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Site Response of Organic Soils

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SITE RESPONSE OF ORGANIC SOILS

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ABSTRACT

A primary source of uncertainty in any evaluation of the seismic stability of the Sacramento-San Joaquin Delta levee system is the site response characteristics of the shallow organic soils that commonly underlay the levees. This paper provides an overview of recent 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. 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.

INTRODUCTION

The State of California Department of Water Resources (DWR 1992) performed a preliminary evaluation of the seismic stability of the Sacramento-San Joaquin Delta levee system 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). The potential consequences of future earthquakes include deformations within the organic strata and/or liquefaction of the sands and silts within and beneath the levees.

Limited data exists regarding the dynamic properties of organic soils subjected to strong seismic shaking. Seed and Idriss (1970a) presented properties for Union Bay peat in their study of recorded motions at Union Bay, Seattle. These early relationships were based on a broad interpolation of data and considerable judgment. Although their use is no longer recommended, these relationships have been widely referenced. More recently, Stokoe et al. (1994) presented test results for two peat specimens from a bridge site in New York, and Kramer (1996) presented results for tube samples of peat from Mercer Slough in Washington. Boulanger et al. (1998) presented cyclic laboratory test results for tube specimens of peaty organic soil from Sherman Island in the Sacramento-San Joaquin Delta, with the resulting modulus reduction and damping curves summarized in Figure 1.

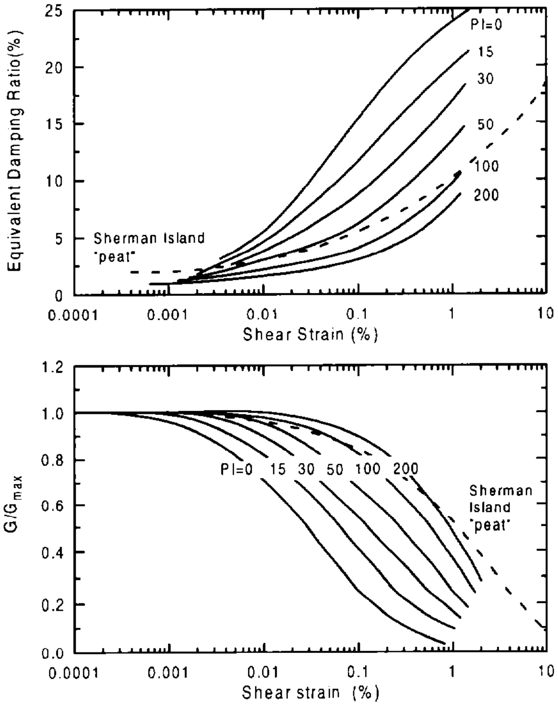

Fig. 1. Median modulus reduction and damping for Sherman Island peat versus curves by Vucetic and Dobry (1991) for NC and OC Clays of varying plasticity (Boulanger et al. 1998).

