Opinion Paper prepared for the International Workshop on the Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response

by

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This paper presents the opinions of the author regarding key questions in the field of nonlinear property determination, modeling, and use. The discussion is framed by the research interests of the author in the general area of seismic site response and, more specifically, the topics of site response analysis and site classification for the purpose of building-code development.

The study of site response has received much attention over the last few decades. However, there are still important issues related to nonlinear soil properties that have yet to be addressed. Among these, the adequate modeling of uncertainty is a key issue to be resolved in order to make current site response methodologies compatible with probabilistic seismic hazard analysis. Typically, site response analyses are performed using deterministic methods with given nonlinear soil properties. Deterministic site response analyses, however, do not account for the potential change in ground motion uncertainty (e.g. standard deviation values of ground motion parameters) associated with wave passage through the soil. An alternative is to perform a large number of deterministic analyses in which both input motion and soil properties are varied according to prescribed statistical functions (e.g. a Montecarlo approach).

To perform non-deterministic analyses, a better understanding of nonlinear soil properties is necessary. In particular, non-linear soil models should include an adequate characterization of uncertainty. The soil models should reflect uncertainty associated with material behavior (aleatoric variability) separately from estimation of modeling uncertainty (e.g. epistemic uncertainty introduced by the selection of the model and the testing methodology). The parameters within a soil model should be defined statistically (e.g. mean values, standard deviations, and covariance matrices). A good example of such a model is given by the recent Ph.D. work of Darendeli at the University of Texas at Austin (Darendeli 2001).

Site response analyses can be performed either using relatively simple models or with more elaborate numerical methods. We can consider the equivalent linear model (where soil nonlinearity is expressed in terms of damping and modulus reduction curves) a "simple" model and a nonlinear dynamic constitutive model implemented in Finite Element codes an "elaborate" model. An important question is: how can we justify the use of the more elaborate models? The author's suggestion is that the models should be evaluated on the basis of how much they reduce modeling uncertainty. To achieve this, parameters in soil models must be defined statistically. Moreover, it is important that the statistical definition of soil properties includes a covariance matrix.

In addition to the issue of an adequate modeling of uncertainty, potential biases can be introduced in an analysis due to the use of a poor nonlinear soil model. Two factors that can contribute to such a bias include:

- *Effect of confining stress on small-strain damping*. This issue is particularly important for deep soil deposits (e.g. basins where a strong impedance contrast is not found in the upper 100 m). The selected small-strain damping value can significantly affect the results of a site response analysis. The effect of confining stress on small-strain damping is particularly important because of the large confining stresses at large depths (where strain values are bound to be small). The effect of soil disturbance is larger for small-strain properties due to the destruction of the soil's microstructure. Accurate measurements of small-strain damping for natural soils will likely have to be conducted using field measurements. Current research at Washington State University aims at the development of a triaxial testing machine that will operate within High Resolution X-Ray Computer Tomography (CT) equipment. The use of CT while conducting tests is also a promising new tool to evaluate the effects of microstructure changes on small-strain soil properties.
- *Failure strain*. When modulus reduction curves are used in conjunction with a specific undrained soil strength value for soft clays, there is an implied value of strain needed to reach the undrained strength values. This parameter can control the response of soft clay sites subject to very intense motions (for example, near-fault ground motions), yet it is not always included in non-linear soil models.

In addition to issues related to the modeling of nonlinear soil properties, spatial variability of soil properties (both small-strain properties and nonlinear properties) is an important issue that is not necessarily resolved by laboratory testing.

In current practice, site response is commonly accounted for by using building codes. Various site classification schemes have been developed over the years for their implementation in seismic building codes. The site classification used in the current building code (IBC 2003) mainly makes use of the average shear wave velocity (e.g. small-strain properties) over the top 30 m of a soil profile. The potential effect of non-liner soil behavior is introduced through the intensity dependence of amplification factors for each site class. Although this is a robust classification scheme, alternative classification schemes (e.g. Rodriguez-Marek et al. 2001, *Earthquake Spectra*) which include a differentiation between soil types (e.g. different nonlinear soil properties) and soil depth have shown the possibility of reducing the epistemic uncertainty associated with site effects.

Despite the importance of characterizing the nonlinear behavior of soils, site-to-site variability is a larger contributor to uncertainty in site amplification factors than uncertainties in material nonlinear properties. Nonetheless, as the database of strong ground motions increases and our understanding of nonlinear soil behavior improves, modeling issues will become more important when evaluating trends in site response. With this introduction, the author considers that the following modeling issues are relevant to site response using simplified site classification schemes:

- *Characterization of variability***.** The variability of non-linear soil parameters within similar soil types has yet to be fully characterized. This variability will become increasingly important as the ground motion database grows. Eventually, a large ground motion database could yield a quantification of both intra-class and inter-class variability (in a similar manner to the intra-event and inter-event subdivision of uncertainty in attenuation relationships). The estimation of variability in non-linear parameters will contribute to an estimation of lower bound values for intra-class uncertainties. The eventual characterization of the variability of nonlinear soil properties across similar generic soil classes, however, will not stem from one research group but from a compilation of research results from various researchers/institutions. The identification of such data sets is important, as is a correct quantification of modeling uncertainty. The objective should not only be to reduce uncertainty, but also to characterize it appropriately.

- *Small-strain properties.* The importance of small-strain properties has been discussed above. Although current codes do not account for soils deeper than 30 m, studies by various researchers have shown that profile depth is an important parameter. An eventual inclusion of depth in building codes has to be preceded by extensive studies justifying its importance (or a statistical lack thereof). The result of site response analyses for deep soil sites is largely dependent on small-strain damping. Small-strain damping, in turn, is likely also a function of confining stresses. New soil models should address this issue.

An altogether separate issue that may merit discussion in this forum is the use of microtremor and ambient noise measurements to characterize the seismic response of a given site. The relevance of this issue lies in the fact that this method is gaining popularity for the measurement of average small-strain properties at a given site. These small-strain properties are important as they serve to anchor the modulus reduction curves, as well as for site classification purposes in building codes. The validity of microtremor measurements for purposes of site classification should be discussed within the geotechnical community.