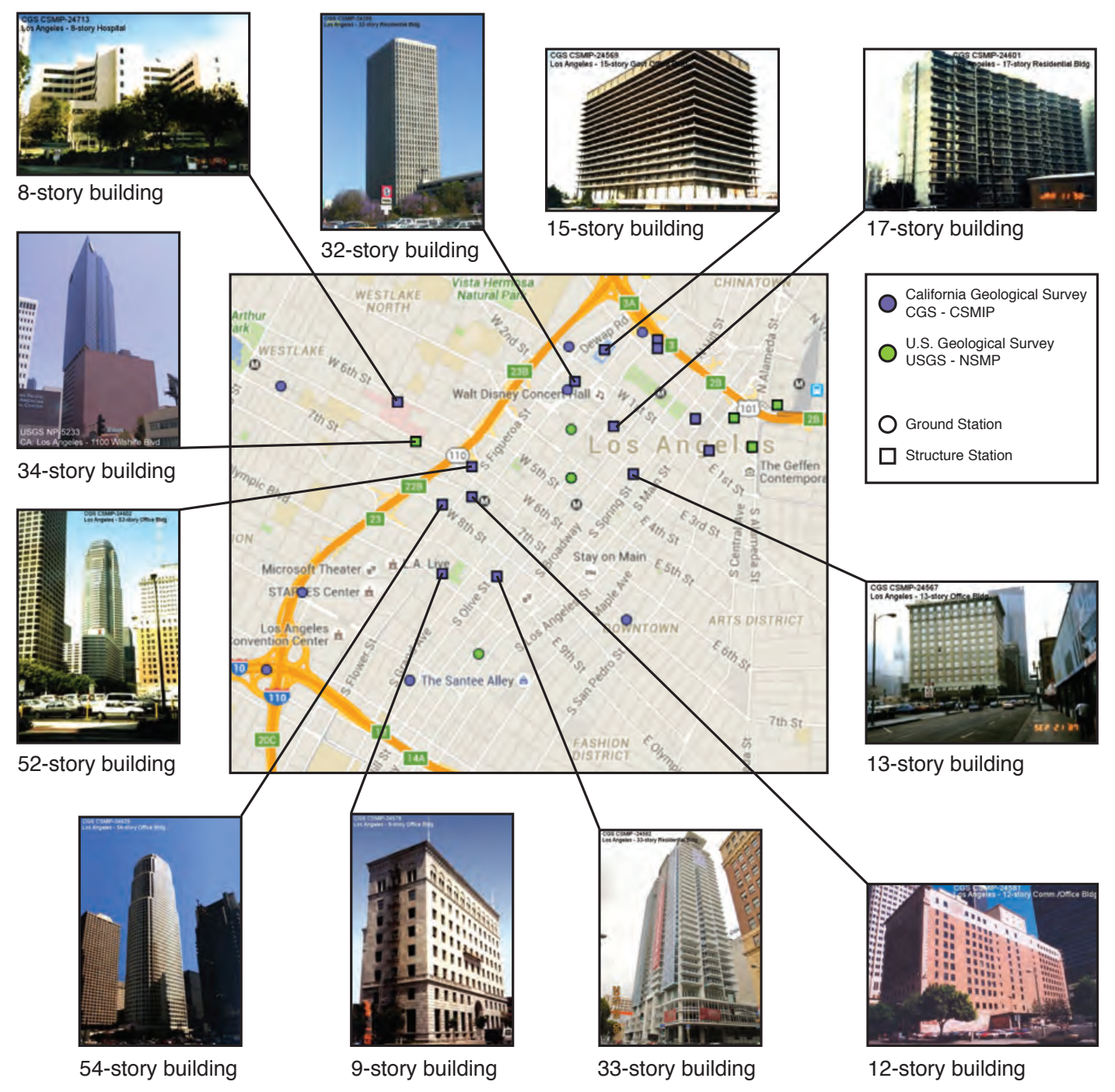
Spatial variability and ground motion uncertainty during earthquakes can significantly influence both our interpretation of seismic data and the behavior of structures and infrastructure systems, especially those susceptible to differential motions, or those that benefit from more diffuse wave-fields. Spatial variations typically observed in ground motions are mostly the consequence of wave interferences, refraction, scattering and other phenomena resulting from the three-dimensional nature of the crust, the surface topography, site conditions, and heterogeneities in the transmitting media. Also influential but regularly ignored is the presence of the built environment, especially in the case of densely urbanized regions. We are interested in investigating the extent to which the presence of building-foundation systems can modify earthquake ground motions and contribute to their variability. We present preliminary results from a series of three-dimensional simulations using a finite element software for seismic wave propagation problems, with and without the presence of simplified building (block) models. We explore the level of influence exerted by the built environment on the ground motion through comparisons between the simulations with building models and equivalent simulations without them. This is the initial step of a project in which we seek to identify parameters that can serve as proxies to characterize site-city interaction effects.

Motivation and Goals

The spatial variability of the ground motion at regional and local scales is an important factor in the assessment of potential losses during seismic events, the estimation of earthquake effects, and the interpretation of seismic data. In densely urbanized areas (Fig. 1), the interpretation of strong motion records from instrumentation networks (Fig. 2) is likely biased by the presence of the built environment. We are interested in quantifying such bias. To that end, we use numerical modeling and simulation techniques (and have plans for a later analysis of strong motion records) to identify and quantify the relevance of the effects of site-city interaction (SCI) phenomena on changes introduced to the ground motion and the dynamic behavior of buildings.



