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Semi-analytical technique for isolating the pseudo-Rayleigh component of the field induced by a transiently responding submerged cylindrical shell

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ABSTRACT

A semi-analytical technique is proposed for isolating the pseudo-Rayleigh (A_0) component of the field radiated into the surrounding fluid by a submerged elastic cylindrical shell. The technique is based on the simultaneous use of two fluid–shell interaction models, one based on the Reissner–Mindlin shell theory, and the other on the Kirchhoff–Love shell theory, and is aimed at offering the possibility of analyzing the pseudo-Rayleigh component in its pure form, an approach that has certain rather important advantages over analyzing the component as a part of the overall radiated hydrodynamic pattern. The technique is applied to the analysis of the radiation by two elastic shells with parameters that are common in industry, and the high computational efficiency of the technique is demonstrated.

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1. Introduction

Several distinct wave components of the radiated hydrodynamic field are known to exist when a submerged elastic shell is responding to a transient loading, namely the symmetric Lamb waves S_0, the anti-symmetric Lamb, or pseudo-Rayleigh, waves A_0, and the Scholte–Stoneley waves A, along with, of course, the scattered and incident waves (e.g. Ahyi et al., 1998; Derbesse et al., 2000; Sessarego et al., 1997; Iakovlev et al., 2013, 2014 and references therein).

These individual components have been analyzed in considerable detail, usually as an integral part of the overall radiated field. Occasionally, however, one or more components were isolated and analyzed in their 'pure' form, as, for example, was done in Sessarego et al. (1997) for the S_0 and A waves where such isolating allowed for obtaining pure resonance spectrums of the respective waves uncluttered by the other radiated components. The possibility of producing such resonance spectrums alone would be a more than sufficient justification of the need for reliable and efficient procedures allowing the radiated component isolation, but their use is by no means limited to producing resonance curves, and offers a range of other potential applications. At the same time, we are not aware of any purely theoretical technique that allows for such an isolation.

In the present study, we propose a methodology that allows for a numerical isolation of the pseudo-Rayleigh (A_0) radiated component. The main idea of the methodology is based on our earlier work on cylindrical shells, in particular on the

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Nomenclature

A_0	antisymmetric Lamb (pseudo-Rayleigh) wave
A	Scholte–Stoneley wave
c_f	sound speed in the fluid
c_s	sound speed in the shell material
h_0	thickness of the shell
p	total pressure
p_α	peak incident pressure
r_0	radius of the shell
R_0	radial distance to the source of the pulse
S_0	symmetric Lamb wave
S_R	source stand-off
t	dimensionless time
v_0^*	transverse displacement of the middle surface of the shell
w_0^*	normal displacement of the middle surface of the shell
θ	angular coordinate of the polar coordinate system
λ	exponential decay rate
ν	Poisson's ratio
ρ_f	density of the fluid
ρ_s	density of the shell material
ϱ	radial coordinate of the polar coordinate system

studies of the radiated fields produced by different shell models (Iakovlev, 2008a,b; Iakovlev et al., 2013, 2014).

Namely, it was observed that various shell models produce results of rather widely varying accuracy. The simulations based on the Reissner–Mindlin shell model (Iakovlev et al., 2013, 2014) were found to be most accurate, and were seen to adequately reproduce the S_0 waves, the A_0 waves, and the A waves. At the same time, the simulations based on the Kirchhoff–Love model with the bending stiffness taken into account (Iakovlev, 2008a,b; Iakovlev et al., 2013) produced a wave that was neither the S_0 nor the A_0 wave and that had certain characteristics of both of them; therefore, it was the least useful of the models considered. Finally, the simulations based on the Kirchhoff–Love model with bending stiffness neglected (Iakovlev, 2008a,b; Iakovlev et al., 2013) produced very accurate results for the S_0 wave, but the A_0 wave was not reproduced at all, thus the model was quite useful but *only* in those cases where the S_0 wave alone was of interest.

In one of our recent projects, it became important to be able to isolate the A_0 wave, and, in the light of the above findings, an idea was born to simultaneously use the numerical simulations based on both the Reissner–Mindlin and the Kirchhoff–Love no-bending models, subsequently subtracting the pressure produced by the latter from that produced by the former with the goal of obtaining the A_0 wave in its 'pure' state. The idea has been implemented and was shown to work very well, and it is detailed in the remaining sections of the present study.

2. Mathematical model

The models that we are employing here have been introduced, discussed in much detail, and successfully validated in our earlier work (Iakovlev, 2008a,b; Iakovlev et al., 2013, 2014), thus we include in the present study only a brief summary of the main features of the respective solutions.

To that end, we are considering an elastic circular cylindrical shell of radius r_0 and thickness h_0 submerged into an irrotational, inviscid, and linearly compressible fluid of density ρ_f and with the sound speed c_f. The density, Poisson's ratio of and the sound speed in the shell material are ρ_s, ν, and c_s, respectively. The normal and transverse displacements of the middle surface of the shell are w_0^* and v_0^*, respectively. The polar coordinate system (ϱ, θ) is employed. The geometry of the problem is shown in Fig. 1.

The shell is subjected to an external pressure pulse originated at a point source located at the distance R_0 from the axis of the shell (and, therefore, with the standoff of $S_R = R_0 - r_0$), with the pressure p_α at the instant of its first contact with the

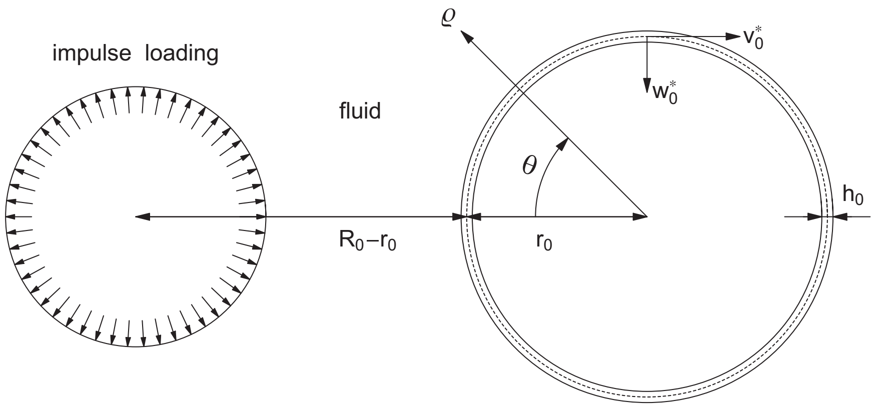

Fig. 1. Geometry of the problem.

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