WATER ENTRY AND EXIT OF A HORIZONTAL CYLINDER

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Abstract

Some members of offshore structures and pipelines are circular cylinders which are often near to, or penetrating the fluid boundaries i.e. the free surface, sea bed or other solid boundary. The hydrodynamic loading and motions of such cylinders is therefore important in a wide variety of applications, e.g. pipelines, docking of ships, lowering of bodies through the free surface and to the sea bed, wave slam etc. Clearly, simple modelling is desirable for these practical applications, in addition to more advanced calculations.

For translational or low-frequency motions, a simple model may be built by ignoring wave damping (viscous damping may be included empirically) and considering the added masses of the submerged portion of the body. With simplified conditions on the undisturbed free surface ($z = 0$), these added masses are known analytically, see Greenhow and Yanbao (1987) and figure 1. For horizontal motions the free surface may not be deflected very much, implying that $\partial\phi/\partial z = 0$ on $z = 0$ is an appropriate boundary condition. Figure 1 shows a comparison between the theoretical added mass and that inferred from simple oscillation experiments. The variation with depth δ is large in both theory and experiment.

For vertical motions, at least at high Froude number ($F_r = V^2/ag$), the free surface does deflect considerably. Nevertheless a crude approximation may be made by applying $\phi = 0$ on $z = 0$ giving added masses shown dotted in figure 1. The force on the body is then given by the rate of change of fluid momentum $F = \frac{-d}{dt}(lA\dot{z}) = -l\frac{dA}{dz}\dot{z}^2 - lA\ddot{z}$,

where A is the added mass per unit length and l is the cylinder length. For constant velocity V of entry or exit this reduces to

$F = -l\frac{dA}{dz}V^2 = \frac{-l\rho}{2} \cdot C_s \cdot 2a \cdot V^2$ where C_s is the so-called slamming coefficient and is shown in the inset in figure 1 (dotted line is the theory, solid line is the experimental result of Campbell and Weynberg (1980)). The most striking features of this force term are V^2 dependence and the fact it always acts upwards regardless of the direction of motion, i.e. it will tend to accelerate rather than retard a cylinder during exit.

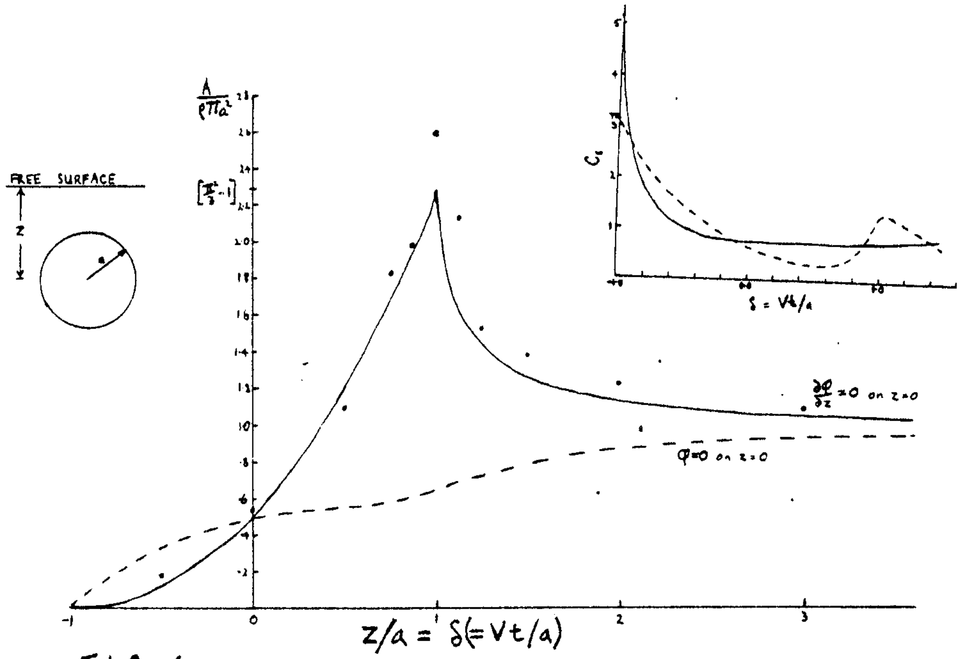


FIG. 1

Clearly the above simplifications of the free surface conditions will introduce errors: for example, for high-speed entry, the effect of free-surface rise is known to be important during the early stages of penetration, see inset in figure 1 (Greenhow and Yanbao (1987) seek to make corrections for this based on the "double-body" approximation). Furthermore the added-mass modelling tells us nothing about the fluid motion or free-surface deflections, and gravity (or finite Froude-number) effects are missing.