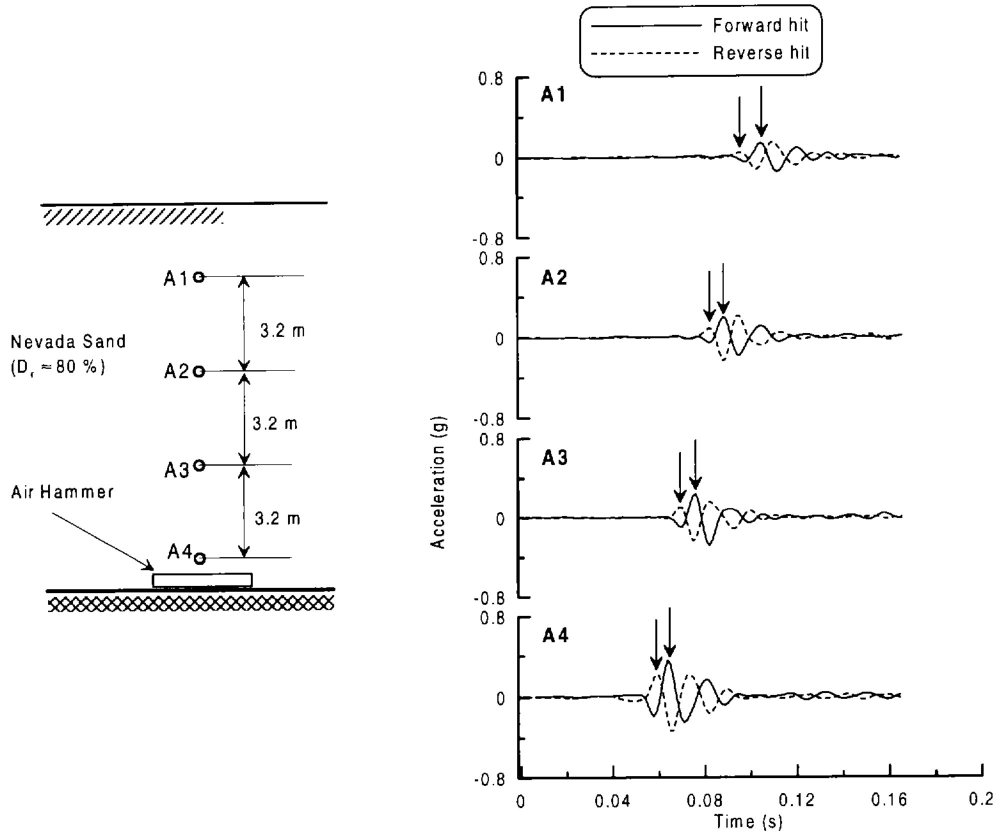

Fig. 2. In-flight shear wave travel time records on Nevada sand ($D_r \approx 80\%$) from centrifuge test at 80 g.

Determining the amplification/attenuation characteristics of shallow organic deposits will require considerable future research since so little has been done to date. Long-term needs include additional measurements of dynamic properties of organic soils in the laboratory, obtaining strong motion records of earthquake shaking at fully characterized sites, and site response analyses comparing predicted and recorded motions to assess the predictive capabilities of analysis methods.

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 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 paper, while Arulnathan (1999) gives a more detailed description and summary of results.

CENTRIFUGE MODELING

Centrifuge model tests were performed using the servo-hydraulic shaker on the Schaevitz centrifuge at UC Davis. This centrifuge has a radius of about 1 m and can provide centrifugal accelerations of up to 100 g. 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.

Shear wave velocity (V_s) measurements were performed in the centrifuge to determine the low strain shear modulus (G_{max}) as:

$$G_{max} = \rho V_S^2 \qquad (1)$$

where ρ is the soil density. A mini air hammer was developed as the in-flight wave source (Arulnathan et al. 2000). The mini air hammer consists of a hollow aluminum cylinder capped at both ends, and fitted with an air port on each end. The cylinder is about 5 cm long, and its outer surface is roughened and epoxy-coated with sand. A teflon piston, about 2.5 cm long, fits inside the cylinder. Tubing connects the air ports to a four-way valve that enables the simultaneous application of air pressure to one end of the cylinder while venting the other end.

After the model has been spun up to the desired centrifugal acceleration, the mini air hammer can be triggered to fire in either direction. The impact of the piston with an end of the cylinder produces a system of waves that emanate from the outer surface of the cylinder. A typical set of signals and the experimental set-up are shown in Figure 2. The soil profile in this case was a uniform deposit of dry dense Nevada sand. These signals were obtained 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. Excellent agreement was obtained between V_s measurements obtained on two soils tested in-flight and in a triaxial device with piezo-ceramic bender elements

DYNAMIC CENTRIFUGE MODELS WITH ORGANIC LAYERS

Soil models were prepared that consisted of an upper dense sand layer, middle peat layer, and 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 3. The lower and upper sand layers were placed dense to avoid liquefaction during shaking, as the focus of these tests was on the peat behavior. The peat was prepared for placing as follows. A large supply of peat tube samples from Sherman Island, with ash contents of 35 to 56% and maximum fiber lengths of 1 to 2 cm, were conditioned with extra water to bring their water contents up to about 340% and allowed to soften for one day. The samples were then easily dissected by hand so that the fibers were fully separated, rather than torn. All the peat samples were then mixed together in one batch and subsequently separated into uniform portions for testing. The resulting peat "slurry" was then placed in lifts in the centrifuge container, and then mechanically consolidated under a vertical stress equal to the effective vertical stress that would later be applied during the centrifuge test. After consolidation, the peat layers had water contents of about 140%.

The models were spun to the desired g-level and allowed to fully consolidate, as evidenced by the pore pressure and settlement readings. Each model was then subjected to a series of earthquakes, progressing from small shaking events to large shaking events. Any excess pore pressures generated by the shaking were allowed to fully dissipate before the next shaking event. V_s measurements were taken before the first shaking event, after select shaking events in the series, and after completion of the last shaking event. These data allowed an evaluation of how the cumulative effects of several shaking events affected the V_s profile.