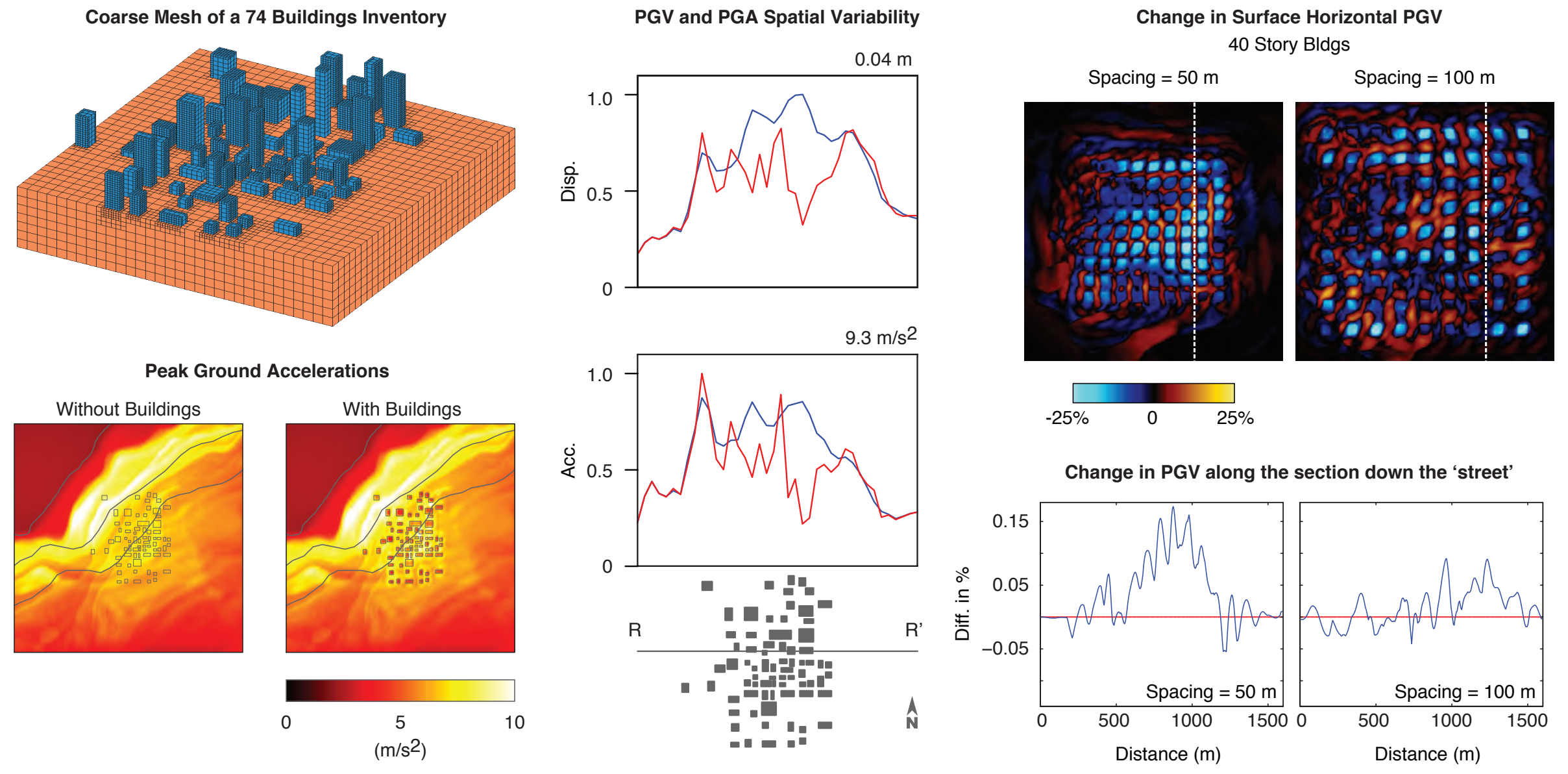
▲ **Figure 1.** Perspective view of the Los Angeles downtown financial district.



► **Figure 2.** Location of instrumented buildings and ground motion stations in downtown Los Angeles.

