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Modeling the transient radiation by fluid-interacting shell systems

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Abstract. *We present a semi-analytical approach, based on the Reissner-Mindlin shell theory, for the numerical analysis of the interaction between elastic circular cylindrical shell structures and external acoustic pulses or weak shock waves. We discuss the advantages and limitations of the approach over alternative methodologies and provide numerical results for the case of a submerged fluid-filled shell.*

Keywords: Transient radiation; impulse loading; fluids; shells; semi-analytical approach.

1 INTRODUCTION

We present a semi-analytical approach based on the Reissner-Mindlin theory of shells for the numerical analysis of the interaction between elastic circular cylindrical shell structures and external acoustic pulses or weak shock waves.

A simpler semi-analytical approach based on the Kirchhoff-Love theory of shells was developed in our earlier work [1-3]. Although it was rather efficient and accurate in reproducing a number of features of the interaction, it had one significant drawback, namely, it was not capable of accurately reproducing all of the shell-radiated waves that comprise the radiated field. In an attempt to improve the accuracy of the approach, we incorporated the more advanced Reissner-Mindlin shell theory in the framework of the semi-analytical approach [4]. The model was applied to the case of a submerged fluid-filled shell and the obtained results demonstrate that not only the symmetric and anti-symmetric Lamb waves are reproduced, but also the Scholte-Stoney wave.

We emphasize that the introduced approach relies on the assumptions of a shell theory, as opposed to completely abandoning all the simplifications due to the unique geometry of the shell structure and switching to a fully elastodynamic model (e.g. [5]).

The main practical goal of this work is to provide practitioners with an efficient tool for pre-design analysis of marine structures.

2 THE MODEL

We consider an elastic circular cylindrical shell of radius r_0 and thickness h_0 filled with and submerged into the same fluid. The fluid is assumed to be irrotational, inviscid, and linearly compressible. The shell is subjected to a transient impulse loading. Instead of addressing the three-dimensional interaction, we consider the middle cross-section of the incident wave-front (i.e., the cross-section by the plane passing through the source and the point where the pulse first contacts the shell), and extend it infinitely in both directions, thus effectively introducing a ‘cylindrical’ incident load. The internal and external fluids are assumed to be governed by the wave equations for their corresponding velocity potentials. The fluid velocity potential components are assumed to satisfy the no-flow conditions on the interface, the decay condition at the infinity, the boundedness condition at the center of the fluid domain and the zero initial conditions. The system of integro-differential equations was solved numerically using

an explicit finite-difference scheme where the integrals were approximated using the trapezoidal rule, and the derivatives were approximated using central differences. A time step of 0.001 was adopted, which ensured convergence for the parameter values of interest. For further details on the model the reader is referred to [4].

3 NUMERICAL RESULTS AND DISCUSSION

We consider a thick steel shell filled with and submerged into the same fluid with radius $r_0 = 1$, thickness $h_0 = 0.1$, sound speed in the material 5790m/s , density 7900kg/m^3 and Poisson's ratio 0.30 . The sound speed and density in the fluid were taken as 1470m/s and 1000kg/m^3 , respectively. The shell was subjected to an acoustic pulse or a very weak shock wave with the source located at the distance of four radii of the shell from its middle surface, with the rate of the exponential decay and the peak pressure in the front of 3.76ms and 25kPa , respectively.

A number of representative snapshots of the field obtained using the proposed model are shown in Figure 1, with the depicted instants chosen to highlight the most important stages of the interaction.