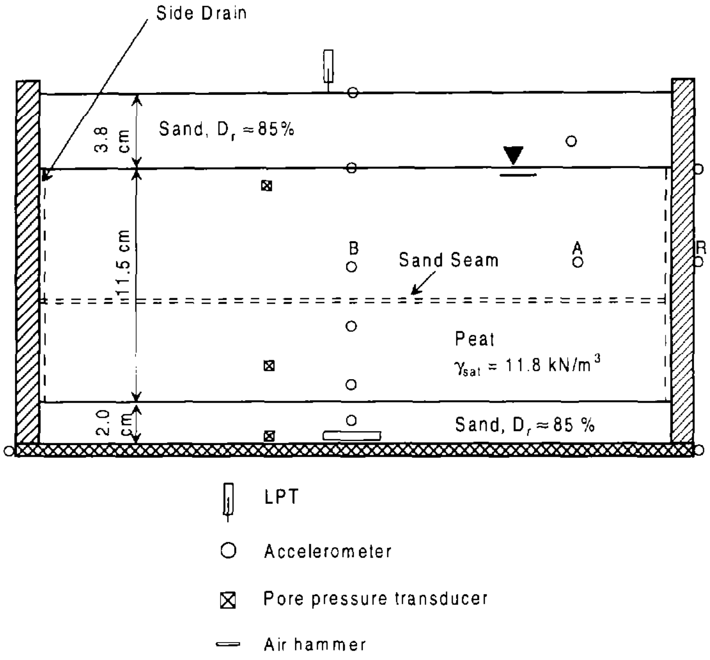

Fig. 3. Configuration of Centrifuge Model 1 in a Flexible Shear Beam Container

TYPICAL COMPARISON OF CALCULATED AND RECORDED RESPONSES

Site response analyses were performed for each shaking event using the equivalent linear site response program, SHAKE91 (Schnabel et al. 1972, Idriss and Sun 1991). 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), as shown in Figure 1. Relationships for sand were derived from the curves by Iwasaki et al. (1976) and Seed and Idriss (1970).

Calculated and recorded site responses for an earthquake motion with a peak base acceleration of 0.4 g are compared in Figures 4 to 6. Acceleration time histories are shown in Figure 4 for seven different depths in the soil profile, with recorded motions shown on the left (Figure 4a) and calculated motions on the right (Figure 4b). The corresponding acceleration response spectra (ARS) for the same seven depths are shown in Figure 5. Maximum accelerations and maximum shear strains are plotted versus depth in Figure 6.

The calculated and recorded responses are in reasonably good agreement for this typical earthquake event. There was a slight overestimation of peak accelerations and slight underestimation of peak shear strains in the upper portions of the upper sand layer. Analyses and comparisons for all the earthquake events and models tested in this study are summarized in Arulnathan (1999).

