IAHR Symposium 1970 Stockholm

ON THE PROBLEM OF APPARENT MASS[a] (E3)

Discussion

Helmut Kobus
Oberingenieur

Institut für Hydromechanik
Universität Karlsruhe

Karlsruhe
Deutschland

The author has developed a method for calculating the added-mass coefficient λ_e for vibrating structures which yields results in close agreement with experiments. The following comments do not refer to the method of calculation, but rather to the remarks about the similarity aspects of modelling vibrating structures.

The fact that λ_e is independent of the mass ratio and depends only upon the deflection curve of the structure and the boundaries of the fluid, is in agreement with Kirchhoff's original treatment for rigid bodies [1], in which the added mass is shown to be proportional to the volume and the density of the displaced fluid, the proportionality factor (i.e. λ_e) varying only with the shape of the body (and, in the case of a structure with flexible boundaries, the deflection curve). Consequently, the added-mass coefficient λ_e can indeed be determined experimentally for any given geometry by simply modelling the fluid boundaries and the deflection curve. For experimental investigation of a more general vibration problem, however, correct representation of added-mass effects is a necessary, but not a sufficient condition: then not only the boundary geometry and the deflection curve have to be modelled correctly, but also the elasticity and damping characteristics as well as the densities of the structure and of the fluid and the flow characteristics.

---

[a] by Dipl.-Ing. Fritz Lange, Institut für Strömungsmechanik, Technische Hochschule München, Deutschland

The similarity requirements for the example treated by the author may best be illustrated by a simple dimensional analysis. For the specified geometry and boundary conditions and with the (author's) assumption that damping effects can be neglected, the eigenfrequency f_L of the structure in vacuum depends only upon bending stiffness, length and mass density,

$$f_L = f(EI; h; \rho_m)$$

which combine to a single nondimensional term to yield

$$\frac{f_L^2 \cdot \rho_m \cdot h^5}{EI} = \text{const.} \tag{24}$$

indicating directly the interrelationship of the various parameters except for the numerical value of the constant.

If now the eigenfrequency f_W of the structure submerged in a fluid is considered, there results

$$f_W = f\left(EI; h; \begin{matrix}\rho_m \\ f_L\end{matrix}; \rho_W; n\right)$$

in which only one of the parameters ρ_m and f_L is truly an independent variable, since by eq. (24) f_L is dependent on the chosen combination of EI, ρ_m and h, or alternatively, ρ_m is defined by given values of EI, h and f_L. Consequently, only one of these parameters needs to be considered. Alternative combination of terms leads to the equivalent relationships

$$\frac{f_W^2 \cdot \rho_W \cdot h^5}{EI} = \phi_1\left(\frac{\rho_m}{\rho_W}; n\right) = \phi_2\left(\frac{f_L^2 \cdot \rho_W \cdot h^5}{EI}; n\right) \tag{25}$$

The term on the left remains invariant for model and prototype conditions only if both parameters on the right hand side also remain invariant. (The interchangeability of the mass density ratio and the term containing f_L is readily apparent from eq. (24).

The merit of the author's analysis consists in rendering eq. (25) in the more specific form of eq.(23) as

$$\frac{EI}{\rho_w \cdot h^5}\left(\frac{1}{f_W^2} - \frac{1}{f_L^2}\right) = \lambda_e(n) \tag{23*}$$

by which he has reduced the 3-parameter problem to one of 2 parameters. It must be pointed out, nevertheless, that the experimental determination of λ_e as suggested by the author, i.e., by modelling only the fluid boundaries and the deflection curve, does by itself not suffice to evaluate the eigenfrequency f_W for the prototype: this can only be achieved if either f_L for the prototype is known, or if it is evaluated from the model by means of eq.(24), which requires correct consideration of the mass density ρ_m.

Finally it is to be stressed that the treatment shown here is restricted to the specific problem of determining the eigenfrequency of vibrating structures for which damping effects are negligible. More general model tests for problems of forced or self-induced vibrations of practical interest, however, usually do make it necessary to consider several additional similarity parameters [2].

References:

[1] H. Rouse, Ed., "Advanced Mechanics of Fluids", John Wiley & Sons, New York 1959.

[2] E. Naudascher, "Flow-Induced Structural Vibrations", Discussion of paper by G.H. Toebes, ASCE Journal of the Engineering Mechanics Division, Aug 1966.