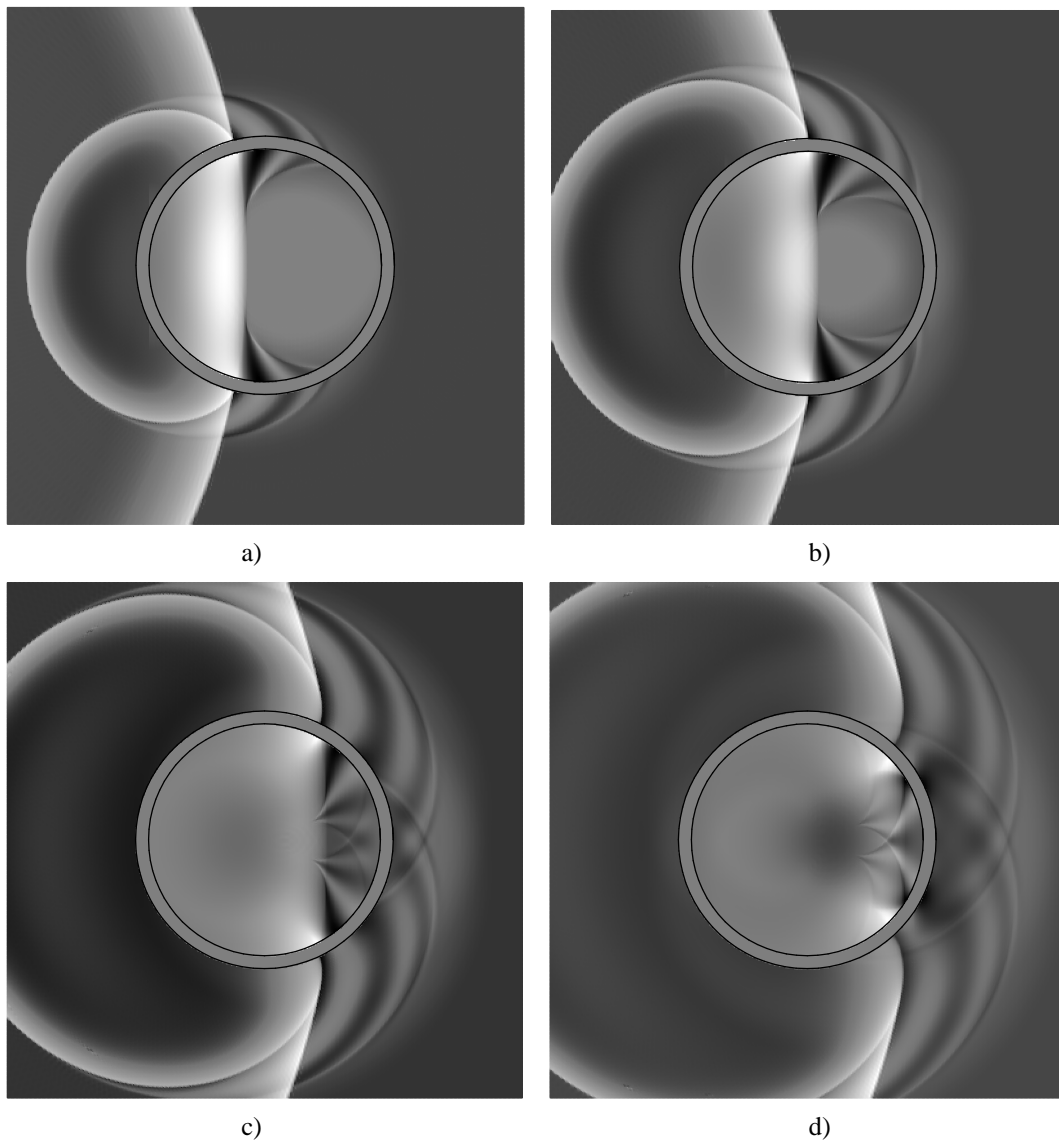


Figure 1: Dynamics of the radiated field for a steel shell with $h_0/r_0 = 0.1$ for a) $t = 0.85$; b) $t = 1.10$; c) $t = 1.55$; d) $t = 1.85$

Three distinctly different types of radiated waves are detectable in both the internal and external fluids. The first two waves are the symmetric Lamb wave S_0 and the anti-symmetric Lamb wave A_0 that have been seen both experimentally and numerically in several earlier studies of a submerged evacuated cylindrical shell [6, 7]. We also highlight the existence of the wave formation that originates in the close proximity of the inner shell surface. The appearance of this wave is matched by the phase change of the A_0 wave in the external fluid, and although not quite as distinctly defined as in the internal one, a wave formation that is certainly not the A_0 wave can also be detected in the external fluid in the proximity of the shell surface. We believe that these waves are nothing else but the Scholte-Stoneley waves, or A waves.

4 CONCLUSIONS

We considered the radiation by a submerged fluid-filled circular cylindrical shell subjected to an external acoustic pulse, and employed the Reissner-Mindlin shell theory to numerically simulate the interaction in question. The obtained numerical results demonstrated that three distinctly different types of radiated waves were reproduced in both the internal and external fluids, namely, the symmetric and anti-symmetric Lamb waves, and the Scholte-Stoneley waves. We believe that the proposed model can be used to provide practitioners with an efficient tool for pre-design analysis of the hydrodynamic field induced by a marine structure responding to a non-stationary load of moderate intensity and short duration.

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