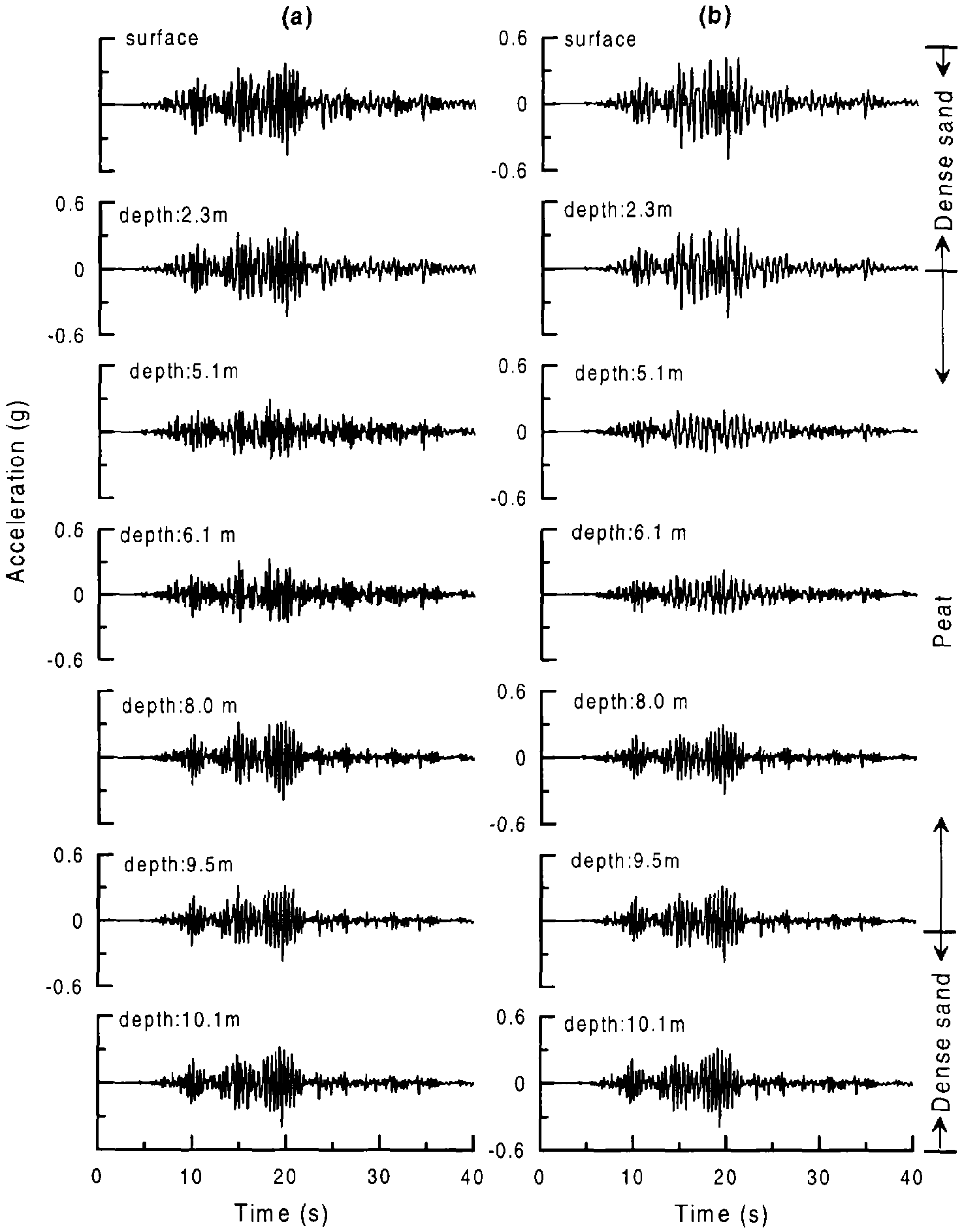

Fig. 4 Accelerations at 7 depths during an earthquake with peak base acceleration of 0.4 g. (a) Recorded (b) Calculated

SUMMARY

This paper provides an overview of some recent research performed on the site response characteristics of organic soils using centrifuge and numerical modeling. Techniques for measuring the shear wave velocity profile of a centrifuge model while in-flight were developed. Extensive check tests were performed to confirm that shear wave velocity measurements in the centrifuge tests were in agreement with measurements in laboratory triaxial tests using piezo-ceramic bender element methods (Arulnathan et al. 2000). Dynamic centrifuge model tests were performed for soil profiles consisting of a peat layer with overlying and underlying sand layers. The models were designed to produce confining stresses in the peat layer that are representative of stress conditions under levees in the Sacramento-San Joaquin Delta. The dynamic 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.

