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Built environment response during earthquake: site-city interaction and clustering effect of buildings

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On the scale of the city, seismic risk analysis requires assessment of seismic ground motion, including site effects, and of structural response. These ingredients are essential to implement management strategies and to reduce human and economic losses. These two elements are often analyzed independently, i.e. ground motion is analyzed without including the urban elements (structures and infrastructures) as secondary sources contaminating the seismic input motion, and the structures are considered as stand-alone constructions, ignoring possible interactions with their urban environment. Nonetheless, it has long been known that surface heterogeneities can significantly alter incident wave fields by amplifying the seismic ground motion in the presence of site effects, or by modifying the boundary conditions of the system. For example, the impedance contrast between soil and foundation is at the origin of the kinematic soil-structure interaction, that introducing scattering and resonant phenomena over the length of the foundations that can pollute the incident wave-field. On the other hand, waves generated by structure vibrations, due to inertial soil-structure interaction, and diffracted back into the ground, are superimposed upon the seismic input ground motion. This is not a local phenomenon, observed at distances of over 50 km.

This effect is not negligible and raises the question of how the response of the sedimentary sites and structures can be polluted by the redistribution of seismic energy on the surface of the city. We called first this phenomenon the Site-City Interaction and for close structures, structure-soil-structure interaction may be considered as the ultimate effect of this coupling. Indeed, structure-soil-structure may change the dynamic response of the structures themselves, particularly by splitting their fundamental frequency, i.e. generating monochromatic beats in the time domain structure response. This observation has been confirmed by centrifuge tests and numerical modeling and by numerical modeling applied to building pair during the 2002 Molise earthquake. At the scale of a city composed of a multitude of resonant structures, it is easy to imagine strong coupling between the multiple structures and the soil, redistributing the incident seismic energy. This raises questions concerning the validity of seismic ground motion assessments in urban areas, the understanding and interpretation of site effects observed during earthquakes and the design capacity of structures if urban environment effects are ignored. This group effect has already been described in physics through the concept of metamaterials. Applied to geophysics, these metamaterials cause a redistribution of seismic wave energy, such as forbidden frequency bands, for example, or ‘bandgaps’.

The purpose of this abstract is to present a state-of-the-art of the multi-coupling effect related to the Site-City observation, including meta-materials and to discuss new observations reported in Grenoble (France) during an earthquake as consequences of the dynamic coupling within a building cluster, and having an non-negligible impact on the building response.