A multi-model approach to study transient response of ship structures subjected to non-contact underwater explosions

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Introduction

Analyzing pressure loads against structures is of paramount importance for marine and offshore engineering, and underwater explosions (UNDEX) represent one of the most critical pressure loads. Research on UNDEX is essential for the design of military ships and protection systems for crew and equipment.

UNDEX generates three main damage mechanisms (Figure 1): primary shock wave, pulsating pressure waves, and high-speed water jets.

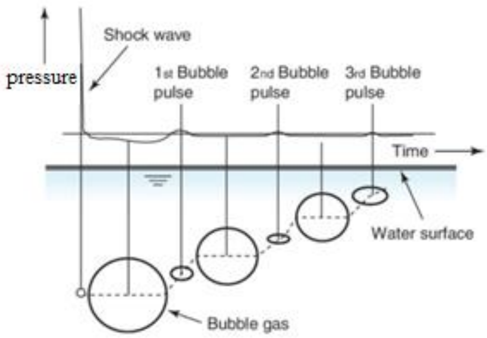


Figure 1: Gas bubble pressure trend.

UNDEX are complex phenomena and the study of their effects on structures needs to solve Fluid-Structure Interaction (FSI) problems.

The following strategies can be used to study UNDEX:

- Experimental campaigns, which have high costs and risks.
- Analytical models, which are not always able to provide reliable results due to the adopted approximations.
- Numerical simulations, which provide reliable results, but have high computational cost.

Nowadays, structural response to UNDEX is well-studied, but induced vibration and radiated noise are not addressed. However, such information is fundamental for the design of protection systems for equipment and DPI for crew.

Moreover, the simulation of far-field UNDEX requires an extended Eulerian domain with a subsequent high computational cost, so strategies to reduce this burden are essential for industrial application.

The aim of the study is the investigation of the dynamic response of a floating military-like structure subjected to far-field UNDEX, focusing on structural deformation, induced vibrations, and radiated noise.

The proposed framework (Figure 2) uses the combination of two software developed by Hexagon:

- Dytran for the simulation of UNDEX and FSI;
- Actran VI for the evaluation of induced vibrations and radiated noise inside the ship rooms.

To reduce the computational cost, a scaled model is used and a combination of 1-D and 3-D simulations is adopted.

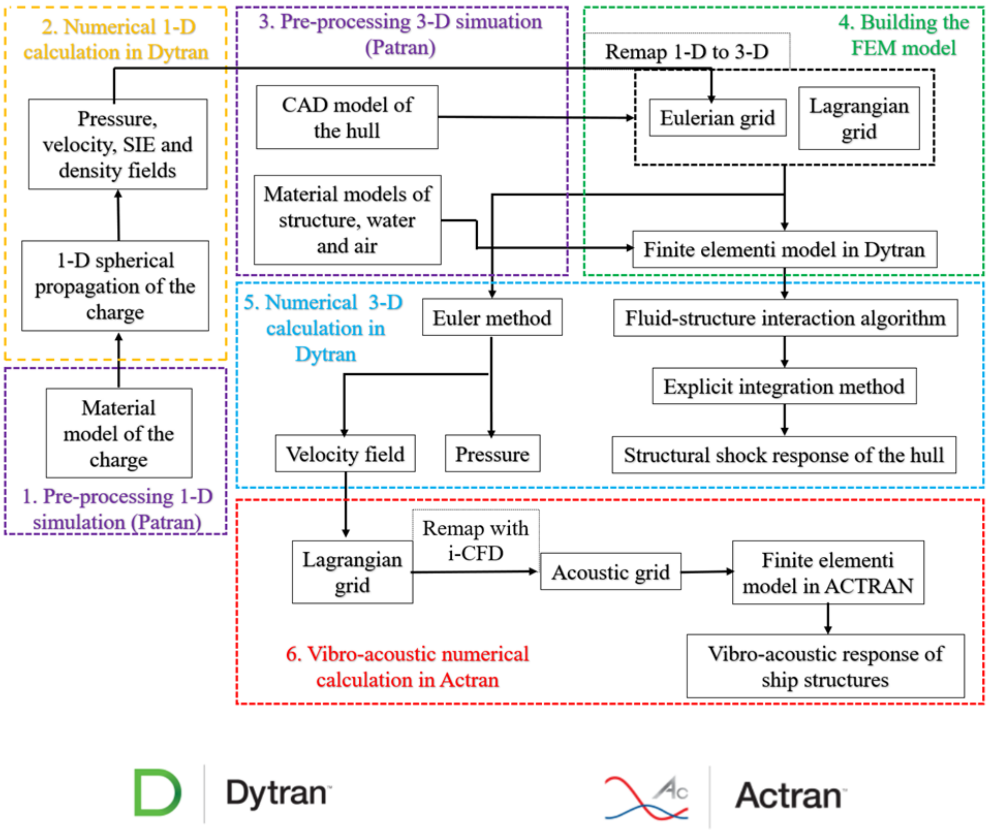
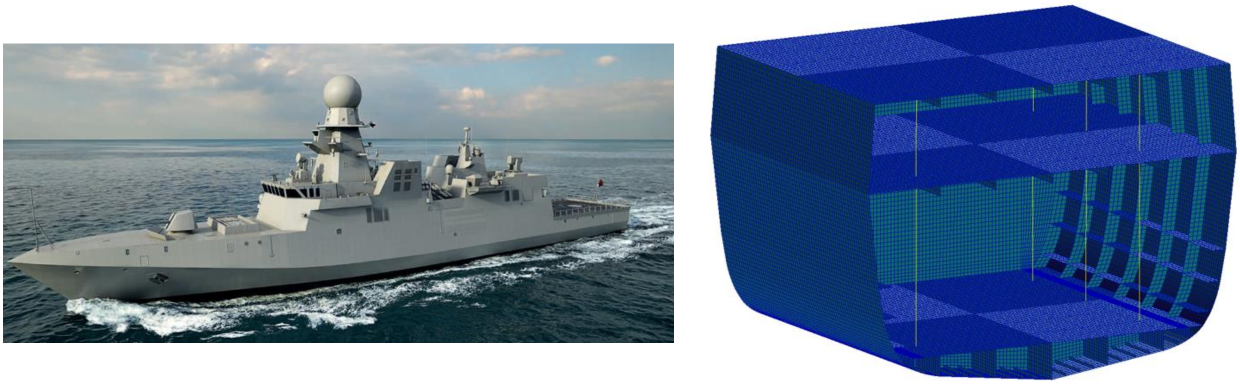


