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Response of Open-Ended Piles in Sand to Simulated Earthquake and Seaquake

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ABSTRACT

During a simulated earthquake, horizontal motion caused about 20% permanent reductions in both the total axial compressive pile resistance and the plug resistance in an open-ended model steel pipe pile. The loss of capacity was primarily caused by a reduction of bearing capacity at the pile toe. But vertical motion resulted in no loss of pile or plug resistance. Plug failure was not observed in any horizontal or vertical shaking test. During a simulated seaquake, due to the induced excess pore water pressure and pressure gradients in the soil, the capacity of short ($\lesssim$ 27 m) open-ended single pipe piles installed in a simulated seadepth of greater than 220 m was reduced severely and the soil plugging resistance was degraded by more than 80%. The soil plug failed because of the upward seepage forces that developed in the soil plug due to excess pore water pressure produced in the bottom of the soil plug during the seaquake. The compressive capacity of short open-ended single piles in a simulated seadepth of less than 220 m was reduced only by about 10%, and the soil plug resistance was degraded by less than 5%. But the compressive capacity of an open-ended pipe pile with greater penetration ($\gtrsim$ 27 m) was not degraded, even in sea deeper than 220 m, and the soil plug within the open-ended pile installed in a simulated deep sea was stable after seaquake motion. In the case of the 2-pile or 4-pile groups, the compressive capacity after seaquake motion was not degraded at all regardless of pile penetration depth beneath the seabed, seawater depth or seaquake frequency.

INTRODUCTION

During an earthquake, 3 components of soil excitation (horizontal excitation of the ground, vertical excitation of the pile due to superstructure feedback, seawater excitation induced by vertical ground shaking, that is, a seaquake) can affect the resistance in soil plugs in open-ended pipe piles installed at offshore sites. While the ground and pile excitation can be modeled by exciting the soil and pile with simulated motions, seaquake excitation induced by the vertical groundshaking can be simulated by pulsing the water pressure at the seabed. A seaquake is a standing vertical compression wave in the ocean produced by vertical excitation of the seafloor during an earthquake. The pressure amplitude varies with the magnitude of the earthquake and the depth of seawater.

The static behavior of soil-plugged piles in sand has been studied by several researchers using model tests (Kishida and Isemoto, 1977; Klos and Tejchman, 1977; Paikowsky and Whiteman, 1990; O'Neill and Raines, 1991; Paik et al., 1993; Choi and O'Neill, 1997). Studies of the behavior of offshore pile foundations due to simulated earthquakes have been performed in small calibration chambers (Ochoa, 1990; Rao, 1997; Choi et al., 1997a, b). Study of the response of soil plugs to a seaquake induced by vertical ground excitation has been performed by Choi et al. (1998).

The first principal objective of this paper is to determine whether horizontal and vertical seismic excitations can degrade the soil plug in an open-ended pipe pile driven into submerged sand so significantly that the plug resistance would have to be reduced or ignored during an earthquake, and whether the seaquake would dislodge the plug. The second objective is to ascertain whether plug-in open-ended pile groups (2-piles or 4-piles) will be stable during seaquake motion induced in a deep sea.

EXPERIMENTAL ARRANGEMENT

The earthquake excitation testing system (Fig. 1a) consisted of a pressure chamber, the model pile, a cantilevered spring-mass system for maintenance of constant biased load on the pile head with a dynamic superposition that represented low-frequency

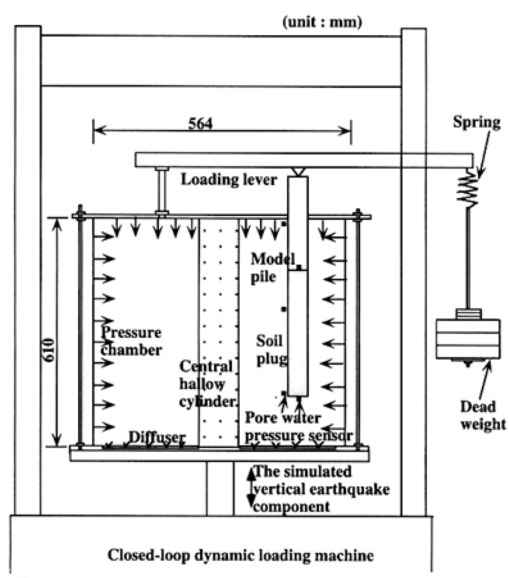

Fig. 1a Schematic diagram of test equipment; horizontal excitation test

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KEY WORDS: Earthquake, seaquake, pressure chamber test, open-ended pipe pile, degradation of compressive pile capacity, deep sea, soil plug.