Background

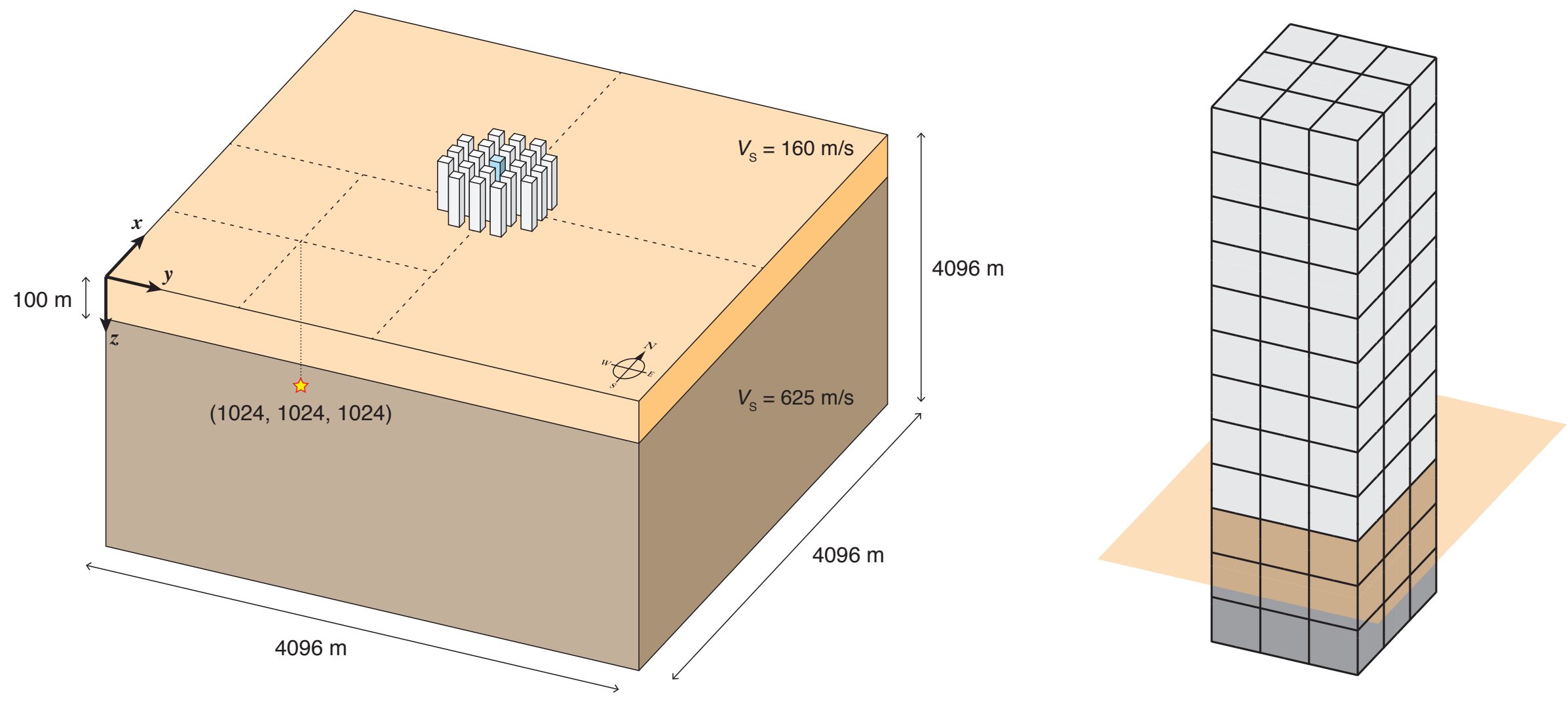
In previous work (see the Relevant References section) we have presented results from implementing modeling alternatives to simulate the dynamic behavior of multiple soil-structure interaction (SSI) systems coupled with local and regional earthquake ground motion simulations. Such efforts have revealed changes in the ground motion and the response of individual structures due to the presence of large building inventories (Fig. 3, left and center). Simulations of a heterogeneous set of buildings near the edge of a soft sedimentary basin, for instance, revealed changes in wavetraveling patterns, with significant influence on the spatial variability and amplitude of the peak ground response. Simulations with regular, homogeneous building clusters have also confirmed this (Fig. 3, right).



▲ **Figure 3.** Sample results from 3D simulations of a realistic city with 74 buildings at the edge of a basin (left and center), and a set of regular 9×9 40-story building cluster for two different spacing configurations showing the effects of SCI on the variability of the ground motion in terms of peak ground response for sections across the 'cities' and 'down-the-street' (right).

Models and Experimental Setup

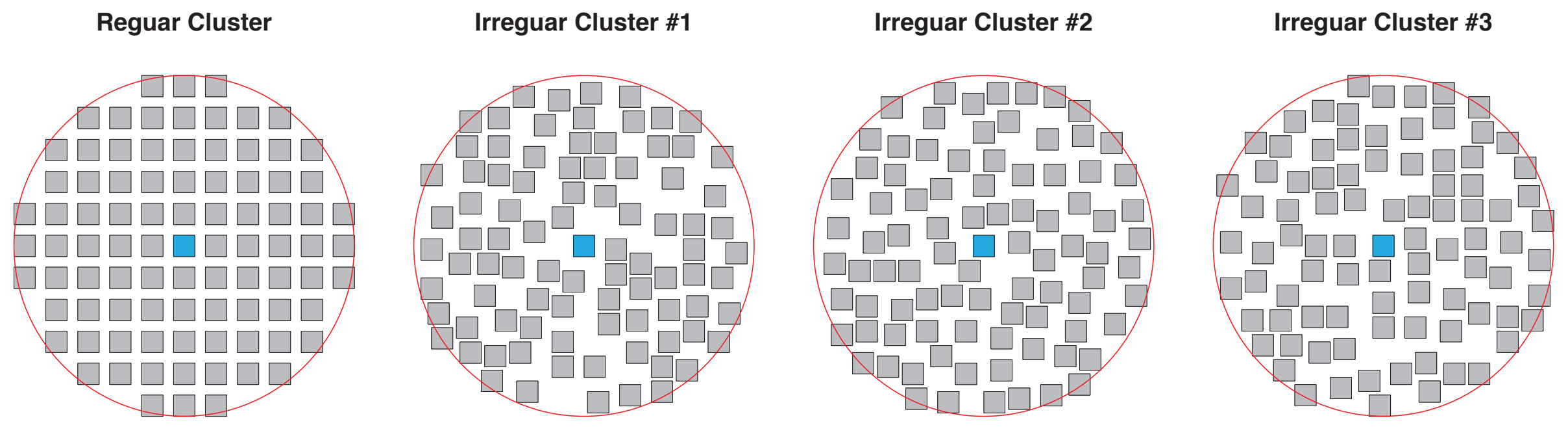
We designed a series of experiments consisting of three-dimensional domain of size 4 km × 4 km × 4 km, with a thin layer over a half-space, an artificial city located at the center of the domain, and a point source beneath the center of the southwest quadrant at a depth of 1 km. The city itself consists of buildings represented with block models for both the structure and the foundation. The models are calibrated to satisfy the dynamic translational models of structures of similar dimensions and height. The simulations are done using Hercules, a finite element parallel code for wave propagation problems.



▲ **Figure 4.** Schematic representation of the models used. Left: modeling domain and location of the city and the point source. Right: finite-element block models representing the buildings in the city.

