A Nonlinear Soils Research Needs Position Paper from the Perspective of the CEUS for the NSF/PEER Nonlinear Workshop on March 18-19, 2004

Chris H. Cramer, U.S. Geological Survey, Memphis, TN

BACKGROUND

My recent background in using nonlinear soils information and models comes from two USGS projects concerning deep soil response of the Mississippi embayment in the central U.S. (CUS). The first project is the USGS's Memphis, Shelby Co. project to generate state-of-the-art seismic hazard maps that include the effect of site geology. The second is an Nuclear Regulatory Commission (NRC) funded study extending the Memphis project to the upper Mississippi embayment. Both projects involved generating site amplifications from available geological, geophysical, and geotechnical information and using them to generate probabilistic seismic hazard maps that include the effects of site geology. The general approach was to use local three-dimensional soil information (Memphis project) or appropriate soil reference profiles (whole embayment project) to generate site-specific site-amplification distributions using several soil response computer programs. These site amplification distributions were then used to modify hard-rock ground motion attenuation relations prior to there use in probabilistic calculations (Cramer, 2003).

SOURCES OF UNCERTAINTY

As part of this research, uncertainty and sensitivity analyses have been performed. The Memphis project showed that the largest sources of uncertainty in the generated site amplification distributions were 1) the input ground-motion time series (time histories) used in the soil response calculations, 2) the measurement uncertainties in the soil profiles (mainly shear-wave velocity – Vs), and 3) the dynamic properties of the soils (modulus and damping curves). The NRC-funded embayment project also focused on the uncertainties inherent in the alternative models and methods of calculating soil response. An unmodeled source of large uncertainty is the effect of dynamic pore pressure changes during strong ground-motion in soft, saturated soils such as found in the Mississippi embayment. Archuleta (1998) documented examples of "cusped" accelerograms (acceleration time histories) that exhibit large amplitude spikes. This soil behavior passes large ground motions though soft soils that are the opposite of the deamplification of ground motion observed at sites such as Treasure Island near the San Francisco, CA during the 1989 M6.9 Loma Prieta earthquake (Darragh and Shakal, 1991). Our research efforts and models have only focused on spatially varying one-dimensional soil profiles and have not progressed into two-dimensional and three-dimensional models and effects that may be needed in the more varied and rapidly changing soil geometry in the St. Louis, MO area. So the uncertainties due to complicated structures and basin effects and their associated research needs are not addressed in this position paper.

RESEARCH NEEDS

While the randomization of input ground-motions and soil profiles addresses and characterizes these uncertainties in soil response fairly well, particular information about the dynamic soil properties of soft soils in the Mississippi embayment (and other areas worldwide) is not available. There are just no geotechnical measurements for these soils. There are only extrapolations and analogous measurements for similar soils elsewhere. So while randomization of standard dynamic soil properties (modulus and damping curves) (EPRI, 1993) provides an estimate of the variability about a median site response curve, the median response level is uncertain and poorly controlled. Further there is a lack of actual strong ground-motion observations for embayment soils and hence no observational constraints on modeling.

Research need #1: Develop and apply geophysical and geotechnical methods of in situ measurement of dynamic soil properties by actively inducing high soil strains in soils.

A starting effort in this area is a scheduled NEES/IRIS/USGS workshop on April 29-30, 2004 in Austin, TX to propose and develop initial cooperative experiments in this area – see http://www.ceri.memphis.edu/~gomberg/NEES/Index.htm for details. But more will need to be done.

Variability in site amplification estimates among soil response codes is the next topic concerning research needs. Hartzel et al. (2004) compared non-linear and improved equivalent-linear code estimates with older equivalent-linear models (SHAKE) and found less high-frequency damping of seismic waves as well as large variations among the newer codes. My embayment response study specifically compared site-amplification distribution and seismic hazard estimates from several codes and found differences ranging up to ± 50%, even with common soil profiles and dynamic soil properties.

Research need #2: Develop a web database of test cases of observations and soil models and conduct multiple computer code comparisons using common soil profiles and known dynamic soil properties as a means of improving existing and new soil response codes. Also make tested codes available (on several computer platforms).

Research need #3: Develop and implement a research program and web information site to better define and specify appropriate geotechnical and geophysical properties needed for non-linear codes, particularly those that require information beyond modulus and damping curves.

Modeling of dynamic pore pressure effects under strong ground motion (high strain) is in its infancy. Recent observations of amplification (cusped behavior) and deamplification (large scale soil failure) in soft soils points to great variability in ground motion estimates depending on which behavior can be expected. Currently there are no documented test cases or research results that indicate what measurable geotechnical properties and ground motion conditions can be used to predict when cusped or deamplified behavior will likely occur.

Research need #4: Develop and implement a research program and web information site to document geotechnical and geophysical properties and conditions governing cusped versus deamplified soil response. Also document pore-pressure modeling alternatives and provide a web database of test cases and information.

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