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DEVELOPMENT OF METHODS TO MEASURE NONLINEAR PROPERTIES AND LIQUEFACTION CHARACTERISTICS OF NEAR-SURFACE SOILS

by

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TECHNICAL ABSTRACT

The goals of this project are to develop first-generation field methods that can be used to evaluate directly: 1. the nonlinear response of soils, and 2 the liquefaction resistance of soils. At this time, the field methods are aimed at testing near-surface soils; that is, soils within 0.5 to 3 m of the ground surface. This work was undertaken because no direct methods are presently available to measure routinely these characteristics in place.

The bulk of this report deals with development of the field method to measure nonlinear soil properties. The generalized test method involves applying static and dynamic loads at the surface of a soil deposit using a truck-mounted, electro-hydraulic shaker (known as a Vibroseis truck in oil exploration) and measuring the dynamic response of the soil mass beneath the loaded area using embedded instrumentation. The resulting field test is a load-controlled dynamic test that induces nonlinearity in the soil beneath the loaded area. Initial testing has focused on vertically and horizontally loading an unsaturated sand deposit, evaluating the magnitude of induced axial and shear strains, and assessing the variation in constrained compression wave velocity, V_P, constrained modulus, M, shear wave velocity, V_S, and shear modulus, G, with strain amplitude. Plane wave approximations as well as more advanced wave analyses were used to evaluate nonlinear strain amplitudes. Nonlinear behavior in both modes of excitation was successfully measured in situ. The measured nonlinear response in shear compares well with the general form of the nonlinear response in shear measured in the laboratory with intact specimens of the sand and with empirical correlations. The nonlinear response in compression also has the same general form as the nonlinear response in shear for this unsaturated sand. However, additional studies are needed to resolve the exact nature of the compressional response in terms of unconstrained versus constrained behavior. Evaluation of in situ material damping was beyond the scope of this initial work.

Initial development of a field method to evaluate the liquefaction resistance of soils was performed in conjunction with a project funded by the National Science Foundation (Career award to Prof. E. M. Rathje). In situ measurement of the relationship between the induced cyclic shear strain and excess pore water pressure are performed in this field test. The same Vibroseis truck used to induce nonlinear soil behavior is used in this test. However, in this case, the Vibroseis is used to induce shaking in an instrumental test area by generating surface waves near (within 3.3 m) the test area. The level of shaking is controlled by specifying the vibrating levels for the Vibroseis. The surface waves induce cyclic shear strains which, in turn, generate excess pore water pressure in the test area. To evaluate shear strain and pore water pressure in situ, a new sensor, called a liquefaction test sensor, has been developed and is embedded below the ground surface. This sensor is used to simultaneously monitor the dynamic soil particle velocity and pore water pressure. Shear strain-time histories are calculated systematically from the measured ground velocities. The excess pore water pressure-histories are measured at the location where the shear strains are calculated using a miniature pore water pressure transducer. Therefore, the full process of cyclic loading is captured, ranging from small-strain loading to significantly pore pressure generation. The results from a field test series performed on a large-scale reconstituted test specimen that was constructed in a test pit are summarized in an appendix in this report.

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NON-TECHNICAL SUMMARY

Evaluation of how much a soil will deform or if it will become fluid-like during earthquake shaking required knowledge of the stiffness, damping and water-pressure-generation characteristics of the soil. Presently, no direct methods are available to measure routinely these characteristics in place. This project has successfully developed first-generation methods for these purposes. The methods involve applying large controlled static and dynamic loads to the ground surface with mechanical shakers. The response of the soil beneath the shakers is measured with embedded instrumentation. The measured response is then analyzed to determine the required soil characteristics.