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# Wave-induced Pore Pressure Responses and Soil Liquefaction Around Pile Foundation

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**A 3D FEM model is proposed and verified with existing experimental data for simulating wave-induced transient and residual pore pressure responses around a pile foundation. The numerical results show that the residual pore pressure tends to be amplified at the bottom of the pile foundation; near it, this pressure increases and the amplitude of transient pore pressure decreases with the decrease of soil permeability. The wave nonlinearity affects both transient and residual pore pressures around the pile. The effect of the pile diameter on the oscillatory pore pressure is much more obvious than that on the buildup of pore pressure. The liquefaction zone around the pile is asymmetric; the maximum liquefaction depth appears at the back of the pile foundation.**

## INTRODUCTION

Piles have been widely used for the foundartions of coastal and offshore structures, such as platforms, long-spanning bridges, offshore wind farms, etc. Under the action of ocean waves, pore water pressure may be induced in the seabed around pile foundations, which is usually accompanied by the reduction of effective stresses. In some extreme conditions, such as hurricanes or storms, the soil around the pile foundation may be liquefied, resulting in large displacements of the pile foundation and the eventual collapse of upper structures. Thus, a proper evaluation of wave-induced pore pressure responses and soil liquefaction around the pile foundation is crucial for the geotechnical design of maritime structures.

Generally, there are 2 significant mechanisms for wave-induced pore pressure responses, which are also observed in laboratory experiments and field measurements (i.e., Nago et al., 1993). The first mechanism, termed transient or oscillatory pore pressure, is characterized by the attenuation of amplitude and the phase lag within the seabed. The other is residual buildup of pore pressure caused by the compression of the soil skeleton, which is similar to the pore pressure responses induced by earthquakes.

Since the 1970s, wave-induced pore pressure responses and liquefaction within a porous seabed have gradually concerned marine geotechnical engineers and researchers. Based on the conventional Biot consolidation equations (Biot, 1941), the transient characteristics of excess pore pressure for an infinite seabed have been studied theoretically by Yamamoto et al. (1978). Then, within the same framework, a series of analytical solutions has been accomplished by considering the finite thickness of the seabed and orthotropic nature of soil (Jeng and Hsu, 1996; Jeng, 1997). On the other hand, the residual buildup of pore pressure has been investigated by some researchers (Seed and Rahman, 1978; McDougal et al., 1989; Sumer and Fredsøe, 2002; Jeng et al., 2007). The empirical relationships obtained from dynamic triaxial or simple shear tests have been employed to model the pore pressure generation under an undrained condition (DeAlba et al., 1975; Seed et al., 1976). All this research, however, mainly focused on one of the mechanisms for the pore pressure responses individually. In fact, the wave-induced transient and residual pore pressure responses are coupled.

Numerous studies have also been conducted to investigate the pore pressure responses and soil liquefaction around marine structures. For instance, Rahman et al. (1977) developed a practical procedure to analyze the pore pressure responses and soil liquefaction under the Ekofisk oil tank. Zhou and Qiu (1993) obtained a closed-form analytical solution of wave-induced seepage pressure acting on the base of a breakwater in an infinite-depth elastic seabed. Based on flume experiments, Sumer et al. (1999, 2006) have systematically examined the pore pressure response around the pipeline buried in the soil and sinking/floating of pipelines. A review of pore pressure responses of soil around offshore structures could also be found in Jeng (2003). Recently, Lu and Jeng (2008, 2010), based on the boundary element method (BEM), investigated the seismic wave-induced pile-soil interaction responses. However, the ocean wave-induced pore pressure responses and soil liquefaction around pile foundations have not been well understood.

In this study, a FEM model is proposed to simulate the wave-induced transient and residual pore pressure responses simultaneously around a pile foundation. The numerical model is verified with the existing experimental data from Sumer et al. (1999). The pore pressure responses in the vicinity of the pile foundation have been compared with those in the absence of pile, and the effects of wave nonlinearity have also been investigated. A parametric study is made to examine the influences of soil permeability and pile diameter on transient and residual pore pressure responses near the pile foundation. Finally, the existing criterion of liquefaction is applied to investigate the distribution of liquefied depth around the pile foundation.

## NUMERICAL MODEL

The wave-induced pore pressure responses around a pile foundation is investigated in this study, which involves the interaction between wave, soil and pile, as shown in Fig. 1. The profile of the

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