SITE RESPONSE OF ORGANIC SOILS IN THE DELTA

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Investigations

The seismic stability of the Sacramento-San Joaquin Delta levee system is a major concern for the State of California. The State of California Department of Water Resources (DWR 1992) performed a preliminary evaluation of the seismic stability of the levees and concluded that the greatest source of uncertainty was the "amplification/attenuation characteristics of shallow organic soils" which commonly underlay the Delta levees. Their assessment of site response characteristics was hampered by the lack of data regarding the dynamic properties of organic soils (including peat).

Limited data exists regarding the dynamic properties of organic soils subjected to strong seismic shaking (Seed and Idriss 1970, Stokoe et al. 1994, Kramer 1996). More recently, Boulanger et al. (1998) presented cyclic laboratory test results (including modulus reduction and damping versus strain relationships) for tube specimens of peaty organic soil from Sherman Island in the Delta.

Centrifuge modeling provides a means of immediately measuring the site response characteristics of organic soils. An advantage of centrifuge modeling is the ability to do a physical parameter study, and thus observe the effects of parameters such as strata thickness, earthquake frequency content, and level of shaking. The results of experimental parameter studies are useful in evaluating the ability of a numerical site response analysis method to capture the parameters' influences.

The research described in this report included (1) subjecting horizontally layered profiles containing organic soil to simulated seismic loading using the 1-m radius Schaevitz geotechnical centrifuge, and (2) dynamic site response analyses of the experimental profiles using the dynamic properties generated from ongoing research at UC Davis. In addition, a method for measuring the shear wave velocity profile of the centrifuge models while in-flight was developed and tested extensively as part of this study. Typical results from this research project are summarized in this report, while a more detailed description and summary of results will be presented by Arulnathan (1999).

Results

Centrifuge model tests were performed using the servo-hydraulic shaker on the 1-m-radius Schaevitz centrifuge at UC Davis. A flexible shear beam (FSB) container was used to simulate shear beam boundary conditions for the soil. Results are presented in prototype units unless otherwise noted.

Considerable research was directed towards developing a method to measure shear wave velocity (V_s) in the centrifuge models. V_s measurements in dynamic centrifuge models greatly enhance the value of the centrifuge test data by providing an important characterization of the soil, and thus a realistic constraint on the numerical models that will eventually be evaluated against the data. A shear air hammer was developed as the in-flight wave source (Arulnathan 1999). The shear air hammer is embedded horizontally in the soil profile of a centrifuge model during placement of the soil. Four accelerometers were placed in an array directly above the shear air hammer.

A typical set of signals and the experimental set-up are shown in Figure 1. The soil profile in this case was a uniform deposit of dry dense Nevada sand at a centrifugal acceleration of 80 g. The signals are of good quality, and the “forward” and “reverse” signals clearly assist in identifying the characteristic points of the wave pattern.

