SHOCK WAVE INTERACTIONS WITH FLUID-FILLED SHELLS

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Summary. In this work a geometrical theory of diffraction is used to study the interaction of an underwater shock wave with fluid filled shells. The fluid inside may be different than the fluid outside the shell.

1 INTRODUCTION

Marine structures can be subjected to both in-air and underwater explosions. Underwater water explosions generate both a shock wave that decay rapidly with time and an oscillating and migrating explosion bubble. The shock waves can propagate over long distances and cause damage to structural panels but generally do not transfer enough momentum to induce overall deformation of the ship. Explosion bubbles oscillate with very low frequencies and can induce whipping of nearby structures and induce severe damage.

Here we consider the effect of underwater blasts on nearby structures. Near the explosive charge, the surrounding water behaves nonlinearly but, at distances larger than 30 times the radius of the charge, the behavior is linear and is governed by the three-dimensional wave equation, and the wave front propagates a speed near 1500 m/s. Previous investigators have analyzed the response of submerged shells to underwater blasts using various analytical or numerical methods. Generally the results are presented in the form of plots of pressure, velocities, or stresses at several points. Recently Iakovlev [e.g. 1] and Hasheminjad [e.g. 2] presented numerical results in graphical from showing the whole field interaction of underwater blasts with cylindrical and spherical shells. These references show complex interactions of many wave fronts that are difficult to identify and follow with time. We present a geometrical theory of diffraction to predict the location of the various wave fronts generated by the interaction of a shock wave with cylindrical and spherical shells.

2 INTERACTION OF UNDERWATER SHOCK WAVE AND A PLATE

First we show that the well-known Taylor's approach in which the plate is modeled as a rigid body is accurate when its mechanical impedance is much larger than that of the surrounding fluid. Then, we show that, when the plate is backed water on both sides, an
incoming shock wave appears to propagate from the left side of the plate to the right side and beyond as if the plate was not there except for a small region near the plate. Sometimes it is said that the plate is transparent to the shock wave. While the incident wave is a pressure pulse with a zero rise time, the pulse on the right side of the plate has a finite rise and therefore the transmitted wave is technically not a shock wave. This important result will be used in the analysis of the interaction of shock waves with various shells. Taylor’s approach is shown not always appropriate for composite structures.

3 SHOCK WAVE INTERACTIONS WITH CYLINDRICAL SHELLS

3.1 Evacuated shells

When the inside of the shell is filled with air the internal pressure is essentially zero. In the surrounding water, three types of waves are observed: the incident or direct wave, the specularly reflected wave, and the creeping waves or Franz waves in the shadow zone. Creeping waves propagate along the circumference and then radiate back into the fluid in the tangential direction.

3.2 Water-filled shells

When the inside of the shell is filled with water, the incident waves propagate through the shell into the fluid as if the shell is transparent to the wave. In the internal space the incident wave reflects from the internal surface of the shell and several new wave fronts with cuspidal singularities are generated. The evolution of these wave fronts is better understood by considering the caustics formed by rays reflecting from the inside surface of the shell.

3.3 Internal fluid with wave velocities that are different than that of water

When the speed of sound is lower inside the shell than outside, two new phenomena occur. Inside the shells, direct rays form two caustics that bound the wave front for the direct wave. In the shadow zone, creeping waves move in a direction normal to the interface and are transmitted into the shell at an angle that can be calculated using Snell’s law. These transmitted waves propagate in the region between the caustics and the shell wall and their wave fronts connect the creeping waves outside the shells and the wave front of the incident wave inside the shell. When the incident wave propagates faster inside the shell than outside, rays that reach the inside surface of the shell and are refracted into the water again form a new wave front in the outside fluid. Other complicating effects have also been identified.

9 CONCLUSIONS

The approach developed here is used to unravel the complexity of the interaction between the shock wave and the structure and bring much needed insight.