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RESONANCE-LIKE PHENOMENA IN SUBMERGED CYLINDRICAL SHELL SYSTEMS SUBJECTED TO MULTIPLE SHOCK LOADS

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Abstract. We consider the interaction between a sequence of two shock waves and a cylindrical shell submerged into and filled with fluid. The focus of our study is on determining the effect that such a two-front loading has on the extremities of the stress state and the peak hydrodynamic pressure observed in the system, with the ultimate goal of providing the practitioner with the information that could be used at the pre-design stage in determining the most and least dangerous loading conditions for fluid-contacting industrial structures subjected to shock loading.

1 INTRODUCTION

As has been recently demonstrated [1], when a submerged evacuated cylindrical shell is subjected to a sequence of two shock waves or acoustic pulses, certain resonance-like effects are observed for certain values of the delay between the incident wavefronts, with very high overall peak stress observed in the system as a result. In the present study, we are advancing the earlier work in that we are trying to determine the effect of the inner fluid on the phenomena observed, and also to establish if there are any fundamental differences between the scenarios of an evacuated and fluid-filled shell.

2 MATHEMATICAL FORMULATION

We are using the semi-analytical methodology that has been introduced in [2-5] and adapted for the double-front loading in [1], but assume that now there is an internal fluid present as well. The fluids are assumed to be governed by the wave equations, and the Love-Kirchhoff theory of thin shells is used to model the structural dynamics. Such formulation has certain limitations as far as the shell thickness is concerned [5], but since our primary objective is to investigate the resonance-like effects, these limitations are of little importance, especially for very thin shells (thickness-to-radius ratio of 0.01 or less) that are considered here. The polar coordinate system is employed, and Figure 1 summarizes the geometry of the problem.

