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Pore Pressure Buildup in the Subsoil Under a Caisson Breakwater

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ABSTRACT

This paper summarizes the results of an experimental investigation of pore pressure buildup in the subsoil underneath a caisson breakwater subject to rocking motion. In the experiments, soil was silt with d_{50} = 0.045 mm. Foundation of the caisson was simulated by a rectangular plate, slightly buried in the soil. Pore water pressures were measured. With the rocking motion of the caisson, the pore-water pressure first builds up, reaches a maximum value and begins to fall off, and is eventually dissipated. The effect of amplitude and period of the caisson motion on pressure buildup was investigated in detail. The size and shape of the caisson were also investigated.

KEY WORDS: Breakwaters; caissons; gravity structures; liquefaction; pressure buildup; rocking motion; subsoil; waves

INTRODUCTION

Two of the foundation failure modes of caisson breakwaters are (1) slip surface failures and (2) excess settlement. In the former, the hydrodynamic loading on the subsoil creates stresses which exceed the strength of the soil (the so-called general shear failure). In this process, the strength of the soil may be influenced by pore pressure buildup due to cyclic shear deformations in the soil. In the second failure mode, vertical settlements occur when soil consolidation takes place. Here, too, consolidation may be affected by the buildup of pore pressure in the soil. (Coastal Engineering Manual, 2006, Chapter 2, Part 6, can be consulted for a detailed description of failure modes of caisson breakwaters.)

In their review on buildup of pore pressure underneath marine gravity structures subjected to wave loads, De Groot et al. (2006) consider various case histories. They report that pore pressures in the subsoil under a model caisson breakwater reached as much as 50% of the initial effective stress values in a large-scale model experiment (Kudella et al., 2006), one of the case histories considered. The corresponding figures for the other cases reviewed in de Groot et al. (2006) are: 7% for Ekofisk oil storage tank in the North Sea (field observation), 40% and 20% for two different storms for a typical North Sea gravity platform (obtained from a centrifuge test), and 30% for the well-documented Niigata-breakwater case, the widely reported case history in connection with the damage that occurred on 29.October, 1976 where the breakwater was hit by an extreme storm (the latter figure was obtained from calculations).

The pore pressure buildup is generated by two different mechanisms: (1) by wave motion, and (2) by caisson motion. In the first case, wave-induced pressure is transferred onto the subsoil surface, the seabed, through the rubble-mound bedding layer (Fig. 1). In the second case, the caisson motions are transferred to the seabed in the form of rocking motion just underneath the breakwater. Both of these effects generate cyclic shear stresses/strains in the subsoil. The latter is essentially equivalent to shaking up the subsoil steadily as the waves continue. This gradually rearranges the soil grains at the expense of the pore volume of the soil. The latter pressurizes the water in the pores, and presumably leads to buildup of pore-water pressure in the case of an "undrained" soil (silt and fine sand, or sand confined with a surface clay layer at the top) where the pressures will not dissipate as rapidly as they accumulate. In the extreme condition where the residual pore pressure exceeds the initial effective stress, liquefaction occurs. With the soil liquefied, effective stresses between individual grains vanish and the water-sediment mixture acts like a liquid.

As mentioned previously, Kudella et al. (2006), in a large-scale model experiment (the wave-flume length being 307 m, the width 5 m, and the depth 7 m), carried out tests with a model caisson breakwater placed on sand simulating the subsoil with a thin clay layer on the surface (Kudella et al., 2006, Fig. 9). One of the most important findings of Kudella et al. was that the accumulated (residual) pore pressures generated in the subsoil under the breakwater were due to caisson motions alone (the rocking motion), the wave contribution being negligible. This result is important in the sense that the processes related to the pore pressure buildup can be studied in the laboratory with a test setup where the model breakwater executes a rocking motion, in the absence of waves. (It may be noted that, in Kudella et al.'s experiments, rocking motion of the breakwater, which was large enough to generate pressure buildup, could only be induced by severe breaking wave impacts. Non-breaking waves did not generate pressure buildup.)

The objectives of the present study are two folds: (1) To study the pore pressure buildup in a systematic manner, using a test setup where the