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Non linear Analyses for Site Response
Opinion Paper

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Current state-of-practice in evaluating the dynamic response of soil deposits and earth structures has relied heavily on the commonly used equivalent linear approach to model the nonlinear, strain dependent behavior of soils. One dimensional wave propagation response analyses are usually used to estimate soil surface ground motions for use as input to the design of structures. For earth slopes and for earth embankments, two-dimensional finite element response analyses are commonly used.

Inputs to these analyses include acceleration time histories at bedrock, and non linear material properties of the various soil strata underlying the site. Material properties include the dynamic shear modulus at low strain (which is estimated from measurements of shear wave velocities in the field), and relationships describing the variation of shear modulus and damping ratio with shear strain. For routine projects, these relationships are obtained from published literature on similar soils. Uncertainties in the dynamic material properties are usually estimated by using a range of shear wave velocities and specifying reasonable bounds on the ranges of published modulus and damping relationships. At high strain levels (between 2% and 10%), laboratory data in terms of the modulus reduction and damping are scarce and less reliable. In practice, these curves are usually extrapolated for use in site response analyses without a sound basis.

For sites located close to major active faults and subjected to strong ground shaking, for soft soil deposits with relatively low shear strength, and for liquefiable deposits, this opinion paper suggests that site response, liquefaction and deformation can be more appropriately estimated using recently developed fully nonlinear procedures. A three-dimensional cyclic plasticity soil model (Wang et al 1990) was used in such an approach. This model has been incorporated into the site response analysis (with multi-directional shaking) program SUMDES (Li et al, 1992). Computed site responses were compared with downhole recordings at Port Island, during the Kobe eartquake (Wang et al, 2001). A two-dimensional version of this model was implemented (Wang and Makdisi, 1999) into the two dimensional finite difference program FLAC (Itasca, 1998).

The model parameters are estimated based on the basic soil properties used in the equivalent linear analyses, and/or on interpretation of laboratory test results for monotonic and cyclic loading, as well as in-situ measurements (field SPT and shear wave velocity data). This bounding surface plasticity model is also able to simulate pore water pressure generation and liquefaction behavior during specified cyclic loading that is critical for deformation analyses of soil structures. A model simulation for an undrained cyclic torsional shear test on sand is presented in Figure 1. A summary of model details and its practical applications is provided in Wang et al (2004).

In current practice, two non-linear soil models are often used in the dynamic response analyses of soil structures: these are the Mohr-Coulomb (or bi-linear) model and the hyperbolic stress strain model. Both of these models have certain limitations in appropriately matching the shapes of the modulus reduction and damping curves published in the literature. Other nonlinear site response models are available that provide a better fit to the non-linear soil properties (e.g. D-MOD, MARDES, and others). The bounding surface plasticity model provides a better match to published relationships as shown in Figure 2. The model simulations provide a very good fit to the modulus reduction curves currently being used in equivalent linear analyses. Simulations of the damping curves show differences with published data at high strain levels above 0.1 percent. The higher damping from nonlinear model is a consequence of strength limitations that is not modeled in the equivalent linear approach. It is recommended that uncertainties in damping at high strain levels be explored to assess their accuracy and evaluate their impact on the results of site response studies during strong shaking.

Non linear analyses provide a more realistic approach for evaluating the impact of strong ground shaking on soft, and potentially liquefiable soils, and their effects on estimated ground motions at the surface of these deposits. It is the recommendation of the authors of this opinion paper that nonlinear analyses be encouraged and incorporated into the state-of-practice for evaluating site response, to better understand the uncertainties in nonlinear soil behavior, and assess their impact on site response.

References

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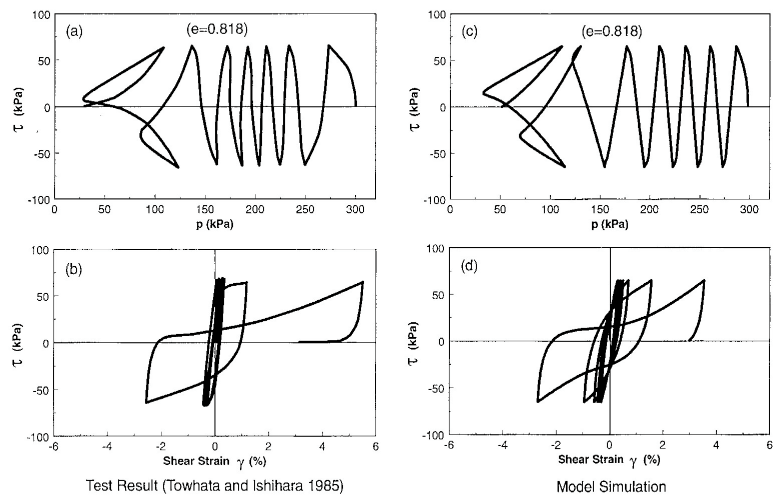

Figure 1. Model Simulation of Undrained Cyclic Torsional Shear on Toyoura Sand

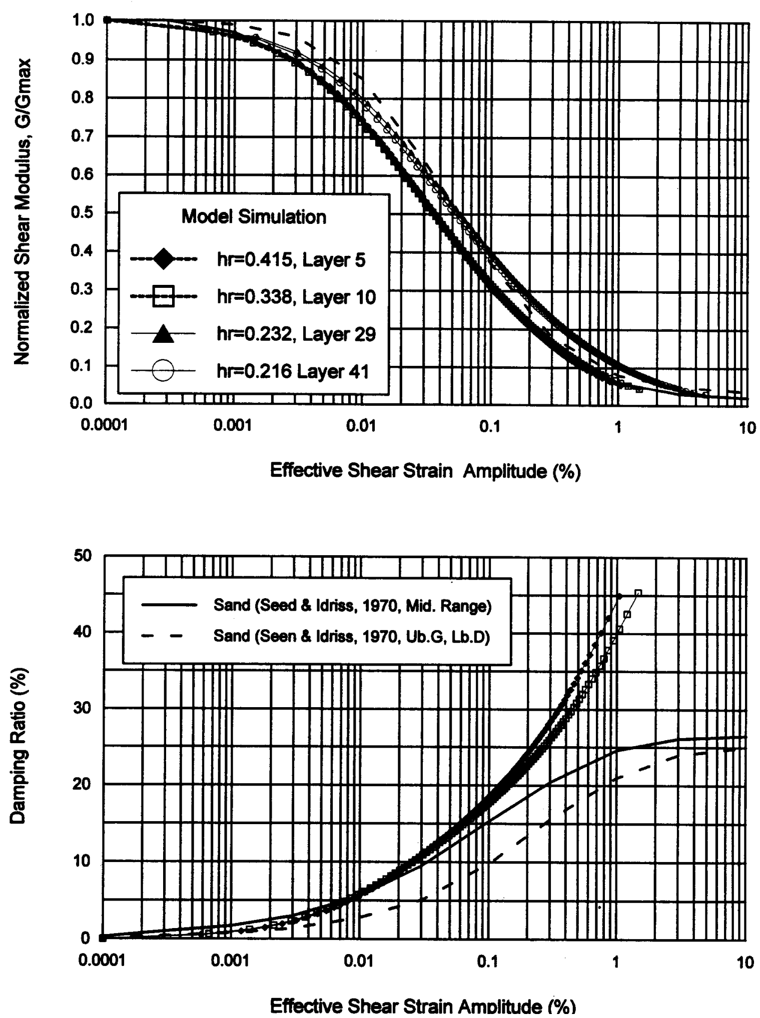

Figure 2. Model Simulation for Normalized Modulus and Damping Ratio.