Opinion Paper

PEER Workshop on Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response

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Two topics that are not specifically covered in the list of breakout session discussions but are directly relevant to the topic at hand are 1) three-dimensional site response and 2) in-situ dynamic soil response model verification. In terms of three-dimensional site response, I refer to the effect of geologic structure (basin effects, complex soil layering) and of the spatial variability of soil properties. Both of these complexities can have important effects on site response and should be considered in new dynamic soil response models. Secondly, if the goal is to develop reliable models for dynamic soil response than in-situ site response verification is paramount. Vertical array ground motion data is still underused in assessing in-situ soil response and verifying dynamic soil response models.

Predicting the level of ground shaking for a site requires an understanding of the soil conditions at the site. Site soil conditions are variable and are generally characterized using one-dimensional in-situ methods. The resulting site characterization is generally sparse; therefore, uncertainty enters the problem at multiple points in the soil characterization and spatial representation of soil. Many site response studies are deterministic and one-dimensional relying on a single boring log to characterize the site geology. These existing methods do not appropriately account for the spatial variability in the parameters (i.e. stiffness, density, unit weight, strata thickness, etc.). Methods for characterization of spatial variability exist but are not widely applied to site response. Spatial variability of soils will lead to similar variability in predicted ground motions. This inherent spatial variability can be quantified with geostatistical methods. Geostatistical methods can also be used to create more accurate three-dimensional models of the soil properties; therefore, new advanced models for dynamic soil response should include geostatistical parameters to characterize the spatial variability of the soil properties. Understanding and quantifying the variability in site response as a result of spatial variations in geologic structure and soil properties will be required for accurate dynamic soil response models.

Many researchers have documented the uncertainty and inherent variability in soil properties (Terzaghi, 1955; Haldar and Tang, 1979; Haldar and Miller, 1984a, 1984b; Phoon and Kulhawy 1999). In an early paper, Terzaghi (1955) discussed how the spatial variability of soils is inherent and can be linked to the complex depositional environment. By understanding geologic processes, geotechnical engineers learn to have a qualitative feel for spatial variability. The key to assessing the effect of spatial variability and moving forward in this discipline is to be able to quantify that uncertainty.
Some previous work has demonstrated spatial variability in soil properties (DeGroot, 1996; Soulie et al., 1990; Jaksa et al., 1997). Degroot (1996) looked at the spatial variability in four different in-situ studies: cone penetrometer tests, standard penetration tests, field vane tests, and dilatometer tests. Using geostatistical methods, Soulie et al.

(1990) used horizontal and vertical variograms to describe the spatial variability of in-situ undrained shear strength in a clay deposit. At a different site, Jaksa et al. (1997) found that vertical spatial variation using five cone penetrometer tests. In terms of soil stratigraphy, Nobre and Sykes (1992) used geostatistics to estimate the uncertainties in bedrock contours and found a large range for bedrock contours (1550 m). New advanced dynamic soil response models should build on this previous research and use statistical methods to characterize uncertainty and spatial variability.

In addition to spatial variability of soil properties, more regional geologic structure can also impact site response. For example, basin generated surface waves cannot be modeled by any one-dimensional model. Three-dimensional regional structure is required to account for surface waves. For example, preliminary evidence in San Francisco Bay indicates that surface waves are generated at the basin edge and propagate throughout the basin and therefore should be evaluated for their effect on the seismic hazard of the region (Baise et al., 2003). These surface waves have been observed by many researchers (Johnson and Silva 1981; Boatwright 1991; Hanks and Brady 1991; Graves 1993) and are consistently described as a 0.5-2 Hz resonance in recorded ground motions at locations around the margins of the bay for weak and strong motion (i.e. the 1989 Loma Prieta earthquake).

Once models are developed, verification is required to assure that the model can accurately represent the in-situ dynamic soil response conditions. Vertical array ground motions present an advantage to surface motions in that the waveform can be tracked as it propagates through the site profile and the deepest instrument in the vertical array provides a more local reference site than a nearby surface rock site to assess the incoming wavefield. Vertical array ground motions can therefore be used as an in-situ verification of site response models (Baise et al., 2003). Using a vertical array of instruments, the downhole recorded ground motions represent an input to the overlying materials, and the uphole recorded ground motions represent the output. Current research does not always take full advantage of this growing dataset.

References:

Baise, L.G., Glaser, S.D., and Dreger, D.S. (2003). Site Response at Treasure and Yerba Buena Islands, San Francisco Bay, California. *Journal of Geotechnical Engineering*, **129** (5), 415-426.

Boatwright, J. (1991). Ground Motion Amplification in the Marina District. *Bull. Seism. Soc. Am.* 81 (5), 1980-1997.

DeGroot, D.J. (1996). Analyzing Spatial Variability of In Situ Soil Properties. *ASCE: Proceedings of Uncertainty '96, Uncertainty in the Geologic Environment: From Theory to Practice.* 210-238.

Graves, R.W. (1993). Modeling Three-dimensional Site Response Effects in the Marina District Basin, San Francisco, California. *Bull. Seism. Soc. Am.* 83 (4), 1042-1063.

Haldar, A., and Tang, W.H. (1979). Probabilistic Evaluation of Liquefaction Potential. *Journal of Geotechnical Engineering*. **105** (12), 145-163.

Haldar, A., and Miller, F.J. (1984b). Statistical estimation of cyclic strength of sand. *Journal of Geotechnical Engineering***. 110** (12), 1785-1802.

Haldar, A., and Miller, F.J. (1984a). Statistical estimation of relative density. *Journal of Geotechnical Engineering***. 110** (4), 525-530.

Hanks, T.C. and A.G. Brady (1991). The Loma Prieta Earthquake, Ground Motion, and Damage in Oakland, Treasure Island, and San Francisco. *Bull. Seism. Soc. Am.* 81 (5), 2019-2047.

Jaksa, M.B., Brooker, P.I., Kaggwa, W.S. (1997). Inaccuracies associated with estimating random measurement errors. *Journal of Geotechnical and Geoenvironmental Engineering*. **123** (5), 393-401.

Johnson, L.R. and W. Silva (1981). The Effects of Unconsolidated Sediments upon the Ground Motion During Local Earthquakes. *Bull. Seism. Soc. Am.* 71 (1), 127-142.

Nobre, M.M. and Sykes, J.F. (1992). Application of Bayesian Kriging to subsurface conditions. *Canadian Journal of Geotechnical Engineering*. **29**: 589-598.

Phoon, K.K. and F.H. Kulhawy (1999). Characterization of geotechnical variability. *Canadian Journal of Geotechnical Engineering.* **36**: 612-624.

Soulie, M., Montes, M. and Sayegh, G. (1990). Modeling spatial variability in soil parameters. *Canadian Geotechnical Journal*. **27** (5), 617-630.

Terzaghi, I. (1955). Influence of geologic factors on the engineering properties of sediments. *Economic Geology, Fiftieth Anniversary Volume*, 557-618.