Forces on Cylinders and Spheres in a Sinusoidally Oscillating Fluid

S. K. Chakrabarti and A. L. Wolbert. In the author's paper, he reports test results on forces on horizontal tubes in a sinusoidally oscillating fluid in a U-shaped vertical tunnel. Hydrodynamic coefficients derived from the Morison equation are shown to depend on the period parameter $U_mT/D$ ($U_m =$ maximum velocity, $T =$ oscillation period, and $D =$ tube diameter) and verify results of Keulegan and Carpenter [1] except at high values of $U_mT/D$ where $C_m$ has lower values. Notably, however, both experiments are conducted with one-dimensional oscillatory flow and no changing free surface.

The discussers have recently performed similar tests in waves past a vertical tube. The test setup is shown in Fig. 1(a). Test results will be reported in the future. The coefficients obtained from two one-foot instrumented submerged sections showed dependence on the period parameter rather than the Reynolds number. However, $C_m$ decreases from about 2.7 to about 1.8 at $U_mT/D = 12$ instead of 0.7 shown by the author. $C_D$ increases from near 0 to about 1.3 unlike the author's value of 2.9 at $U_mT/D = 12$. The total measured force on the tube was verified (within ±5 percent) by the mean curve drawn through the $C_m$ and $C_D$ values.

Transverse (or lift) forces measured on the tube sections show frequencies which are multiples of the wave frequency, as found by the author. However, the author's Fig. 8 shows $f$/f $= 2$ predominating for $U_mT/D$ from 0 to 50, while the discussers' results indicated $f$/f increasing from 1 to 3 for $U_mT/D$ between 0 and 17. In this respect the discussers' findings agree with those of Isaacson [2].

The resultant of the in-line and lift forces may be much higher than the in-line force alone. The writers agree with the author that the often-ignored transverse force should be considered in the design of cylindrical members. Fig. 1(b) shows an example of the resultant force on a tube at $U_mT/D = 15$. Note that the maximum resultant force acts at an angle of about 135 deg and is about 60 percent higher than the in-line force.

While the discussers generally agree with the author's conclusions, they would like to make the following comments. The accuracy of the author's data is the result of the controlled environment under which the test was made. Applicability of these results to prototype conditions is probably limited. The dependence of the hydrodynamic coefficients on the period parameter (with slightly more scatter) has also been found by the discussers. However, as evidenced from the preceding discussion, the results on $C_m$ and $C_D$ and particularly the nature of the lift frequencies change drastically in a two-dimensional flow under a changing free surface caused by a progressive wave.

References


2 Marine Research and Development, Chicago Bridge and Iron Company, Plainfield, Ill.

3 Numbers in brackets designate References at end of Discussion.

B. L. P. Miller. Professor Sarpkaya's results for circular cylinders indicate that $C_D$ and $C_M$ are independent of Reynolds number apparently confirming the findings of Keulegan and Carpenter (1) in a similar flow situation. However, since dimensional arguments suggested that $C_D$ and $C_M$ were functions of the Reynolds number as well as the Keulegan-Carpenter number, Keulegan and Carpenter's results have been re-examined. Scatter to the extent observed in their results [3] can often be traced to a missing parameter particularly when the intrinsic quality of the experiment is high. Their values for $C_D$ and $C_M$ were replotted in the Reynolds number ($R_B$) - Keulegan-Carpenter number ($N_B$) plane as shown in Figs. 1 and 2. It was found that constant coefficient contours could readily be drawn showing a clear Reynolds number dependence. The results of Sarpkaya's investigation (taken from [4]) are

4 Division of Maritime Science, National Physical Laboratory, Teddington, Middlesex, England.

5 Numbers in brackets designate Additional References at end of Discussion.

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also plotted in Figs. 1 and 2 (filled symbols). There is remarkable agreement between the two sets of results in this form of presentation. The apparent disagreement shown in Sarpkaya’s Fig. 4 is due to the different Reynolds number ranges examined in the two experiments. The general trends of the Crj contours are qualitatively supported by the higher Reynolds number investigations of Ranee [5].

This result has important implications concerning the validity of predictions of full-scale loads on ocean structures from model tests at low Reynolds numbers. Such extrapolation can only be confidently undertaken when the influence of Reynolds number is fully appreciated. Even in the limited Reynolds number range of these two sets of results the changes in Crj are quite dramatic. The extension of this type of experiment to higher Reynolds numbers is therefore essential.

**Additional References**


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**DISCUSSION**

**The Shrink-Fit of a Cylindrical Shell Onto a Discontinuous Rigid Mandrel**

S. J. Becker. Equation (1) of the paper and its solution is the same whether the restraint on the cylinder is internal (mandrel) or external (restraining band). Accordingly, would the author comment on any relation between his paper and the Discussion and Author’s Closure of the paper by Burton Paul, “Shrink Fits of Moderately Long Bands on Thin-Walled Cylinders,” Journal of Engineering for Industry, TRANS. ASME, Vol. 84, Aug., 1962, pp. 338–342?

R. Schmidt and D. A. DaDeppo. The author has investigated shrink-fit problems of considerable interest. However, the paper assumes that the shell is very thin as compared to distances between inflections, and therefore it is immaterial whether contact takes place at the shell’s inner or middle surface. Hence it might be advisable to use a large-deflection theory.

However, a word of caution is appropriate here, as many extant nonlinear theories assume that strain derivatives are of the same order of magnitude as strains themselves. That this is not always the case can be seen from the strain compatibility relation,

$$a e' = -(1 + e) \sin \beta,$$

where $$a$$ is the constant radius; $$\beta$$ is the meridional rotation; $$\gamma, \theta, z$$ are cylindrical coordinates; and $$e' = d e / d z$$. Equation (1) indicates that, for small strains and rotations, $$ae' \approx -\beta$$, i.e., if strain is much smaller than rotation, the dimensionless derivative of strain is of the same order of magnitude as the rotation.

Of course, no new shell theory can be developed herein. However, let us trace several possible steps in the derivations. According to footnote 5, the meridional couple $$M_z$$ is related to the changes of curvature by

$$M_z = -D (\chi_\theta + \nu \chi_\theta),$$

where

$$\chi_\theta = \beta'/(1 + e), \chi_\theta = (\cos \beta - 1 - e \beta)/a(1 + e).$$

Now, let us differentiate (2) together with (3) before and after neglecting strains in comparison to unity. Then, with $$e \ll 1$$ and (1), after linearization, we obtain

$$M'_z = -D \beta'',$$

and

$$M'_z = -D (\beta'' + \nu \beta'/a^2),$$

respectively, the second one of which, at least formally, is different from the first and the expression used in the paper. Hence, the ne-