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Impact on composite plates in contact with water

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Abstract

In marine applications, composite structures in contact with water are subjected to impacts by projectiles large and small. While the presence of water is known to affect the dynamics of immersed structures, its effects on the impact dynamics is unclear. This study shows that the contact force history is not affected if the mass of the projectile is large. The opposite is true if the mass of the projectile is small compared to that of the target

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1. Introduction

Foreign object impacts are more likely to induce damage in composite structures than in metallic structures and that damage can result in significantly reduced mechanical properties [1]. The dynamic behavior of plates in contact with water has been studied by many authors since Lamb [2] and the presence of a heavy fluid leads to lower natural frequencies. This article will consider impacts on composite plates in contact with water and examine how the presence of water affects the contact force history and the dynamic response of the plate after impact.

A model for the dynamic response of a structure to low velocity impacts should account for the dynamics of the structure, the dynamics of the projectile, and the local indentation in the contact zone. When the mass of the projectile is small compared to that of the plate, only a small region surrounding the contact zone participates in the response during the impact. This is called a wave-controlled impact. When the mass of the projectile is large compared to that of the plate, the entire plate participates in the response and this case is called a boundary controlled impact [1]. The effect of local indentation depends on the ratio between the indentation and the overall bending deflections. If this ratio is small, indentation effects can be neglected otherwise they have a significant effect on the contact force history. These factors were studied in [3]. In marine applications, structures made of isotropic and composite materials in contact with water are subjected to various types of impacts including those induced by logs or debris generated by tsunamis (Haehnel and Daly [4], Naito et al [5]) or by ice floes. Added-mass

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effects on rigid bodies are reviewed in [6]. Here we examine the dynamic impact response of composite plates in contact with water.

2. Vibration of structures in contact with water

The vibration of structures in contact with a fluid is analyzed by modeling the structure as a beam or a plate and the fluid is usually modeled as an inviscid and irrotational fluid for which the velocity potential satisfies Laplace's equation. Kinematic and dynamic boundary conditions are applied at the fluid-structure interface and it is usually assumed that the modes shapes for the "wet modes" are the same as those for the "dry modes". In addition to the strain energy and the kinetic energy of the plate, kinetic energy is also stored in the fluid. This section examines general trends for beams and plates interacting with fluids.

2.1. Immersed cantilever beams

Structures oscillating in a fluid induce motion in the surrounding fluid while at large distances, the fluid remains undisturbed. Experimental results for cantilever beams in vacuum, in air, and in water [7] show that the natural frequencies in a fluid are directly proportional to those in vacuum (Fig. 1.a). For this particular beam E=214 GPa, ρ =7800 kg/m^3, L=300 mm, b=19 mm and h=1.6 mm. The presence of air has a very small effect on the natural frequencies while for beams submerged in water the frequencies are strongly lowered. These results illustrate the "added-mass" effect by which the interaction of the beam and the fluid is equivalent to a virtual fluid mass moving with the beam (Fig. 1.b). The natural frequencies in a vacuum and in a fluid are in the ratio

$$\omega_F / \omega = (1 + m_a / m)^{-1/2} \quad (1)$$

where m is the mass of the beam per unit length and m_a is the corresponding added mass of the fluid. Fig. 1.a shows the virtual added mass for a rectangular beam fully immersed in a fluid from which we find the mass ratio

$$m_a / m = \pi \rho_F b / (4 \rho h) \quad (2)$$

which is the result first obtained by Chu in 1963 cited in many publications including [8]. For the beam in water, Eq. 1 predicts a frequency ratio ω_F/ω of 0.6749 which is very close to the slope of the line obtained by fitting the experimental results (Fig. 1.a).

In the first example, the cross-section is rectangular and the mid-plane, the xy-plane in Fig. 1.b, is parallel to the free surface of the water. Han and Xu [9] considered the vibration of cylindrical cantilever beams clamped at the bottom (Fig. 2) and calculated the first three natural frequencies for eight values of the radius to depth ratio (a/h= 0.003, 0.005, 0.010, 0.020, 0.025, 0.030, 0.040, 0.050). The 24 natural frequencies (3 modes x 8 depth ratios) of the beams in water are proportional to those of the beams in vacuum with a slope of 0.8823. The analysis assumed a density of water of 1000 kg/m^3 and for the cylinder a density of the 2450 kg/m^3 and an elastic modulus of 2.94x10^7 kPa. The depth of water h=20 m.