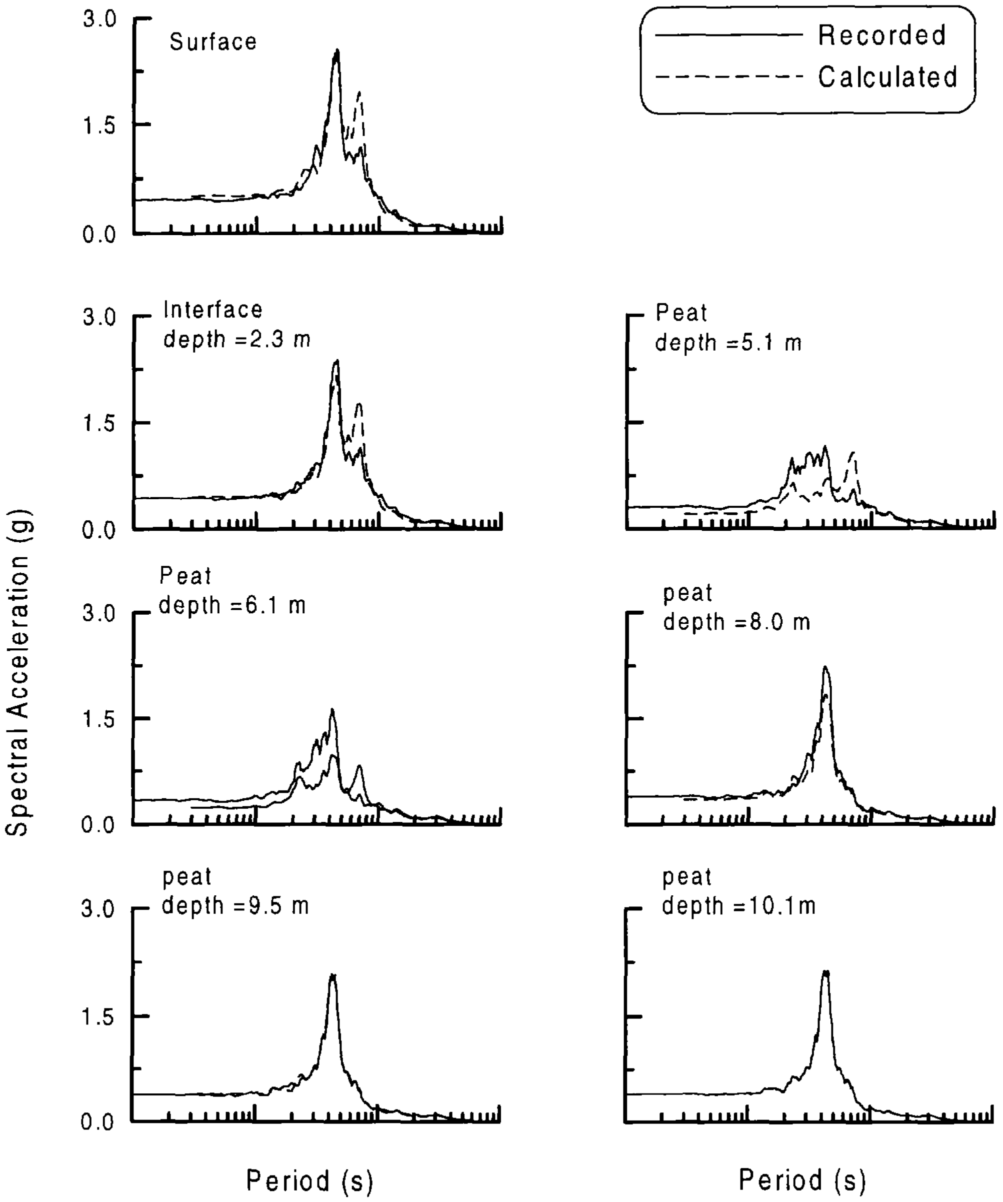

Fig. 5. Acceleration Response Spectrum (5% damping) for same seven depths.

Further analysis results and interpretations are presented in Arulnathan (1999).

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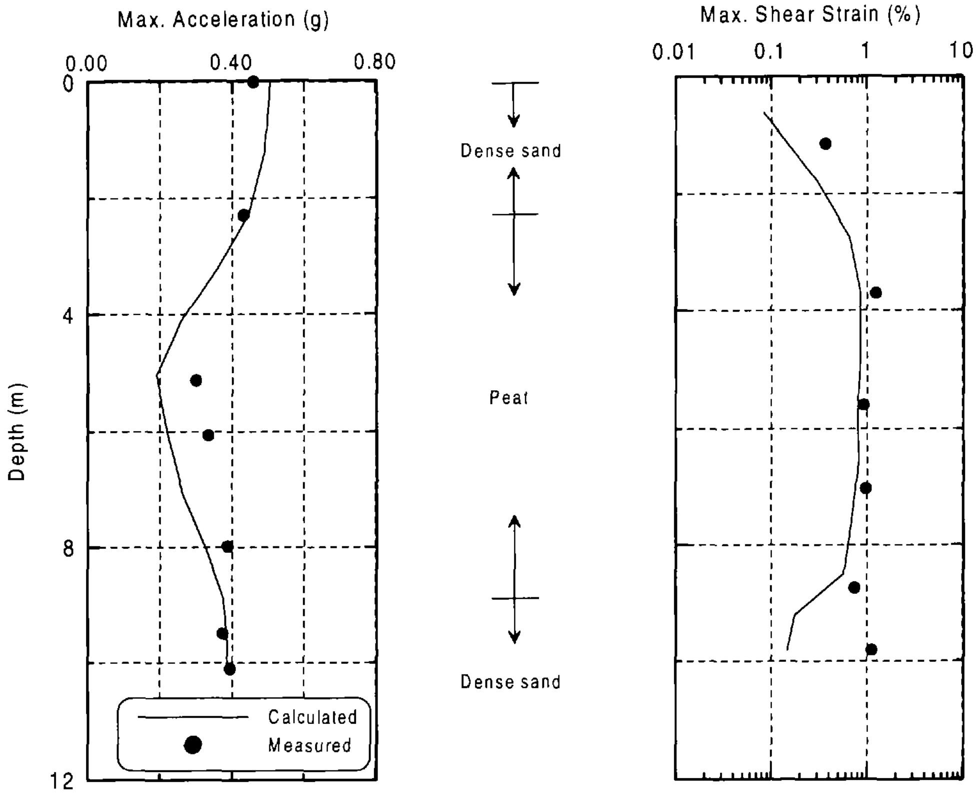

Fig. 6. Peak acceleration and shear strain vs. depth for same model.

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