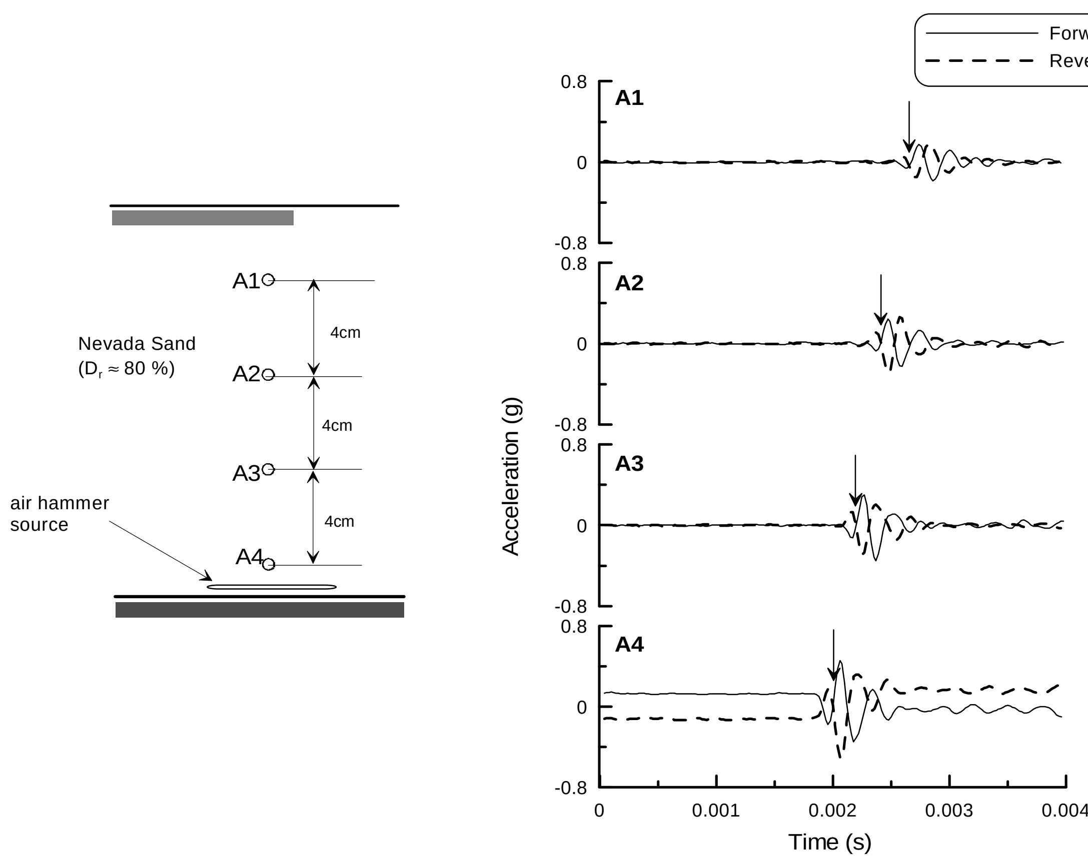

Fig. 1. In-flight Shear Wave Travel Time Records on Nevada Sand ($D_r \approx 80\%$) from Centrifuge test using Air Hammer Source at 80 g.

The reasonableness of the in-flight V_s measurements was checked against V_s measurements on the same sand in a triaxial device using piezo-ceramic bender element tests. These bender element tests were also performed over a wide range of confining stresses. The V_s values obtained in the centrifuge and the triaxial device were essentially identical over the entire range of imposed confining stresses, as illustrated by essentially identical regression results. Similar comparisons of in-flight V_s measurements with bender element V_s measurements were also performed on a reconstituted peaty organic soil ("peat"), and again the measurements were in excellent agreement.

Soil models were prepared that consisted of an upper dense sand layer, a middle peat layer, and a lower dense sand layer. The thickness of each layer was varied to control the range of consolidation stresses on the peat and the fundamental period of the entire soil profile. The soil profile used in one of the dynamic centrifuge tests is shown in Figure 2.

A large amount of data was obtained from the centrifuge model studies, and these data are currently being analyzed and interpreted by Arulnathan as part of his doctoral research. The analyses include back-calculation of stress-strain behavior for the peat, and 1-D site response analyses using the available information for dynamic properties of peat.

Site response analyses were performed for each shaking event using an equivalent linear site response program. The in-flight V_s measurements were used to define the low-strain shear moduli (G_{max}) input to the analyses. The modulus reduction and damping relationships selected for the peat layer were the median relationships obtained for tube samples of Sherman Island peat by Boulanger et al. (1998). The modulus reduction and damping relationships for the sand layer were selected based on relationships commonly used in practice.

