Variation of Permeability during Liquefaction and Its Effects on Seismic Response of Saturated Sand Deposits

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Abstract
Liquefaction phenomenon causes considerable increase in the soil permeability due to creation of easier paths for water flow. For an accurate modeling of seismic behavior of saturated sand deposits, in addition to properly modeling contraction behavior of liquefied sand, variation of permeability coefficient during liquefaction should be taken into account. In this paper the effects of variation of permeability during liquefaction on soil seismic response is studied using a fully coupled dynamic analysis. A well calibrated critical state two-surface plasticity model has been employed in the numerical analysis which is capable of accounting for the volumetric/shear response of soil skeleton in a wide range of densities (void ratios) and confining pressures. The OpenSees platform is used to conduct the numerical simulations. The simulation results indicate that incorporating the permeability variation in the numerical model is necessary for capturing both pore pressure and settlement responses of a liquefiable soil mass.

Keywords: permeability, liquefiable soil, coupled analysis, OpenSees, Excess pore pressure ratio.

1. INTRODUCTION

Shaking of a saturated sand deposit results in the structural change of the soil skeleton and decrease of void ratio. Due to the void ratio decrease, the permeability coefficient must reduce. However, this reduction in the void ratio and its effect on the permeability is not significant. On the other hand, structural change of soil skeleton results in reduction of pore shape factor and tortuosity which causes a significant increase in the permeability coefficient during liquefaction [1]. At the onset of liquefaction, soil particles lose full contact with each other which creates easier paths for water to flow. The creation of such flow paths reduces the pore shape factor and tortuosity and consequently leads to an increase in the permeability coefficient at the time of initial liquefaction. The basic mechanism that is involved in this phenomenon is pore pressure increase.

Arulanandan and Sybico [1], based on the measurement of changes in the electrical resistance of saturated sand deposit in the centrifuge tests, concluded that "in-flight permeability" of saturated sand during liquefaction increases up to 6 to 7 times greater than its initial value. Jafarzadeh and Yanagisawa [2] by measurement of the volume of the expelled water from saturated sand columns in shaking table model tests indicated that the average permeability coefficient during excitation is 5 to 6 times greater than its static value.

For an accurate modeling and simulation of seismic behavior of saturated sand deposits, in addition to properly modeling contraction characteristics of liquefied sand, the variation of permeability coefficient during liquefaction should be taken into account. Using the initial permeability coefficient in the process of liquefaction modeling causes erroneous predictions of various aspects of liquefied ground behavior.

A common method for taking the permeability increase into consideration in the process of liquefaction modeling is "constant increased permeability coefficient". In this method, the average value of the "initial static permeability" and "permeability during liquefaction" is considered a constant permeability coefficient throughout the numerical simulation. This average value was considered $3.67k_0$ by Arulanandan and Sybico [1], $10k_0$ by Balakrishnan [3] and $4k_0$ by Taiebat et al. [4] (where k_0 is the initial, static value for soil permeability).

Although the amount of settlement can be simulated reasonably well by using "constant increased permeability coefficient", this method does not reflect the actual mechanics of pore water pressure generation and dissipation and the predicted pore pressures by this method will not be accurate. Therefore, an accurate simulation of pore pressure generation and dissipation and consequent settlement during liquefaction requires incorporating the actual variation of permeability in the numerical model.