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Influence of Sand Liquefaction on Self-burial of a Pipe Subject to Wave Action

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Coastal or offshore structures such as pipelines installed on the seabed are subject to cyclic horizontal loads either by direct hydrodynamic wave action or through the cyclic movement of risers or flow lines transmitted by floating structures. In fine sandy or silty soils, such cyclic loads may lead to liquefaction of the surrounding bed, which can play an important part in the processes of erosion, trenching or self-burial of the pipes. A large 1-g physical model was built to study the fluid-soil-structure interaction, with special emphasis placed on the conditions in which liquefaction occurs around a pipe instrumented with pore-pressure transducers. The experiments indicate a strong increase in pore pressure at the pipe-soil interface, and lateral visualization revealed the liquefaction of a soil band in the vicinity of the pipe. The penetration of the structure can be related to the phenomenon of liquefaction.

INTRODUCTION

The process of self-burial of structures resting on the seabed as a result of wave action has been extensively studied by Lyons (1973), Lambrakos (1985), Brennoden et al. (1986), Wagner et al. (1987), Palmer et al. (1988) and Morris et al. (1988), among others. Many of these studies were devoted to specific pipe-soil interaction in order to draw up design criteria for pipeline stability. The first experimental program was conducted at the University of Grenoble by Branque et al. (2001, 2002) to quantify the influence of cyclic amplitude and sand density on pipe penetration and changes in lateral resistance. Transitory liquefaction of the soil close to the pipe was noted in some of the tests, with peak cyclic pore pressures reaching the effective overburden stress.

In recent years, increasing attention has been paid to the effect on the stability of coastal or offshore structures of wave-induced liquefaction, in combination with scour effects. Field observations indicate that liquefaction can play an important part in erosion and stability problems for breakwaters or pipelines. Theoretical approaches have been devoted to the conditions of occurrence of seabed liquefaction due to the cyclic shear loading induced by waves (Sumer et al., 1999; Sassa et al., 2001; Cheng et al., 2001). Within the framework of the European program LIMAS (Liquefaction Around Marine Structures), experimental studies were conducted in sand flumes with buried pipes by Sumer et al. (2005a, b); Teh et al. (2003) focused on the effect of liquefaction of the entire seabed on pipeline sinking or flotation. Within the same program, a series of tests was performed at the University of Grenoble, oriented towards the study of fluid-soil-structure interaction, emphasizing pore-pressure measurements at the pipe-soil interface and within the soil. The conditions of liquefaction occurrence and their effect on pipe stability were studied. The first experimental results are presented here. In most of these tests, the effects of hydrodynamic forces were simulated by applying cyclic loads or displacements on the pipe model. Nevertheless, Damgaard and Palmer (2001) discussed the order of magnitude of the different processes leading to pipe instability and found that the hydrodynamic forces necessary to move a pipe resting on the seabed laterally cause sediment transport and liquefaction before any significant movement of the pipe occurs. Hence such experiments are more representative of the cyclic effects of a floating structure linked to flow lines or risers resting on the seabed.

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EXPERIMENTAL SETUP

General Settings

The experimental setup constructed at the University of Grenoble by Branque (1998) is similar to the one used in the Pipestab research program undertaken by Brennoden et al. (1986) and Wolfram et al. (1987). In the present research program, large modifications were made to the setup in order to achieve better control of the loading conditions, and to view laterally the liquefaction process around the structure. A rigid tank 2 m long, 1 m wide and 1 m deep is filled with sand. One side of the tank is made of glass, about 1 m × 1 m, for direct visualization of the deformation in the sand. Fig. 1 gives a general view of the experimental setup.

A trolley supporting a 1-m-long pipeline section can roll on 2 horizontal rails along the length of the tank, parallel to the windows. The pipe itself is free to move vertically between 2 guides and then penetrate the sand under its self-weight. The section of pipe and the glass are connected with a rubber joint, allowing the visualization of a 2-dimensional cross-section of the pipe-soil interaction perpendicular to the pipe axis. It is also possible to make a video of the experiments and show the occurrence of liquefaction.

Pipe Instrumentation

These experiments used a structure consisting of a half-pipe 200 mm in diam and 24 kg/m in mass/unit length. The pipe section was instrumented with 5 Druck PDCR 4030 pore-pressure transducers located on the external surface in contact with the soil. The pore pressure in the soil is transmitted to the transducer through a porous stone fixed at the connection between pipe and transducer. This part was carefully saturated before each test. The