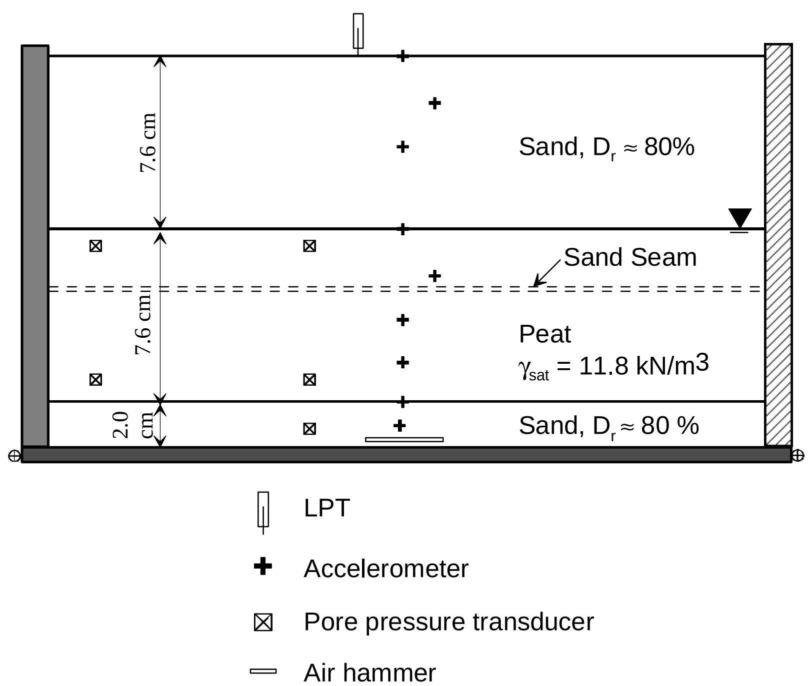

Fig. 2. Configuration of Centrifuge Model 2 in a Flexible Shear Beam Container

Calculated and recorded site responses for an earthquake motion with a peak base acceleration of 0.33 g are compared in Figure 3 in terms of the acceleration response spectra (ARS) for motions recorded at 10 depths in the soil profile. The calculated and recorded responses are in good agreement for this typical earthquake event. More general conclusions must wait until analyses and comparisons can be completed for all the earthquake events and models tested in this study, which all together total 38 cases to analyze. As noted previously, more detailed analyses and interpretations of these data will be presented in Arulnathan (1999).

