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Qualitative Estimation of Momentary Liquefaction in a Sandy Seabed Based on Pore Water Pressure

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The pore water pressure in a seabed plays an important role in the stability of the seabed, and it is generally used to estimate seabed liquefaction induced by oceanic loads. When the principle of effective stress is applied, it can easily be derived that the increase of pore water pressure in the seabed means a decrease of effective normal stress and a higher likelihood of liquefaction. In fact, wave influences the load boundary conditions and pore water pressure boundary conditions simultaneously. On the basis of the liquefaction criterion of pore water pressure, two cases are studied: (1) the case where a different seabed is subjected to the same oceanic load and (2) the case where the same seabed is subjected to different oceanic loads. The relationship between pore water pressure in the seabed, the uplift force induced by the wave, and the possibility of liquefaction is established. The results show that the pore water pressure in the seabed under the wave trough ($p < 0$) should be used to estimate the likelihood of liquefaction rather than the positive pore water pressure under the wave crest ($p > 0$). In the first case, the uplift force and possibility of liquefaction in the seabed decrease when $|p|$ increases. However, in the second case, the uplift force and possibility of liquefaction in the seabed increase with $|p|$. In addition, these results are used to estimate the possibility of seabed liquefaction in examples, and the evaluation based on pore pressure is compared with that based on vertical effective stress. This conclusion will be applied for a comparison of the possibility of liquefaction due to pore water pressure between diverse cases.

INTRODUCTION

Seabed response under oceanic loads is a hot topic nowadays. In previous studies, responses and the stability of the seabed under wave loads were intensively discussed. When wave propagates over the seabed, the pore water pressure and stresses in the seabed soil are influenced. Wave loads may result in a failure of the seabed. Therefore, the pore water pressure and stresses of soil induced by wave loads have been the focus of much research. This change of the state of soil can cause liquefaction of the seabed. Liquefaction is an instable state of the seabed, caused by cyclic loads (e.g., earthquakes, waves). Liquefaction of seabed soil occurs when the vertical effective stress of the soil is vanished. A liquefied seabed loses its bearing capacity, which is catastrophic for offshore structures built on it. Many offshore accidents induced by seabed liquefaction have been reported in the literature (Christian et al., 1974; Herbich et al., 1984; Horikawa, 1988; Lu and Hanyga, 2005a). Consequently, liquefaction of the seabed caused by wave loads is an important problem facing ocean engineers.

Pore water pressure in the seabed has become an important variable since Biot's consolidation theory (Biot, 1941) was generally adopted to study responses of the seabed under wave loads. The pore water pressure in the seabed is related to the stability of the seabed and can be used to estimate seabed liquefaction (Zen and Yamazaki, 1993). Furthermore, compared with stresses or displacements in the seabed, the pore water pressure in the seabed can be measured conveniently and accurately by field tests or laboratory tests. Many researchers analyzed the pore water pressure in the seabed under different conditions (Lu and Hanyga, 2005b; Lu and Jeng, 2007), including theoretical studies considering the pore water pressure in seabed soil induced by ocean waves in cases with or without structures.

Yamamoto et al. (1978) derived an analytical solution of pore water pressure and displacement in a 3-D seabed under wave loads. It was found that the seabed response was strongly related to the soil permeability and stiffness ratio of soil. Furthermore, Jeng and Lin (1997) discussed pore pressures and stresses in the seabed with variable permeability and nonlinear wave. Wang et al. (2000) researched an anisotropic seabed with an embedded pipeline and the distribution of pore water pressure around the pipeline. Jeng et al. (2000, 2001) studied the interaction of seabed-caisson/breakwater-wave and the pore water pressure around marine structures. Later, Jeng and Ou (2010) extended the model to three dimensions to study the interaction of seabed-breakwater-wave. Zhang et al. (2011) analyzed a pipeline buried in a 3-D seabed in a numerical model, and Liao et al. (2013) proposed an analytical solution for a seabed under combined wave and current loads. It was found that the seabed response, such as pore pressure, was affected by the current.

When it comes to laboratory tests, the pore water pressure was measured in most experiments of seabed subjected to wave loads. Pore pressures in a coarse sand and fine sand seabed under wave loads were measured in experiments carried out by Yamamoto et al. (1978). Good agreements were found between theoretical results and experimental data. Zen and Yamazaki (1990) studied the pore pressure under cyclic wave loads by a new developed apparatus. They observed momentary liquefaction in their experiment. Chowdhury et al. (2006) investigated seabed momentary liquefaction in a 1-D cylindrical vessel, and the pore pressure was measured as a concerned variable. Wang et al. (2013) studied the pore pressure around a monopile in the seabed while both wave and current were considered.

Previous research extensively studied the pore water pressure in a seabed; liquefaction was also partially studied. However, there is

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