International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 18, No. 1, March 2008, pp. 56–64

Energy-based Evaluation of Excess Pore Pressure Using Damage Potential

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An energy-based model for the prediction of excess pore pressure (EPP) and evaluation of liquefaction potential in saturated sands is proposed using dissipated energy (w_d) and damage potential. The damage concept is adopted for the development of the proposed model. Undrained dynamic triaxial tests are conducted using both regular sinusoidal and irregular earthquake loading conditions. Based on test results, the normalized cumulative excess pore pressure ratio (*NCER*)—the normalized cumulative dissipated energy (*NCW*) as a function of w_d and cumulative absolute velocity (*CAV*)—is developed. Additionally, a procedure is presented for the evaluation of EPP and determination of model parameters for the proposed model. It is found that model parameters for the proposed model can be estimated from the *NCER-NCW* relationship. For the determination of initial liquefaction, the minimum curvature method, using the normalized cumulative stress (*NCS*)-normalized cumulative dissipated energy (*NCW*) curve, is proposed. The predicted initial liquefaction using the proposed method agrees well with the measured initial liquefaction. From results of additional undrained dynamic triaxial tests, the predicted EPP generation using the proposed model agrees well with the measured results for both sinusoidal and earthquake loading cases.

INTRODUCTION

Evaluation of excess pore pressure (EPP) generation and liquefaction potential is an important issue for the foundation design of various offshore structures. Several energy-based EPP generation models have been proposed and used in practice to evaluate liquefaction potential and susceptibility in sands (Nemat-Nasser and Shokooh, 1979; Law et al., 1990; Figueroa et al., 1994; Green et al., 2000; Davis and Berrill, 2001). Most energy-based models define EPP in terms of the dissipated energy produced by induced stresses and strains based on certain model parameters empirically obtained from laboratory test results (Green, 2001). While energy-based EPP generation models have been successfully verified for many dynamic geotechnical problems, these were primarily for sinusoidal loading cases. When realistic irregular earthquake loadings are involved, dynamic responses may differ from those of sinusoidal loadings, and thus correlations between EPP and dissipated energy for sinusoidal loading conditions may no longer be applicable (Ishihara and Yasuda, 1972; Kim et al., 2005).

Recent attempts to assess liquefaction potential have involved investigations of damage potential such as the ARIAS intensity and the cumulative absolute velocity (*CAV*) as a measure of the severity of earthquake motions (Kayen and Mitchell, 1997; Kramer and Mitchell, 2006). As for dissipated energy, the quantity given by damage potential reflects both amplitude and duration of earthquake motions. Damage potential then does not require arbitrary magnitude scaling factors that are needed in scaling of the capacity of the soil to resist liquefaction with varying magnitude (Kayen and Mitchell, 1997). Evaluation of liquefaction using damage potential provides greater flexibility, ranging from a relatively simple procedure of empirical correlations between loading and resistance to a more sophisticated procedure of site-specific and nonlinear analyses of ground response. However, previous studies have been unable to identify a single damage potential that is uniquely related to the generation of EPP in liquefiable soil (Kramer and Mitchell, 2006).

In this study, an energy-based model for the prediction of EPP and the evaluation of liquefaction potential in sands is proposed on the basis of dissipated energy and damage potential. To achieve a more realistic description of the dynamic responses of saturated sands, both regular sinusoidal and irregular earthquake loadings are addressed. As an experimental investigation, undrained dynamic triaxial tests using saturated sand samples are conducted under both regular sinusoidal and irregular earthquake loading conditions. Also, determination of model parameters and initial liquefaction based on the proposed method is presented.

ENERGY-BASED EXCESS PORE PRESSURE GENERATION MODEL AND DAMAGE POTENTIAL

Energy-based Excess Pore Pressure Generation Model

When dynamic loadings propagate through soil, the soil deforms in a hysteretic manner, and a portion of energy is dissipated. The pioneering work of Nemat-Nasser and Shokooh (1979) showed that the dissipated energy (w_d) is closely related to the buildup of the excess pore pressure (EPP). w_d under dynamic loading conditions is commonly represented by the area of the hysteresis loop of stress-strain curves. w_d is then given as follows:

$$w_d = \int_0^t \sigma \cdot d\varepsilon^p \quad (1)$$

where $\sigma =$ applied stress, $d\varepsilon^p =$ plastic strain increment vector, and $t =$ time.

By equating the energy required to rearrange sand particles for achieving w_d, Nemat-Nasser and Shokooh (1979) first introduced the energy concept for the analysis of densification and liquefaction of sands. Following this early work, Davis and Berrill (1982)

Received June 9, 2007; revised manuscript received by the editors October 28, 2007. The original version was submitted directly to the Journal.
KEY WORDS: Liquefaction, dissipated energy, excess pore pressure, damage potential, cumulative absolute velocity, sinusoidal loading, earthquake loading.