Numerical modeling of liquefaction seismic risk analysis

Strong ground motions can trigger soil liquefaction that will alter the propagating signal and induce ground failure. Important damage in structures and lifelines has been evidenced after recent earthquakes such as Christchurch, New Zealand and Tohoku, Japan in 2011. Accurate assessment of the structures' seismic risk requires a careful modeling of the nonlinear behavior of soil-structure systems. In geotechnical engineering, seismic risk analysis is described as the convolution between the natural hazard (input seismic motion) and the vulnerability of the system (characterization of soil and structure). A schema of the thesis framework is shown in Figure 1. This thesis arises as a contribution to the numerical modeling of soil nonlinearity and, in particular, liquefaction evaluation and mitigation.

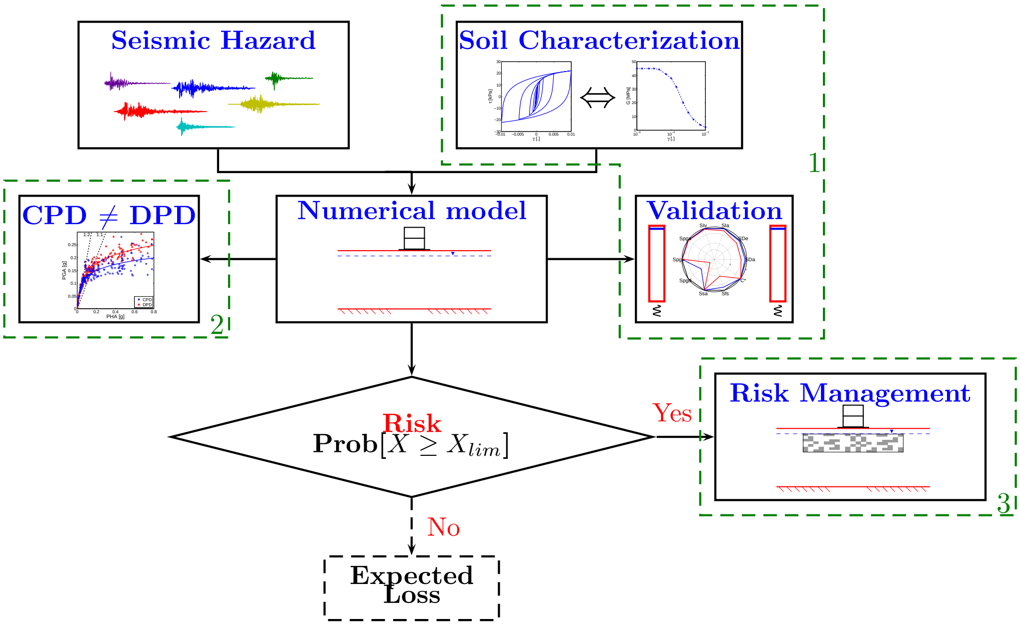

Figure 1: Schema of the thesis framework

For this purpose, the finite element method (FEM) in time domain is used as numerical tool. The 2D plane-strain model used consists of a reinforced concrete building with a shallow rigid foundation standing on saturated cohesionless soil. As the initial step on the seismic risk analysis, the first part of the thesis is consecrated to the characterization of the soil behavior and its constitutive modeling. Special attention is given to the model's sensibility to the numerical parameters. Later on, the model is validated for the 1D wave propagation with the recordings on a japanese site. These results are issued from the participation in the international benchmark PRENOLIN. Even though very few laboratory and *in-situ* data were available, the model agreed well with the measurements for the blind prediction.

The second part, concerns the numerical modeling of coupling excess pore pressure (Δp_w) and soil deformation (i.e. effective vs. total stress analysis). To assess its effects, a coupled (CPD) model was compared to a decoupled (DPD) one where initial conditions were identical and differences were only due to the generation of Δp_w. First, the effect on the ground motion was analyzed by 1D wave propagation. This part contains material from an article published in *Acta Geotechnica* (Montoya-Noguera and Lopez-Caballero, 2014). Afterwards, a 2D soil-structure interaction (SSI) model was studied and the effect of coupling was then evaluated in the structure's settlement and seismic performance. The applicability of CPD and DPD models was found to depend on both the liquefaction level and the SSI effects.

In the last part, an innovative method is proposed to model spatial variability added to the deposit due to soil improvement techniques used to strengthen soft soils and mitigate

liquefaction. Innovative treatment processes such as soil-mixing, bentonite permeations and bio-grouting, among others have recently emerged. However, there remains some uncertainties concerning the high degree of spatial variability introduced in the design and its effect of the system's performance. This *added* spatial variability can differ significantly from the *inherent* or natural soil variability thus, in this thesis, it is modeled by coupling FEM with a binary random field generated by an auto-regressive code. The efficiency in improving the soil behavior related to the effectiveness of the method measured by the amount of soil changed was analyzed. Two cases were studied: the bearing capacity of a shallow foundation under purely cohesive soil and the liquefaction-induced settlement of a structure under cohesionless loose soil. The latter, in part, contains material published in *GeoRisk* journal (Montoya-Noguera and Lopez-Caballero, 2015). Due to the interaction between the two soils, an important variability is evidenced in the response. Additionally, traditional and advanced homogenization theories were used to predict the relation between the average efficiency and effectiveness. Because of the nonlinear soil behavior, the traditional theories fail to predict the response while some advanced theories which include the percolation theory may provide a good estimate. Concerning the effect of added spatial variability on soil liquefaction, different input motions were tested and the response of the whole was found to depend on the PGV of the input motion.

Keywords: Liquefaction · Site response · finite element model · nonlinear soil behavior · spatial variability · binary random field

References

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