Building Clusters

We classify building clusters in two forms, based on the type of buildings, and based on their distribution. The type of buildings can be homogeneous or heterogeneous. Homogeneous clusters are composed of identical buildings, whereas heterogeneous clusters are composed of buildings with different heights and sizes. In terms of the distribution, the clusters can be regular or irregular. Regular clusters have buildings distributed on a rectangular grid. Irregular clusters, on the other hand, are randomly distributed. For now, we only consider homogeneous clusters, in both regular and irregular arrangements (Fig. 5).

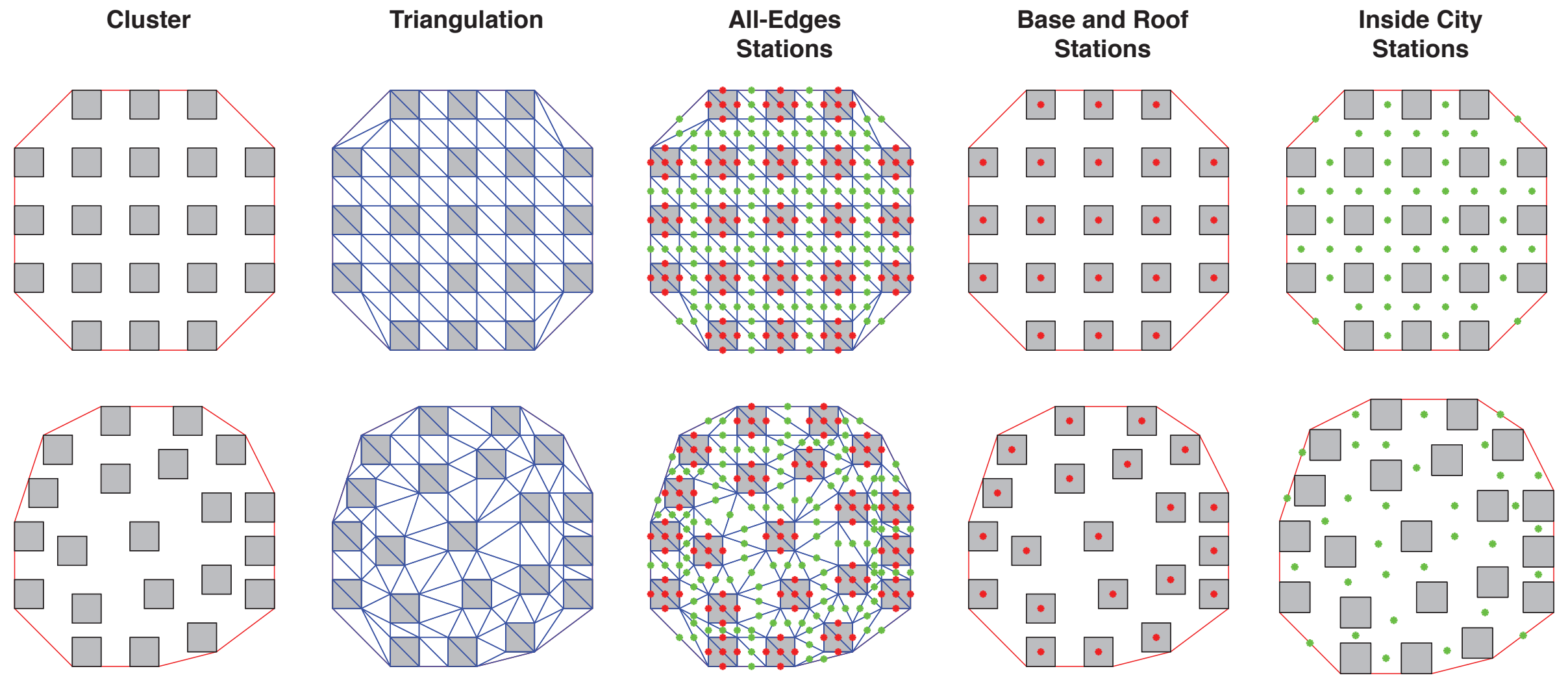


▲ **Figure 5.** Plan view of a regular cluster and three irregular ones, each composed of 89 buildings distributed within a circular area. In each case, all buildings are identical, with an area of 24 m × 24 m, a height of 60 m, and 8 m deep foundations.

In order to generate the clusters, we developed an algorithm that distributes building models in a circular area randomly, while guaranteeing no overlaps and a given nominal separation according to an empirical rule we propose to characterize the average separation of buildings. In the case of the regular cluster in Fig. 5, the buildings separation is 12 m everywhere. Irregular clusters #1–3, also have nominal separations of 12 m. They all have in common the location of a control building at the center of the cluster, which serves as reference.

