INCORPORATING UNCERTAINTIES IN NONLINEAR SOIL PROPERTIES INTO NUMERICAL MODELS

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Advanced nonlinear constitutive models can capture important aspects of soil behavior and can exhibit superior accuracy compared to simpler models provided the material parameters are properly calibrated. However, the price paid by the analyst includes increased complexity, increased number of model parameters, and increased computational effort. It is also well known that advanced nonlinear constitutive models tend to be more sensitive to variations in the model parameters. The issue of model calibration is of paramount importance because how can any model be possibly calibrated if it is so sensitive to material parameters that any slight change in the values of these parameters could bring about so much variation in the predicted response? Many nonlinear models used in geotechnical engineering simulations, including those used by the author in the past and perhaps even those currently being used in OpenSees, have not been studied well enough for their sensitivity. Should we rely on their predictions without knowing how they would change with a slight variation in the input parameters? If they are so sensitive, then what is the point of calibrating them and how can these models even be possibly calibrated?

The author and his students have been using a systematic methodology for understanding the impact of uncertainties in nonlinear soil properties on the predictions of nonlinear models. Sensitivity of a given deterministic model to input material parameters can be quantified in general terms by choosing a relevant response function (usually a scalar variable) and investigating the statistical variation of this response function in terms of the statistical variation of the input parameters. The goal is not to develop fragility curves, and so it is assumed that the forcing function is given and the study focuses only on the uncertainties in material properties. For problems where a closed-form relation exists between the response function and the input parameters, an analytical expression describing the propagation of statistical variations is possible. However, such closed-form solutions are generally not available for more complex problems, and thus the uncertainties are best propagated to the response variables numerically. The latter can be carried out sequentially by first generating random variables and determining the parameters derived from such random variables; these parameters are then input into the deterministic model to determine the value of the desired response function. By performing a multitude of simulations (say, of the Monte Carlo type), the statistics of the response variable can be quantified in terms of an empirical cumulative distribution function (ECDF).

The simplest test would be to apply the approach to local site response models, specifically, to compare the sensitivity of a nonlinear site response model SPECTRA relative to that of SHAKE. For the problem at hand, Arias intensity and relative permanent displacement are chosen as the desired response functions. Both are 'cumulative' in nature and thus reflect response measures that develop over a significant time window. In contrast, the peak ground acceleration (PGA) occurs over a very narrow time window and thus may not serve as a desirable response measure for statistical analysis (since it is known that the PGA is inherently sensitive to the value of damping ratio anyway). Thus, for a given seismic excitation the sensitivity of a given deterministic model to input material parameters can be quantified numerically by first determining the probability density function of the soil parameters from partial descriptors such as mean and standard deviation. Values of the random variables are then generated from these distributions, and are subsequently input into the deterministic models (i.e., SHAKE and SPECTRA) to determine the corresponding values of Arias intensity and permanent deformation for the given seismic excitation. The procedure is repeated hundreds of times to calculate the corresponding ECDFs. Some preliminary results are reported in Refs. [1,2].

A challenging part of the analysis is the repeated use of the nonlinear deterministic model to propagate the uncertainties numerically. For simple models such as SHAKE and SPECTRA, this may not pose considerable computational burden, but for a general 3D problem the stochastic component of the analysis may render the entire approach infeasible. Unfortunately, it is in the 3D analysis where issues pertaining to model sensitivity to uncertainties in soil properties are most relevant. The increased computational effort should not deter us from performing stochastic analysis in 3D, but rather, should serve as an incentive to develop more efficient nonlinear computational algorithms.

References Cited:

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