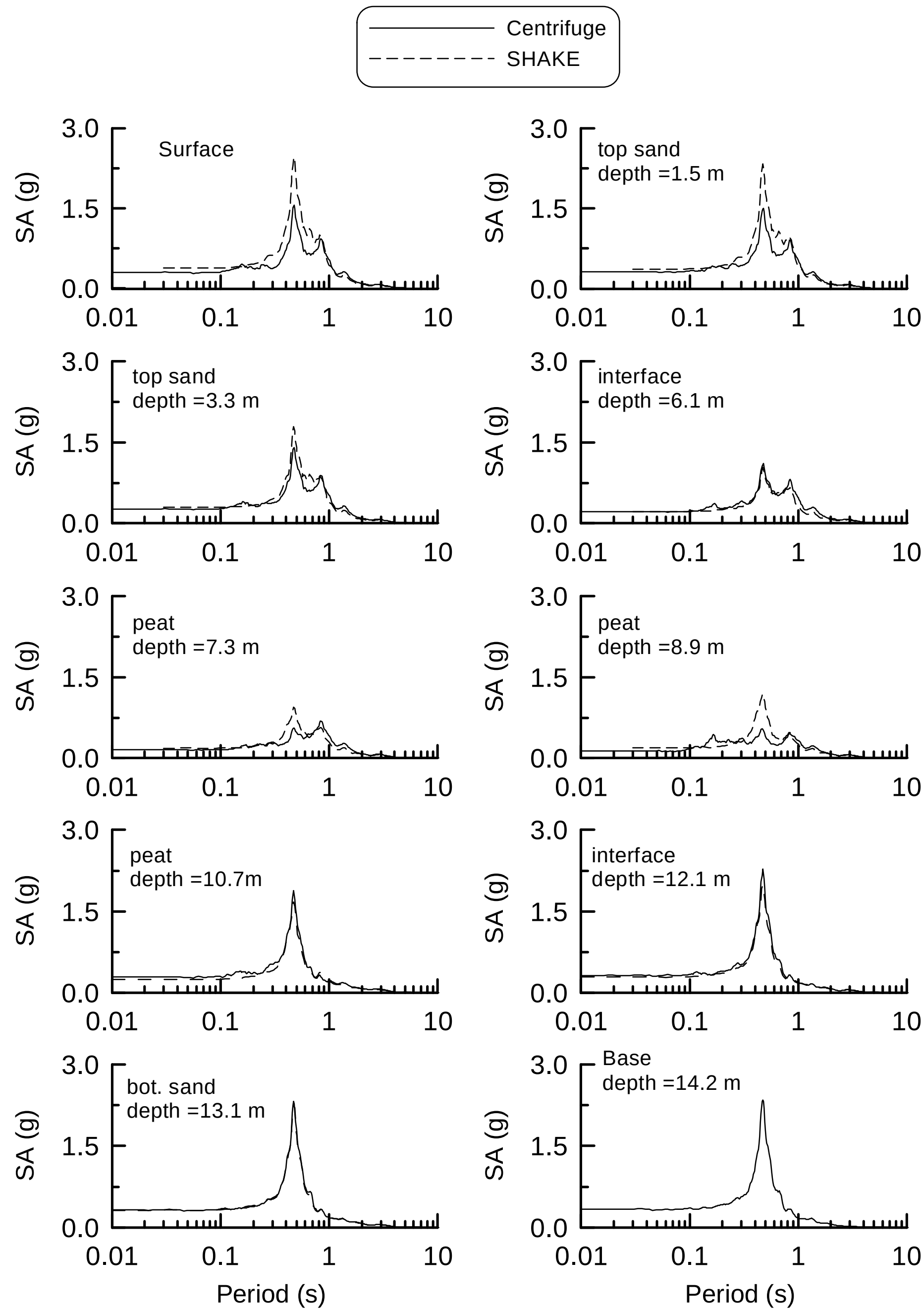

Fig. 3. Acceleration Response Spectrum (5% damping) for Ten Depths in Model 2 During an Earthquake with Peak Base Acceleration of 0.33 g.

Nontechnical Summary

This research evaluated our ability to predict the site response characteristics of organic soils, such as found throughout the Sacramento-San Joaquin Delta, using centrifuge and numerical modeling. Dynamic centrifuge model tests were performed for soil profiles consisting of a peat layer with overlying and underlying sand layers. The soil profile, the earthquake waveform, and the level of earthquake shaking were varied. Good agreement was obtained between the numerical site response calculations and the centrifuge model recordings. These experimental and analytical results provide improved confidence in our ability to model site response characteristics of organic soil deposits.

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Data Availability

The centrifuge test data will be made available in electronic form (ASCI format), including all recorded time histories, as part of the doctoral thesis of Arulnathan. The data will be made available through the Center for Geotechnical Modeling (http://cgm.engr.ucdavis.edu).

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Technical Abstract

Seismic stability of the Sacramento-San Joaquin Delta levee system is a major concern for the State of California. A primary source of uncertainty in any evaluation of the seismic stability of the Delta levee system is the amplification/attenuation response characteristics of the shallow organic soils that commonly underlay the levees. This report summarizes research on the site response characteristics of organic soils using centrifuge and numerical modeling. The centrifuge modeling effort included the development of techniques to measure the shear wave velocity profile for a centrifuge model while in-flight. Excellent agreement was obtained between shear wave velocities measured in the centrifuge tests and in laboratory triaxial tests using piezo-ceramic bender element methods. Centrifuge model tests included variations in the soil profile, the earthquake waveform, and the level of earthquake shaking. One-dimensional site response analyses using an equivalent linear procedure were performed with the measured shear wave velocity profiles and the modulus reduction and damping relationships determined from prior laboratory studies. Good agreement was obtained between the numerical simulations and the centrifuge model recordings. The experimental results provide improved confidence in our ability to model site response characteristics of organic soil deposits.