City Instrumentation

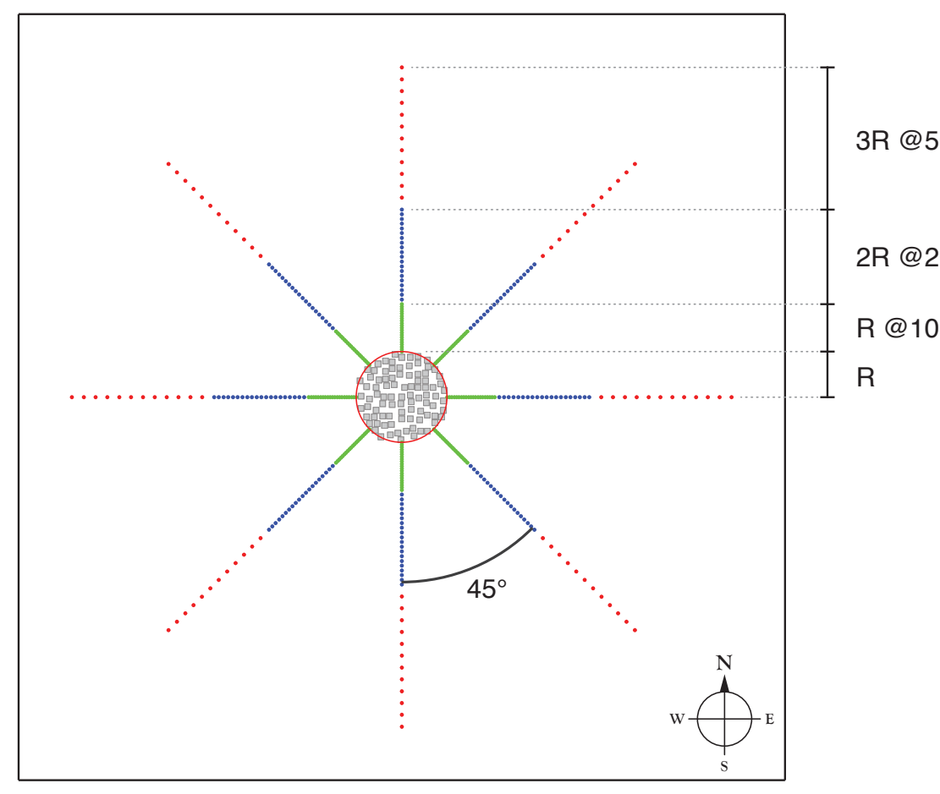
We also developed an algorithm to instrument the numerical models with observation points playing the role of strong motion stations. The algorithm is based on a triangulation process that adapts a mesh to the geometry of the city. The algorithm then selects the location of the stations at the center of each building, which are used for roof and base stations, and then uses a rule based on the nominal distance that characterizes the cluster to pick a subset of stations to measure the ground motion in the city, i.e., between the buildings (Fig. 6).



▲ **Figure 6.** Steps in the algorithm developed to instrument the city.

Ground Instrumentation

To measure the effect of the building clusters on the ground motion outside the city, we also instrumented our models with sets of stations, proportionally spaced away from the city and in reference to the radius of the urbanized area (Fig. 7).

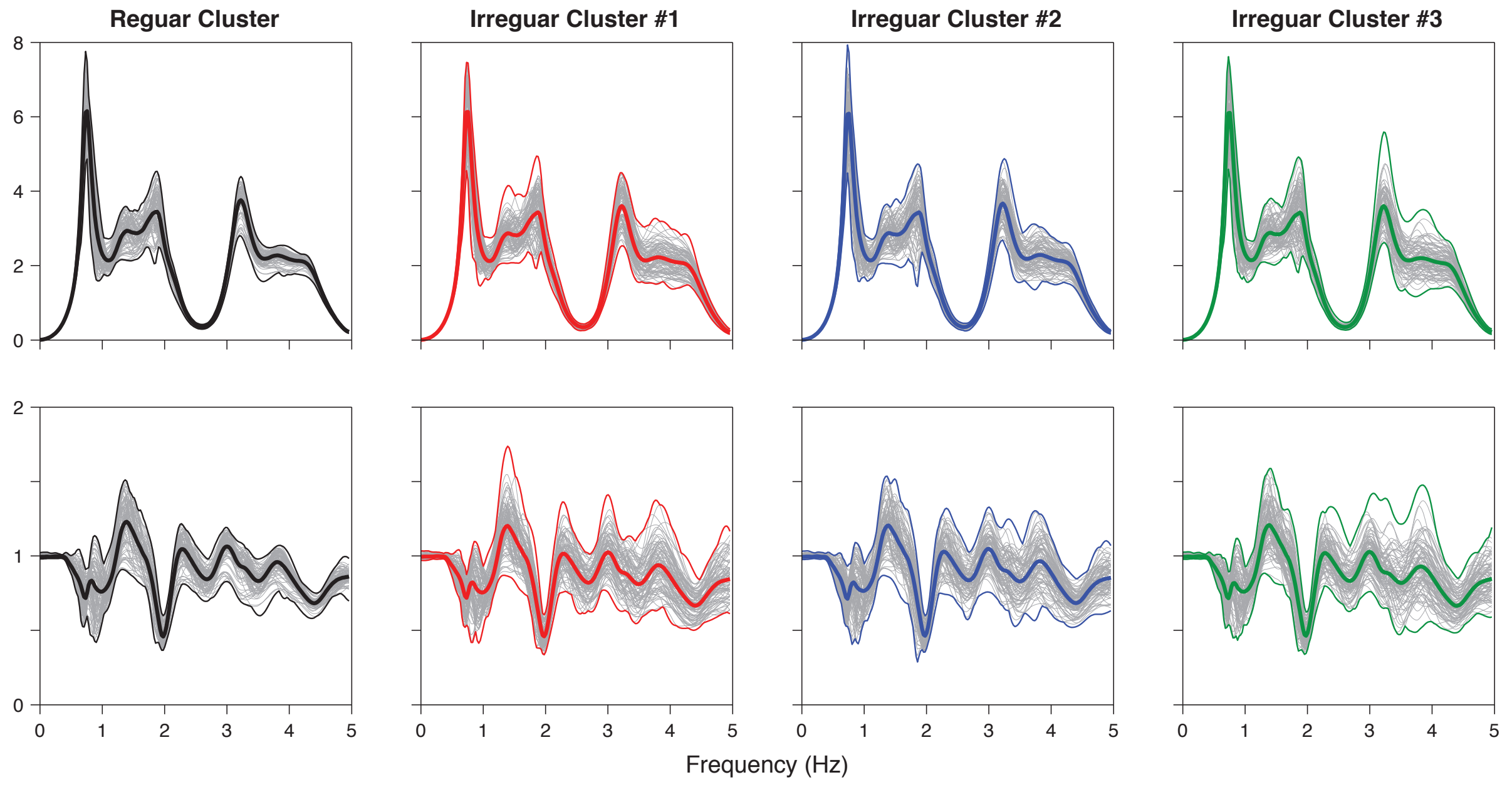


◄ **Figure 7.** Instrumentation of the surface outside the city using eight longitudinal arrays, oriented at different azimuths with a 45° spacing. Each array consists of three sets of stations spaced at 10, 20, and 50 m, along distances equal to 1, 2, and 3 times the radius of the city area.