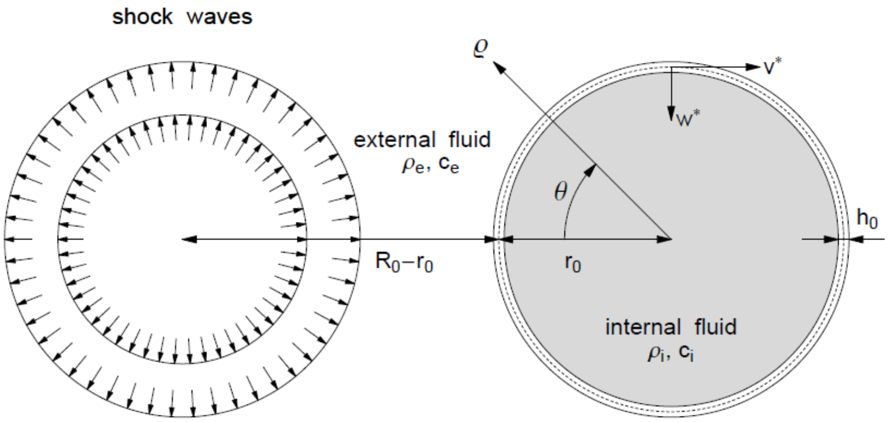


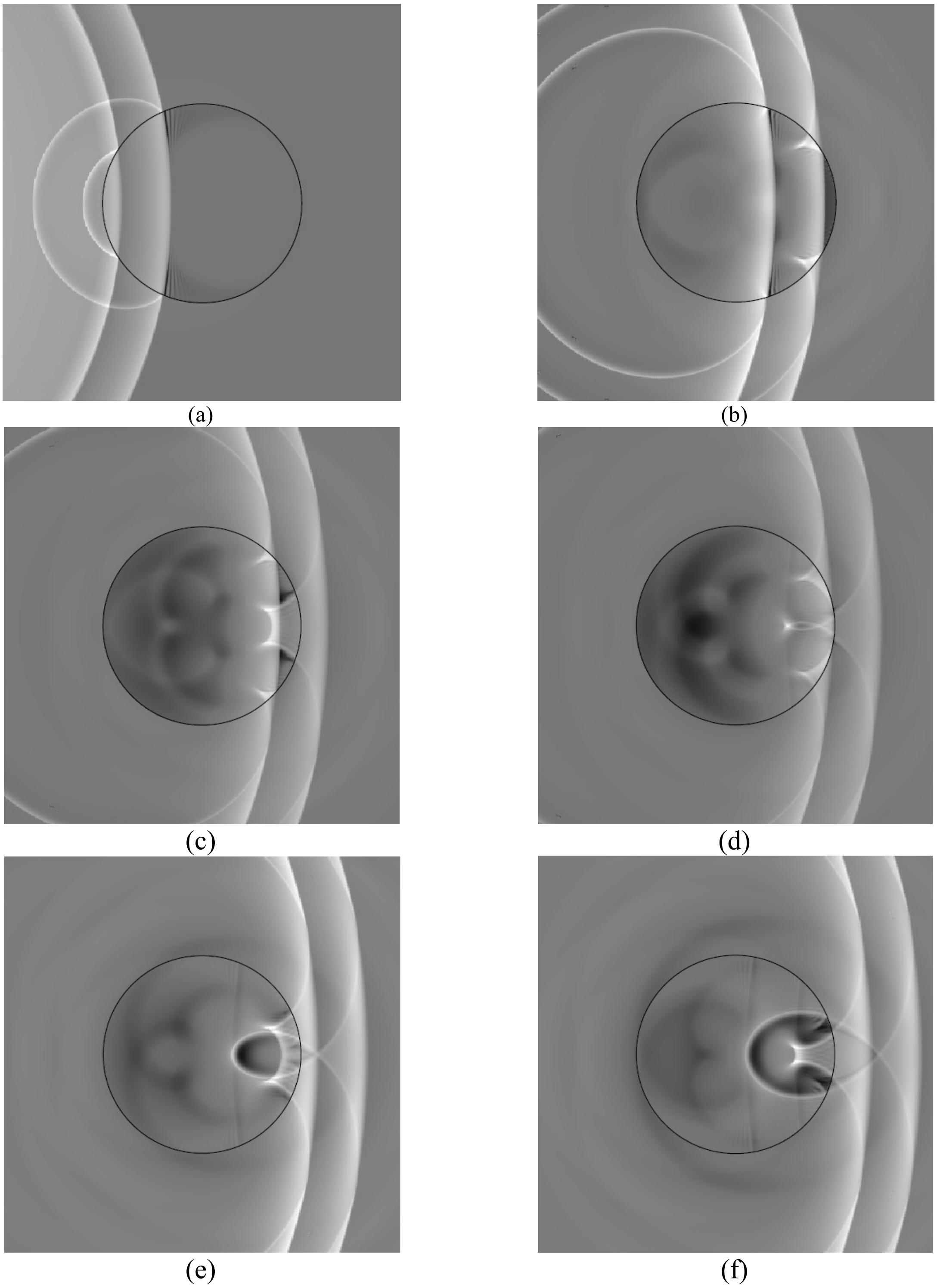
Figure 1: Geometry of the problem.

3 RESULTS AND DISCUSSION

We consider a steel shell filled with and submerged into water, with the thickness-to-radius ratio of 0.01 and subjected to a sequence of two identical typical point-source shock waves with the stand-off of four radii of the shell and the peak pressure of 250 kPa, and with the time delay between the wavefronts of Δ_t. The time in what follows is measured in the dimensionless units with the unity corresponding to the time it takes for the shock wave to move over the radius of the shell.

