Nonlinear Site Response Simulations in Chang-Hwa Region during the 1999 Chi-Chi Earthquake, Taiwan

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Soil dynamics associated with earthquakes has been a big issue for the researches in brgm since decades. Through the development of its own numerical tools (e.g. *CyberQuake*) or through its long time collaboration with Ecole Centrale Paris and other scientific partners, brgm is one of the leader organisation in the numerical modelling related to this field, including the modelling of complex features of non-linear soil behavior under seismic motion.

One of the applications of the non-linear multi-kinematics dynamic model implemented in *CyberQuake* software is presented in Bernardie, Foerster and Modaressi (Soil Dynamics and Earthquake Engineering, 2006), analysing the seismic response at a site located within the Chang-Hwa Coastal Industrial Park during the 1999 Chi-Chi earthquake in Taiwan. Indeed, several observations witness the non-linear seismic soil response in sediments during the earthquake. In fact, large settlements as well as evidence of liquefaction attested by sand boils and unusual wet ground surface were observed at some sites.

In this analysis, computed NS, EW and UP ground accelerations obtained with this model under undrained and two-phase non-linear (i.e. soil skeleton saturated by water) assumptions, are in good agreement with the corresponding accelerations recorded at seismic station TCU117 (a station located on a soft soil about 3 km from the studied site), either for peak location, amplitudes or frequency content. Moreover, both non linear simulations and especially the two-phase one, are able to reproduce the liquefaction state (shear modulus or Vs reduction) observed for the saturated sandy layers in the 1.3-13.5m depth range. This range is in good agreement with the top 14m highlighted by the *in situ* geotechnical tests carried out after the earthquake and by the liquefaction potential analyses. A maximum vertical ground displacement of 25cm was also computed. This value is to be compared to the 33-45cm recorded in the area after the earthquake. Moreover, the computed shear wave velocity profile is very close to post-earthquake shear wave velocity profile measured by CPT and SPT techniques.

Finally, it is shown that in non-linear computations, even though a 1D geometry is considered, it is necessary to take into account the 3D kinematics (i.e. the three components of the input motion) when performing non-linear computations, and not only one horizontal component as it is often performed in practice, in order to account for the coupling existing between components at plasticity and thus, to obtain more realistic predictions.

As seen in this example, the (FEM) modelling methodology adopted by brgm is a powerful tool for investigating non-linear site effects during earthquakes. The combining of this methodology with a seismological analysis such as wave propagation simulation using a finite difference method from source to site is in progress, too.

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