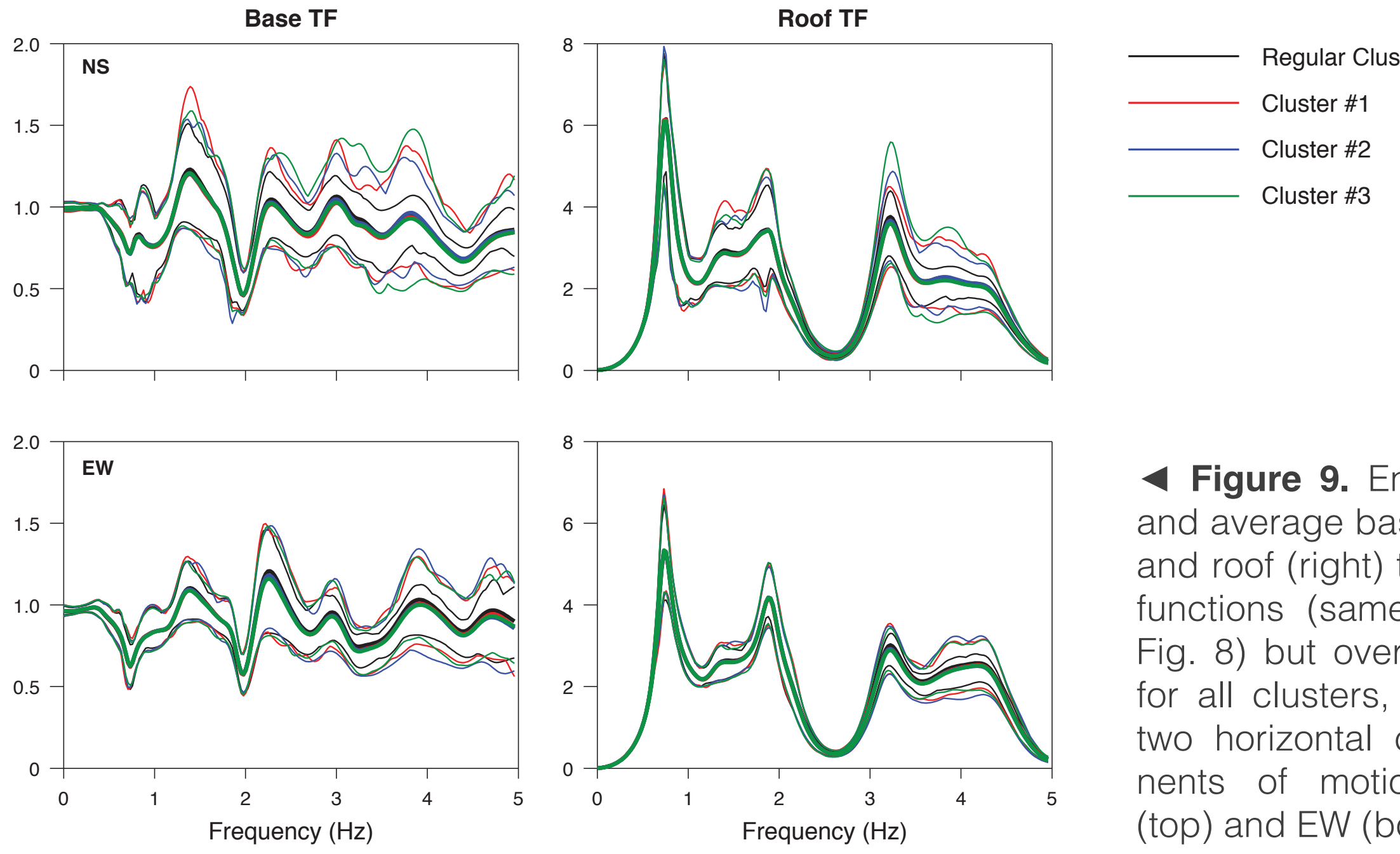
Results

We study the effects of the clusters on both the dynamic behavior of the buildings, and on the ground motion itself, inside and outside the city. We focus here on the four 89-building clusters shown in Fig. 5, and present results in the form of Fourier spectra transfer functions with respect to the free-field response of the model without the presence of the clusters to illustrate the variability the latter introduce to the system.