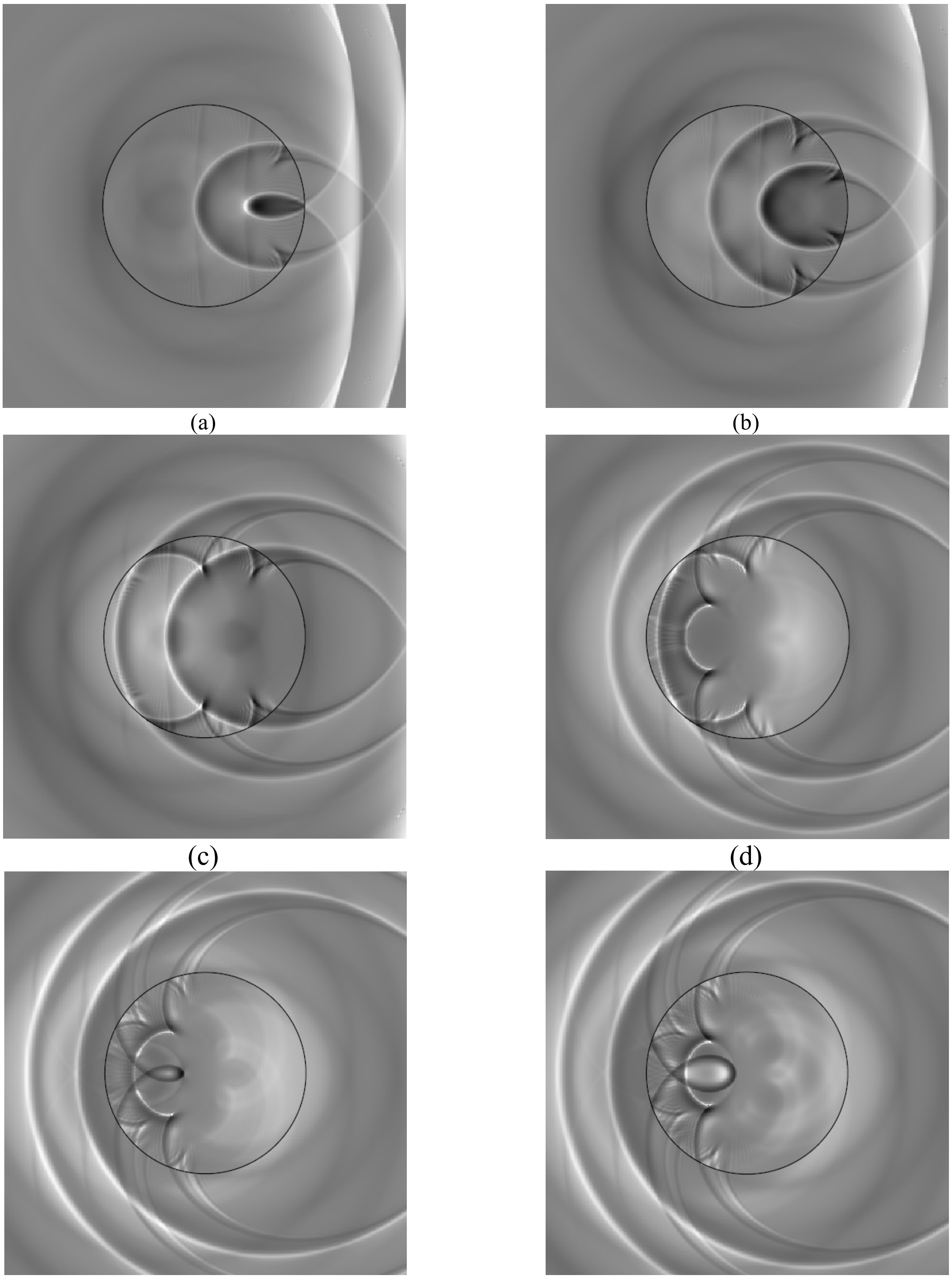
3.1 Fluid dynamics

We first consider the fluid dynamics of the interaction, Figures 2 and 3; the halftones were assigned individually in each image in order to ensure their optimal appearance. It is evident that all the shock wave propagation, reflection, and focusing phenomena observed for a single incident wave [2] are effectively “replicated” with the time-shift equal to the delay between the incident wavefronts; the resulting overall dynamics of the process is considerably more complex than in the case of a single-front loading, and even more complex than in the case of a submerged evacuated shell subjected to two incident waves [1]. Such a complexity, no doubt, will result in a very different structural dynamics, but also quite possibly in different peak values of the hydrodynamic pressure observed in the system; the latter is particularly probable when two regions of high pressure corresponding to two different incident fronts superimpose.



(a) (b) (c) (d) (e) (f)

Figure 2: Fluid dynamics of the interaction for the delay between the wavefronts of 0.50; time instants of 0.70 (a), 1.90 (b), 2.30 (c), 2.50 (d), 2.70 (e), 2.90 (f).



(a) (b) (c) (d) (e) (f)

Figure 3: Fluid dynamics of the interaction for the delay between the wavefronts of 0.50; time instants of 3.10 (a), 3.40 (b), 3.90, (c), 4.40 (d), 4.80 (e), 4.90 (f).

3.1 Structural dynamics

In the light of the fluid dynamics effects discussed, the first priority in addressing the structural dynamics is the analysis of the cumulative effect of the two stress waves propagating in the shell and constructively superposing at certain points, thus possibly resulting in high stress that would constitute a resonance-like phenomenon. To that end, Figure 4 shows the circumferential distribution of the transverse stress in the shell at various most representative time instants.

