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On a Horizontal Cylinder Resting on a Sand Bed Under Waves and Currents

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ABSTRACT

Experiments have been made in laboratory flumes to investigate the interaction of a mobile sand bed with a cylinder under currents and under waves. The cylinder is free to move vertically under its own weight. The presence of a cylinder always caused incipient bed motion and ripple formation to occur at lower Shields numbers. The cylinder axis always dropped and forces were always reduced, sometimes substantially, as a result of bed motion. Hydrodynamic force was measured through the surface pressures by a novel device.

NOMENCLATURE

C_D : drag coefficient
C_F : force coefficient
d : grain diameter
D : cylinder diameter
g : gravitational acceleration
h : water depth
H : wave height
KC : Keulegan-Carpenter number
R_w : bed Reynolds number in waves
R_* : roughness Reynolds number
T : wave period
u_o : amplitude of velocity on a flat bed in waves
$\bar{u}$: mean current velocity
β : Stokes parameter for oscillatory flow around a cylinder
ξ : amplitude of particle motion on a flat bed in waves
λ : wave length
μ : dynamic viscosity
ν : kinematic viscosity
ψ : Shields parameter
ψ_C : critical Shields parameter for incipient motion
ρ : density of water
ρ_S : density of sand
τ_0 : bed shear stress

INTRODUCTION

The stability of pipelines on the seabed when exposed to waves and currents has been the subject of much investigation. To assess instability, hydrodynamic forces are derived from wave/current kinematics with appropriate force coefficients and Coulomb friction has been assumed, again with an appropriate coefficient. However penetration of the pipeline into the bed is now considered to enhance stability. There has been considerable investigation of the lateral cylinder movement produced by wave loading causing the pipeline to dig itself in under its self weight, taking into account many factors, e.g., Soteberg et al. (1988) and papers in the Offshore Technology Conferences (OTC) of 1987 and 1989. Additional terms to represent the soil resistance force have been determined and understanding of stability criteria and associated hydrodynamic coefficients have been improved, for pipelines resting on sands and clays (Verley and Reed, 1989).

There has also been considerable investigation of scour around pipelines (cylinders) where the cylinder is fixed in position in currents (Bijker and Leeuwestein, 1984; Kjeldsen et al., 1973; Sumer et al., 1988); waves (Bijker and Leeuwestein, 1984; Sumer and Fredsoe, 1990; Zdravkovich, 1986) and for a vibrating cylinder (Sumer et al., 1988; Zdravkovich, 1986). The time scale for the development of scour has been investigated for a fixed cylinder in currents and waves (Fredsoe et al., 1991) and the onset of scour around buried pipes has been investigated in currents (Chiew, 1990) and waves (Sumer and Fredsoe, 1991). There has also been some observation of the self burial of pipelines in the field, associated with tidal motion, and spoilers for enhancing self-burial have been proposed (Hulsbergen, 1984, 1986). The influence of spoilers on self burial and scour in waves has been investigated in a laboratory study where the cylinder is fixed or moved vertically in a stepwise manner on a screw-bolt system (Gokce and Gunbak, 1991). In this system the imposed vertical force is not known and the experimental conditions are thus not completely defined. However, spoilers were shown to enhance burial.

In this study we investigate in the laboratory the situation where the cylinder is free to move vertically under its own weight, but not horizontally, on a sand bed under the action of currents and waves. No dynamic response is to occur. Hydrodynamic forces are to be measured from the average differential pressure on either side of the cylinder through an innovative and inexpensive device.

An important question is whether the cylinder becomes exposed or buried as a result of bed movement. If the cylinder were to become exposed hydrodynamic loading would be increased and instability would be more likely. It is not possible to reproduce full-scale values of all the relevant non-dimensional parameters involving the kinematics, the sand properties and the cylinder. In particular Reynolds numbers cannot be modelled. However the essential geometries and the Shields numbers for bed movement will be realistic so that the trends may be expected to relate to full-scale situations. Even so only a very limited parameter range has been investigated.

APPARATUS

The experiments were undertaken mainly in the 0.5-m-wide wave/current flume which is 20 m long and 0.4 m high in the Manchester Hydrodynamics Laboratory. The water depth was usually 0.25 m; wave heights up to 0.1 m and current velocities up

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