Changes in the Buildings Behavior

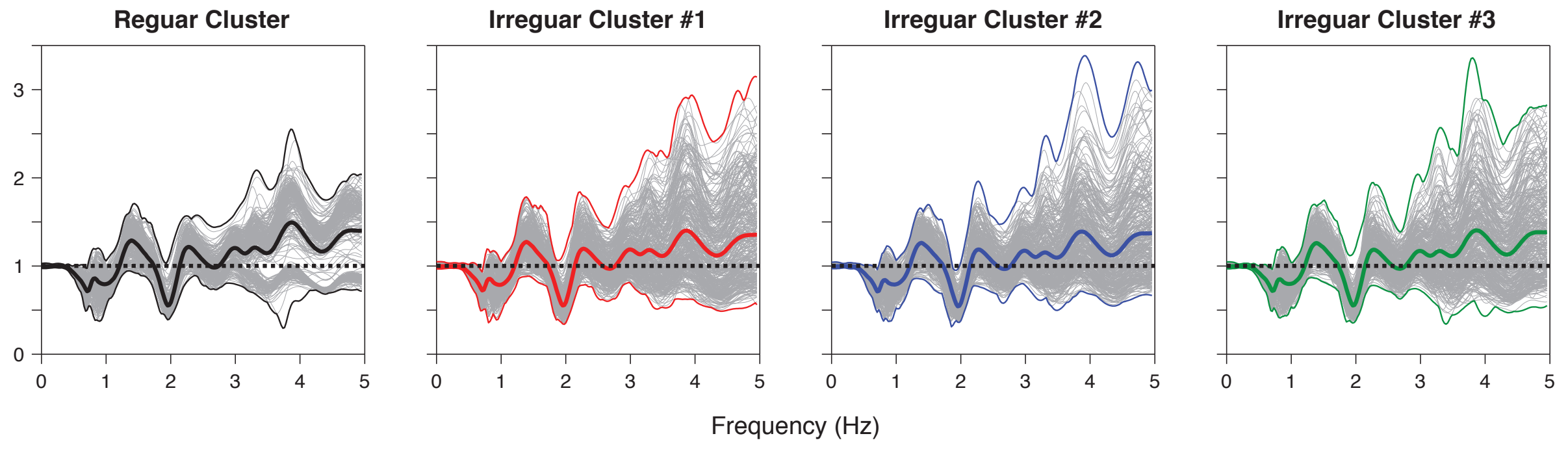


▲ **Figure 8.** Roof (top) and base (bottom) transfer functions with respect to the free field response for all buildings in each cluster (gray lines), in the NS (x) direction. The upper and lower envelopes are shown in color (thin lines), along with the averages (thick lines).



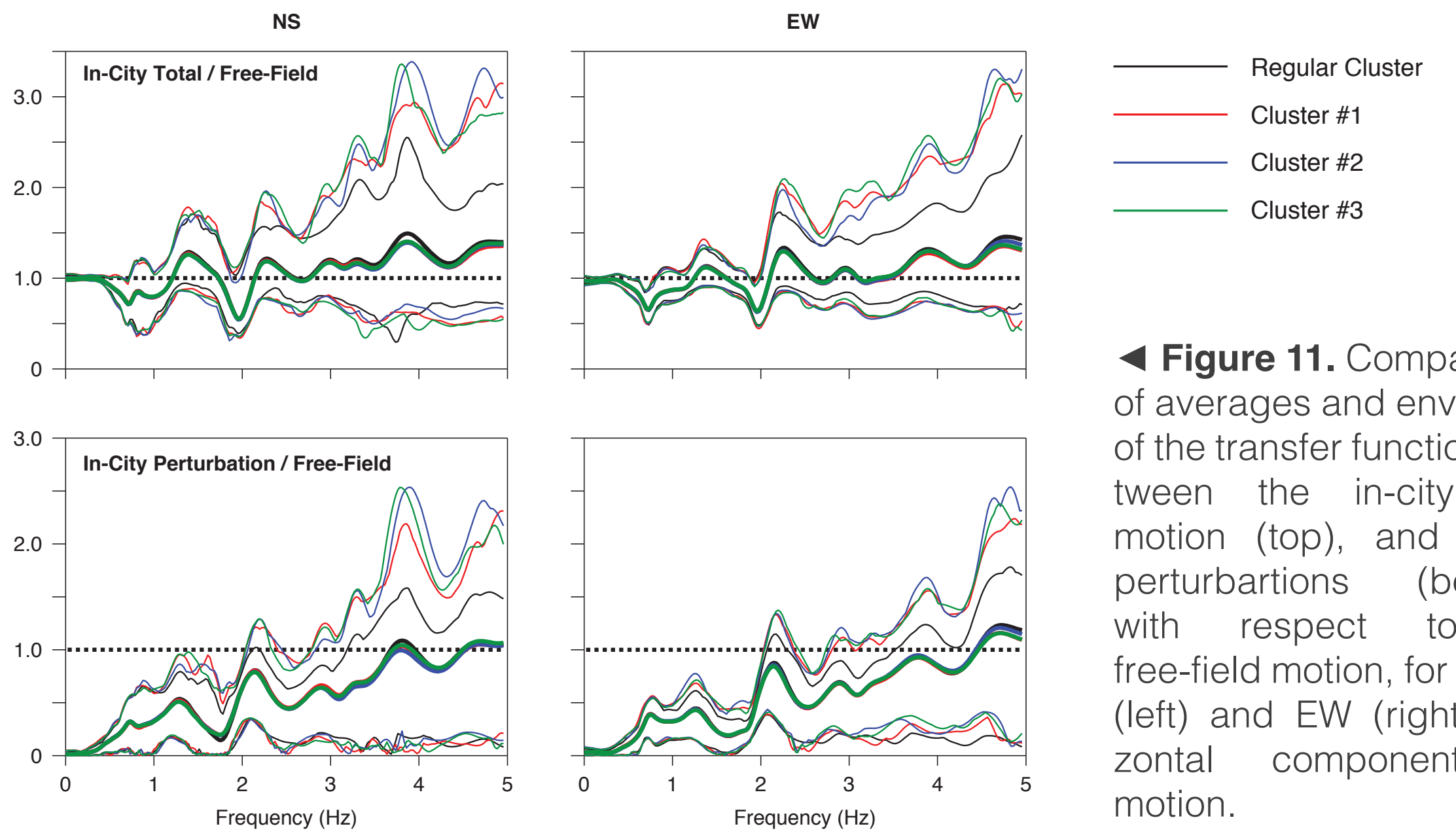
◄ **Figure 9.** Envelope and average base (left) and roof (right) transfer functions (same as in Fig. 8) but overlapped for all clusters, for the two horizontal components of motion, NS (top) and EW (bottom).