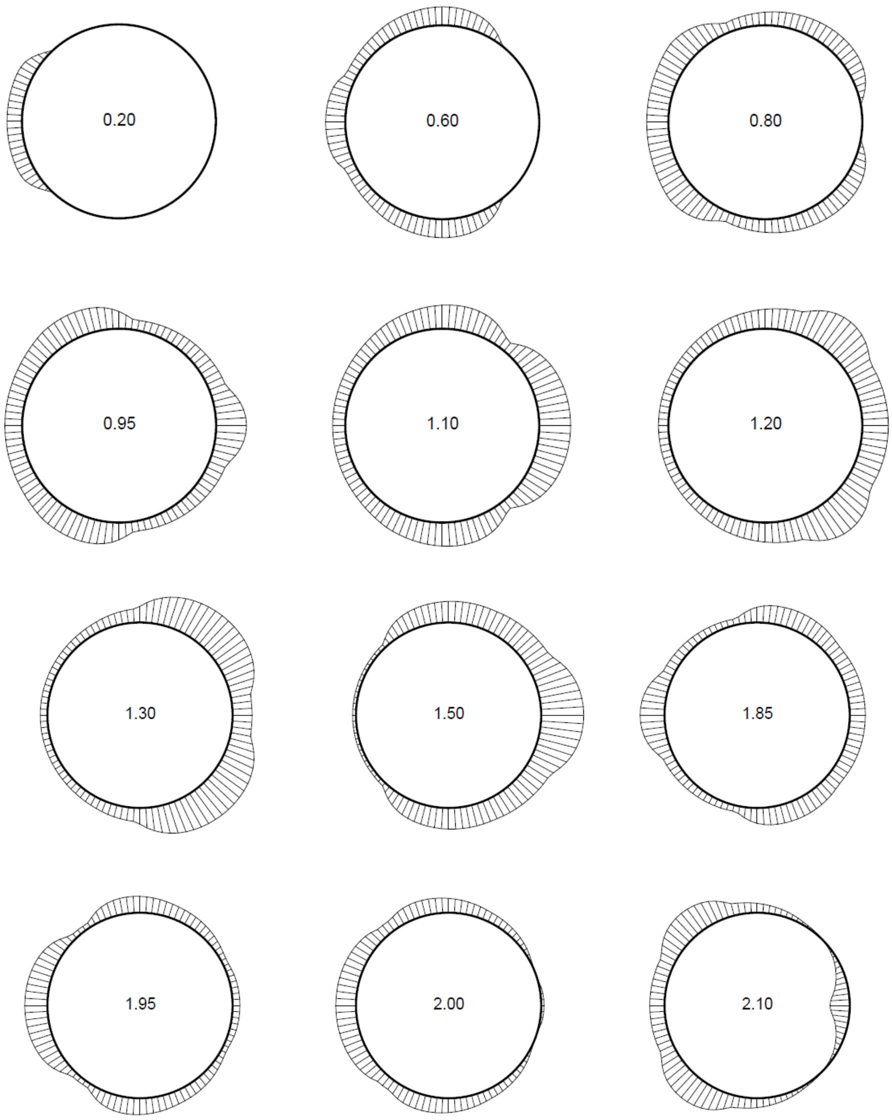


Figure 4: Structural dynamics of the interaction for the time delay between the wavefronts of 0.50 (the inception of the second stress wave upon the contact at 0.50 is clearly visible).

As representative as the sequences of stress snapshots are, they are not an ideal choice for pre-design analysis where it is often needed to carry out simulations for hundreds of different structural configurations. In such case, a much more preferred outcome would be a single numerical value representing the peak stress in the system for a certain combination of the parameters of interest, and Figure 5 shows the results of such parametric study for the transverse stress (the stress is normalized to the peak incident pressure p_α).

It is clear that there is a specific range of values of the delay where *both* the peak tensile and peak compressive stresses are very high, much higher (by 64% and 67% in their highest, respectively) than the respective peaks observed in a single-front scenario. The existence of such loading conditions clearly indicates the possibility of occurrence of the resonance-like phenomena that we hypothesized about earlier.

