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Reflection and transmission of regular water waves by a thin, floating plate

F. Nelli [a,*], L.G. Bennetts [b], D.M. Skene [b], J.P. Monty [c], J.H. Lee [c], M.H. Meylan [d], A. Toffoli [e]

[a] Centre for Ocean Engineering Science and Technology, Swinburne University of Technology, Hawthorn, VIC, Australia
[b] School of Mathematical Sciences, University of Adelaide, Adelaide, SA, Australia
[c] Department of Mechanical Engineering, University of Melbourne, Melbourne, VIC, Australia
[d] School of Mathematical and Physical Sciences, University of Newcastle, Callaghan, NSW, Australia
[e] Department of Infrastructure Engineering, University of Melbourne, Melbourne, VIC, Australia

HIGHLIGHTS

- Reflection and transmission of waves by thin plate.
- Low reflection values when the plate is allowed to drift.
- Wave transmission dependent by incident period and amplitude.
- Relevant energy dissipation occurring in the presence of water overwash.

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ABSTRACT

Measurements of the wave fields reflected and transmitted by a thin floating plastic plate are reported for regular incident waves over a range of incident periods (producing wavelengths comparable to the plate length) and steepnesses (ranging from mild to storm-like). Two different plastics are tested, with different densities and mechanical properties, and three different configurations are tested. The configurations include freely floating plates, loosely moored plates (to restrict drift), and plates with edge barriers (to restrict waves overwashing the plates). The wave fields reflected and transmitted by plates without barriers are shown to become irregular, as the incident waves become steeper, particularly for the denser plastic and the moored plate. Further, the proportion of energy transmitted by the plates without barriers is shown to decrease as the incident wave becomes steeper, and this is related to wave energy dissipation.

1. Introduction

Thin, floating plates have been used to model sea ice floes (discrete chunks of sea ice) and very large floating structures (VLFSs, e.g. floating runways), with a large branch of these models developed to investigate interactions between surface-water waves and the plates (floes or VLFSs). For these applications, typically, the horizontal dimensions of the plates are comparable to wavelengths, so that the plates flex in response to the waves, in addition to experiencing rigid-body motions.

* Correspondence to: Centre for Ocean Engineering Science and Technology, Swinburne University of Technology, P.O. Box 218, Hawthorn, VIC 3122, Australia.
E-mail address: fnelli@swin.edu.au (F. Nelli).

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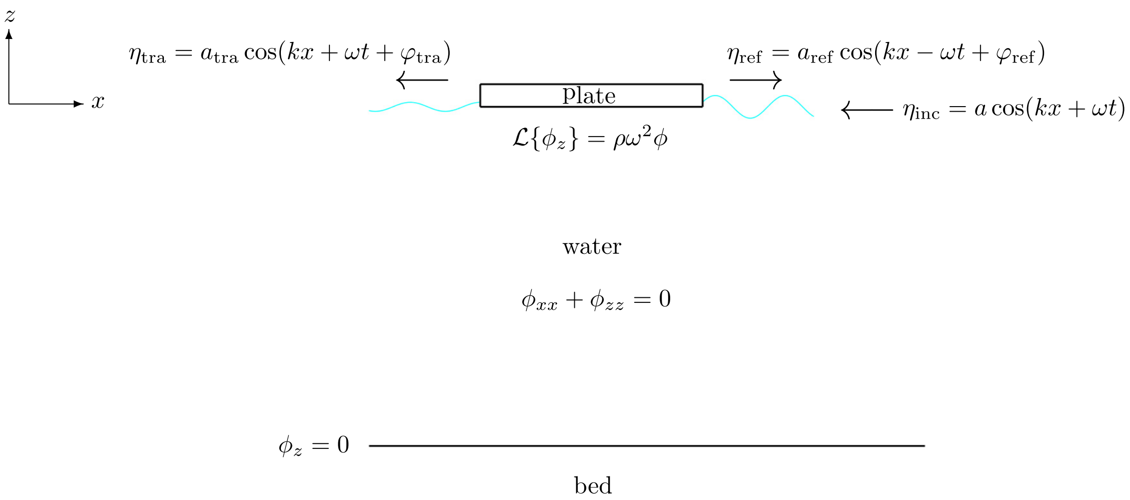

Fig. 1. Schematic of the two-dimensional canonical model and governing equations of the associated boundary-value problem.

