Inelastic dynamic soil - structure interaction

Two of the most important problems in geotechnical earthquake engineering are treated in this dissertation: the seismic ground response and the response of single piles under seismic loading. Over the years numerous researchers have addressed the problem of seismic ground response and several methods have been proposed for site response analysis, including: • equivalent-linear models, • nonlinear phenomenological/empirical 1-D models, and • advanced 2-D constitutive models based on plasticity theory. Due to the simplicity and numerical stability the equivalent-linear method is even nowadays the most widely used method for seismic ground response analyses. However, this method is not free of limitations: the use of a frequency-independent factor for the determination of "effective" strain leads to a spurious filtering of high-frequency components and an overestimation of the acceleration in case of strong shaking (Constantopoulos et al., 1973; Yoshida et al., 2002). A more accurate simulation of the real soil behavior under stronger shaking can be achieved using simplified 1-D nonlinear constitutive models. Despite the increased accuracy of the 1-D nonlinear models, most simplified nonlinear models overestimate damping as they utilize the Masing criterion for unloading/reloading. Furthermore, the often use of the hyperbolic backbone curve results to a spurious "trimming" of accelerations. The approximate extension of these models into 2 dimensions presents difficulties. To fill this gap advanced 2-D constitutive models based on theory of plasticity have been developed. Although, these models are the most reliable in description of the 2-D nonlinear behavior of soil, they are difficult to be applied in everyday practice because of the usually numerous parameters required. In this dissertation a new phenomenological nonlinear constitutive model proposed by (Gerolymos (2002), capable of simulating complex nonlinear characteristics of the dynamic response of soil in 1 dimension, is calibrated and validated against several experimental results. Then, it is utilized for a thorough parametric study of the nonlinear seismic response of soil deposits. The nonlinear seismic response of single piles is the objective of the second part of this dissertation. Nonlinearity refers not only to the pile surrounding soil but also on the bending behavior of the pile itself. The hysteretic model BWGG is now used for the simulation of the soil resistance as a function of the pile deflection at each depth. The calibration of the constitutive model is achieved by exploitation of several experimental results from the literature: in-situ full-scale experiments and small-scale centrifuge tests. Following the calibration, the model is verified by comparison with established analytical solutions. Current seismic design of bridge structures is based on a presumed ductile response. A capacity design methodology ensures that regions of inelastic deformation are carefully detailed to provide adequate structural ductility, without transforming the structure into a mechanism. Brittle failure modes are suppressed by providing a higher level of strength compared to the corresponding to ductile failure modes. For most bridges, the foundation system may be strategically designed to remain structurally elastic while the pier is detailed for inelastic deformation and energy dissipation. This approach is intended to avoid the difficulty of post-earthquake inspection and the high cost associated with repair of a severely damaged foundation. Essentially-elastic response of the foundation is usually ensured by increasing the strength of the foundation above that of the bridge pier so that plastic hinging occurs in the pier instead of the foundation. However, several case-histories (especially from the Kobe 1995 earthquake) have shown that: (a) pile yielding under strong shaking cannot be avoided, especially with piles embedded in soft soils; and (b) pile integrity checking after an earthquake is a cumbersome, yet feasible task. In order to explore the nonlinear inelastic response of pile-column bridge systems and the influence of the pile inelasticity and soil-structure interaction on ductility demand, some preliminary parametric analyses are conducted. Emphasis is given in the inelastic response of the pile itself.