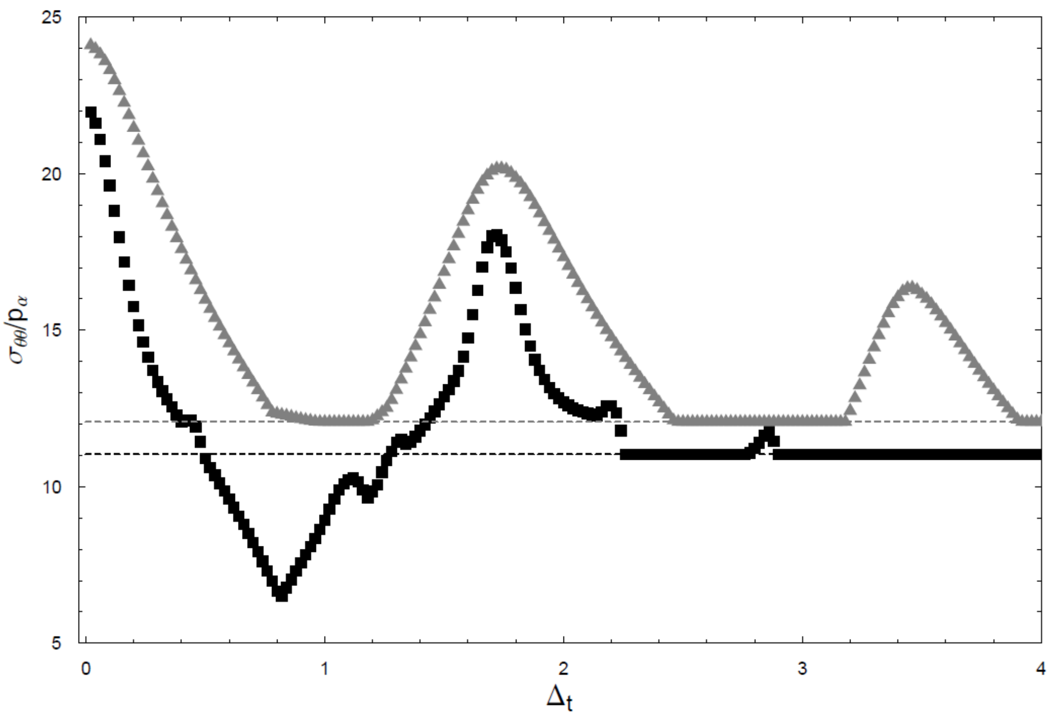


Figure 5: The evolution of the peak tensile (squares) and peak compressive (triangles) transverse stress in the system for varying delay between the wavefronts (the dotted lines represent the respective peak stresses for a single-front scenario).

4 CONCLUSIONS

We have demonstrated that when a submerged fluid-filled shell is subjected to two consecutive shock waves, then for certain delays between the incident wavefronts, a very significant increase of the peak tensile *and* peak compressive stress is possible, in contrast to the case of a submerged evacuated shell where the increase was observed for only the peak compressive stress.

We have also demonstrated that the fluid dynamics of the interaction is dramatically different as well from the case of an evacuated shell, and a detailed study of the resulting peak pressures is work in progress.

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REFERENCES

[1] Iakovlev, S., Seaton, C. T., Sigrist, J.-F., Submerged circular cylindrical shell subjected to two consecutive shock waves: Resonance-like phenomena, *Journal of Fluids and Structures* (2013) 42: 70-78.
[2] Iakovlev, S., External shock loading on a submerged fluid-filled cylindrical shell, *Journal of Fluids and Structures* (2006) 22: 997-1028.
[3] Iakovlev, S., Interaction between a submerged evacuated cylindrical shell and a shock wave. Part I: Diffraction-radiation analysis, *Journal of Fluids and Structures* (2008) 24: 1077-1097.
[4] Iakovlev, S., Interaction between a submerged evacuated cylindrical shell and a shock wave. Part II: Numerical aspects of the solution, *Journal of Fluids and Structures* (2008) 24: 1098-1119.
[5] Iakovlev, S., Santos, H. A. F. A., Williston, K., Murray, R., Mitchell, M., Non-stationary radiation by a cylindrical shell: numerical modeling using the Reissner-Mindlin theory, *Journal of Fluids and Structures* (2013) 36: 50-69.