Particularly for sea ice applications, wave–plate interaction models are used to predict the proportions of incident wave energy reflected and transmitted by the floe, as this provides predictions of the distances ocean waves travel into the ice-covered ocean and impact the ice cover [1–3].

The canonical theoretical wave–plate interaction model is a Kirchoff–Love thin-plate floating on top of an inviscid, incompressible fluid undergoing irrotational motions, meaning the water velocity field can be defined as the gradient of a scalar potential function. It assumes linearity (in terms of the Bernoulli water pressure, the material response of the plate, and the moving boundary conditions) and harmonic time dependence at a prescribed angular frequency $\omega = 2\pi/\tau$, thus fixing the open-water wavelength λ (for a given water depth). The plate oscillates in response to an incident wave at the prescribed frequency, in both its rigid-body and flexural modes, but does not drift. Water and plate motions are coupled at the lower surface of the plate only, assuming that all points on this surface remain in contact with the water during motion. This produces a boundary-value problem for the time-independent component of the velocity potential, ϕ, in which the plate cover provides a high-order surface condition, effectively removing the vertical geometry of the plate from the problem. Reflection and transmission result solely from impedance mismatches (i.e. different wave numbers) between the open water and the plate-covered water.

Meylan and Squire [4] studied wave reflection and transmission by an ice floe of uniform thickness h, using a two-dimensional version of the canonical model (one horizontal dimension and one depth dimension, with coordinates x and z, respectively), similar to the theoretical model used in this study, although neglecting draught of the plate and its surge motion. Fig. 1 shows a schematic of the two-dimensional canonical model and the associated boundary-value problem for ϕ. The operator $\mathcal{L}$ involved in the surface condition is defined as $\mathcal{L}\{\bullet\} = \rho g$ for the intervals of open water, where ρ is the water density and $g \approx 9.81$ m s^{-2} is the constant of gravitational acceleration. For the interval occupied by the plate, it is defined by

$$\mathcal{L}\{\bullet\} = (\rho g - \omega^2 m)\bullet + \frac{Eh^3 \bullet_{xxxx}}{12(1-\nu^2)} \tag{1}$$

where m is the plate mass per unit length, E is its Young's modulus and ν is its Poisson's ratio. Free edge conditions, $\phi_{xxz} = 0$ and $\phi_{xxxz} = 0$, are applied at the ends of the plate.

Motion is forced by a train of regular waves (with sinusoidal profiles), incident on the plate from its right-hand side, with surface elevation $\eta_{\mathrm{inc}} = a\cos(kx + \omega t)$, where a is a prescribed amplitude and $k = 2\pi/\lambda$ is the open-water wave number. The plate partially reflects and partially transmits the incident waves. Far enough away from the plate that the exponentially decaying local motions have died out, the reflected and transmitted fields are regular wave trains, with surface elevations

$$\eta_{\mathrm{ref}} = a_{\mathrm{ref}} \cos(kx - \omega t + \varphi_{\mathrm{ref}}) \quad \text{and} \quad \eta_{\mathrm{tra}} = a_{\mathrm{tra}} \cos(kx + \omega t + \varphi_{\mathrm{tra}}), \tag{2}$$

respectively, where a_{ref} and a_{tra} are the reflected and transmitted amplitudes, and φ_{ref} and φ_{tra} are phases. In the front field, on the right-hand side of the plate, the incident and reflected waves superpose to create a partial standing wave field. In the rear field, on the left-hand side, the wave field consists of transmitted waves only.

The canonical model is energy conserving, meaning that the energy in the incident waves is distributed into the reflected and transmitted waves. This property is expressed as $R + T = 1$, where $R = |a_{\mathrm{ref}}/a|^2$ and $T = |a_{\mathrm{tra}}/a|^2$ – the proportions of energy reflected and transmitted – are referred to as the reflection and transmission coefficients, respectively.

Meylan and Squire [4] found that R is generally less than order 10^{-2} for plate lengths less than approximately one-third the incident wavelength, implying that the incident wave is almost entirely transmitted in this regime. Longer plates were