In an effort to provide accurate calculations with exact free-surface conditions the method of Vinje and Brevig was recently applied to the entry and transient motion of a vertically moving wedge in initially calm water (see Greenhow (1987)). The results for high-speed entry agreed very well with those calculated by self-similar theories which ignore gravity. Encouraged by this, runs have been made for various F_r values for constant speed entry and exit of a cylinder starting from various initial conditions. The preliminary results presented below, together with a video of experiments to be shown, indicate a wide and fascinating diversity of fluid motions. The results shown below (mostly for F_r = 0.51) are certainly not comprehensive and it is felt that further calculations will shed more light in the near future.

Figure 2 shows a ¼-submerged cylinder impulsively started downwards. A jet is quickly formed as in experiments and similar calculations with wedge entry. Figure 3 shows a ½-submerged cylinder entering the fluid with low-velocity, for which the fluid is able to flow in to cover the top of the cylinder. For higher speeds, figure 4, this is not possible and a cavity is formed behind the cylinder. For these entry cases, the hydrodynamic force on the body predicted by the added mass modelling (indicated by 0) is in fair agreement (see insets).

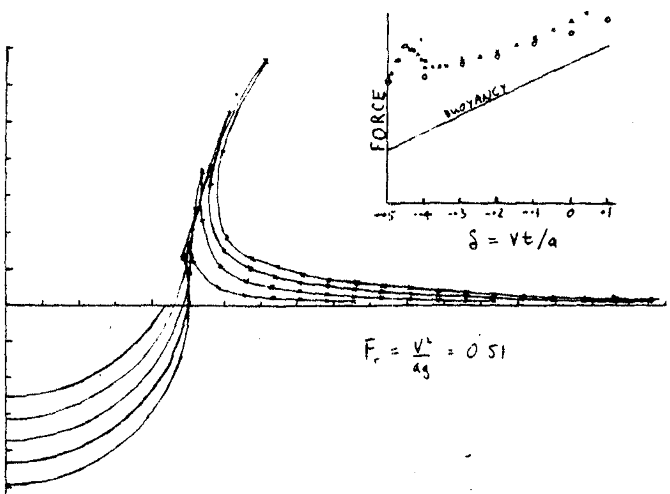


FIG. 2

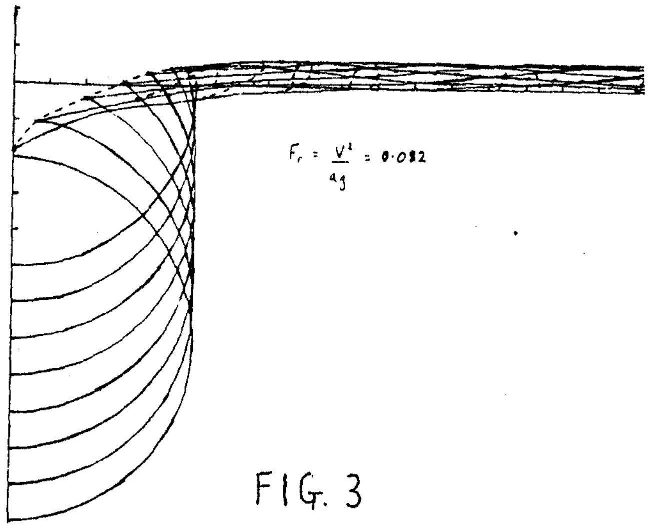
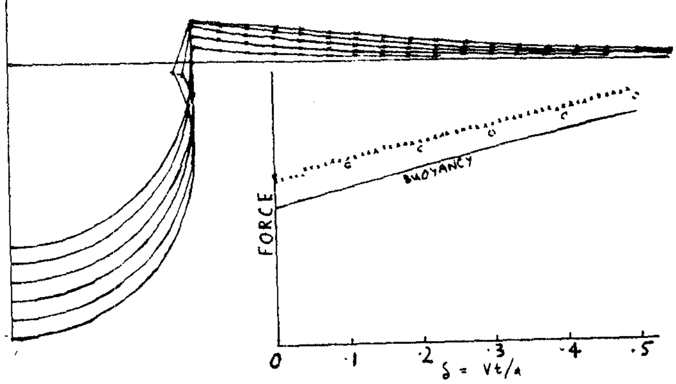