Changes in the Ground Motion Inside the City



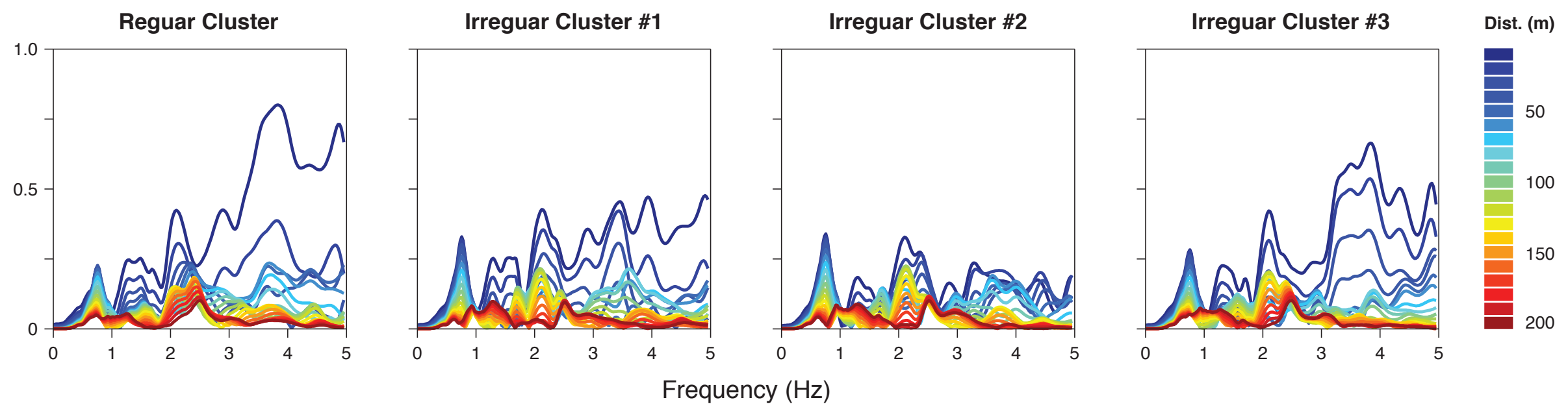
▲ **Figure 10.** Fourier transfer functions between the ground motion inside the city and the corresponding free-field motion for the model without the city, in the NS component, with envelopes and averages for different 89-building clusters.

Results (cont.)

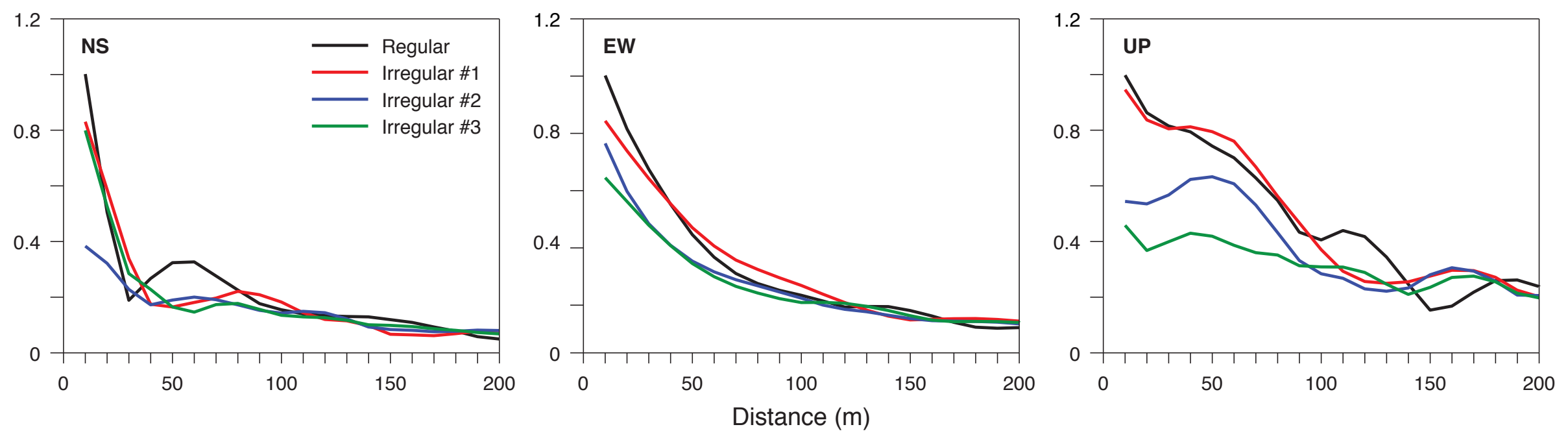


◄ **Figure 11.** Comparisons of averages and envelopes of the transfer functions between the in-city total motion (top), and in-city perturbartions (bottom), with respect to the free-field motion, for the NS (left) and EW (right) horizontal components of motion.

Change in Ground Motion Outside the City



▲ **Figure 12.** Transfer functions between the Fourier amplitude spectra of the perturbations observed along the West array (NS component) with respect to the Fourier amplitude spectra of the free field, obtained at the same locations for the model without the clusters.



▲ **Figure 13.** Decay in peak perturbation velocities along the West array normalized with respect to the perturbation observed at the "city limit", for all three components of motion.

Conclusions and Ongoing Work

While these are only initial results, they reveal a few interesting facts about the effect of the clusters on the ground motion and the buildings dynamics. First, we note that structure-soil-structure interactions are significant. They alter the individual soil-structure interaction systems. Second, we highlight the effects on the ground, both inside and outside the city. It is of interest to note that regular clusters have slightly less impact than irregular ones, but overall, both envelopes and averages of changes observed with respect to the free field, are in good agreement, with the changes being greater at the higher frequencies. We are currently working on other cluster models with variable nominal spacing and other types of buildings, and plan to also study heterogeneous clusters. We hope to be able to identify correlations between the nominal spacing and the amount of variability introduced to the ground and building responses, and to correlate these to the properties of the cluster and the site conditions.

Acknowledgements

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