FIG. 3

FIG 4 $F_r = \frac{V^2}{ag} = 0.51$



For exit of a ½-submerged cylinder, the fluid flow, pressure at two points and force on the cylinder is shown in figure 5. The variation of the pressure, which can be understood in terms of the "draw down" and "rush up" of the fluid under the cylinder, has also been observed in a similar experiment, as shown, although the conditions were not identical. The force predicted by added mass modelling is only very approximate, but is at least in the correct direction, which is not always the case for the flow shown in figure 6. After step 50 in this flow the calculations break down, whilst in experiments the fluid under the cylinder quickly becomes full of bubbles. This indicates either cavitation (the calculations predict a large area of large negative pressures on the cylinder surface between the points marked •) or spontaneous free-surface breaking.

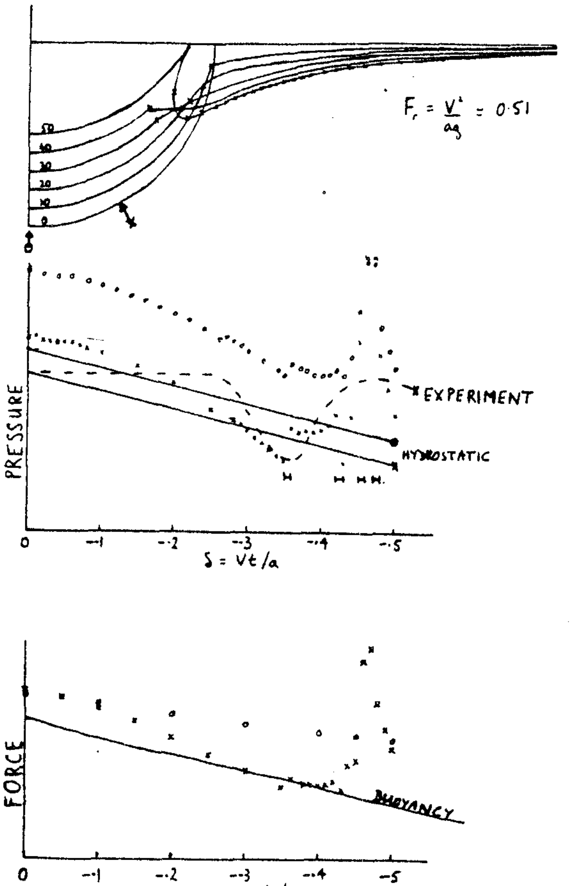


FIG. 5

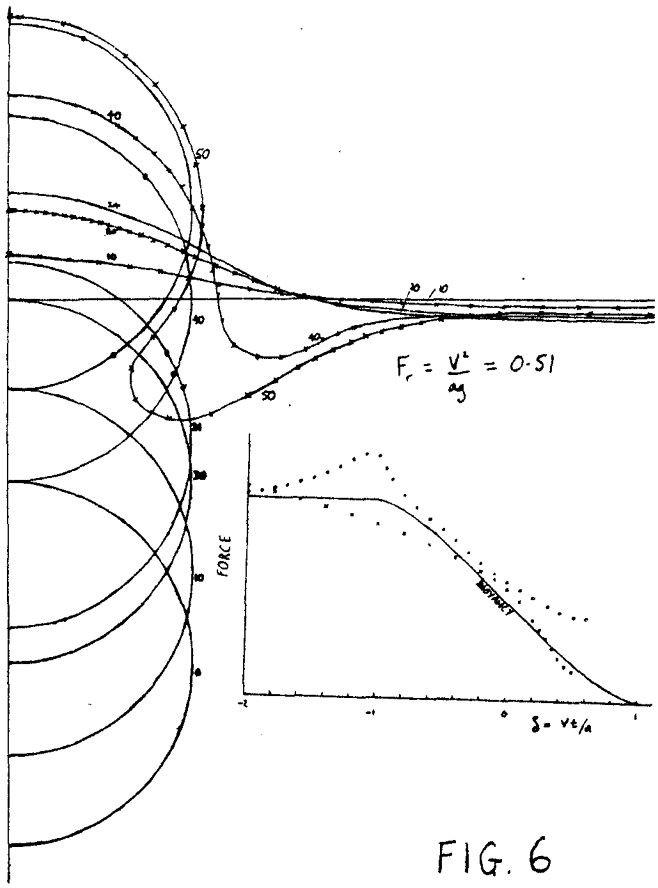


FIG. 6

References

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3) Greenhow M. (1987) "Wedge entry into initially calm water" to appear in Appl. Ocean Research.