Figure 2: Workflow of the proposed framework.

The case study

A corvette (Figure 3(a)) is considered ad military ship and only the mid-portion between two bulkheads is modelled to reduce computational costs. Moreover, the considered structure is scaled according to the impact factor theory.



(a) (b)

Figure 3: (a) the target military ship and (b) the modelled structure.

For what concern the explosion scenario, a far-field UNDEX is considered with a side positioning of the charge (Figure 4) and evaluating only the influence of the first peak pressure.

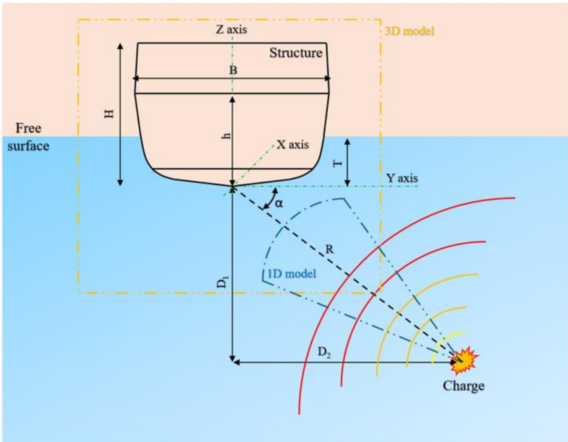


Figure 4: UNDEX scenario.

For the vibro-acoustic simulations, a frequency range between 20 and 2000 Hz is considered, and the structural velocity field is extracted from Dytran and remapped into Actran VI using i-CFD tool, which also performs a Discrete Fourier Transform (DFT) to work in the frequency domain.

Results

In Dytran the explosion and the far-field wave pressure propagation are modelled into the 1-D domain. A remap is then performed and the 3-D domain is used for the near-field pressure propagation and FSI problem to calculate stresses and deformation of the target structure. Figure 5 reports the pressure field calculated with the 1-D domain and then remapped into the 3-D domain, while Figure 6 reports the pressure wave that hint the structures and the generated stresses.

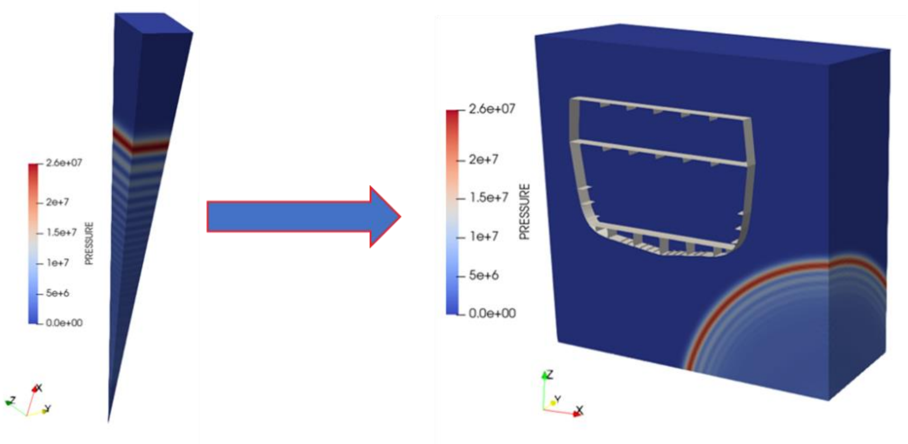


Figure 5: Pressure field in 1D and 3D domain.

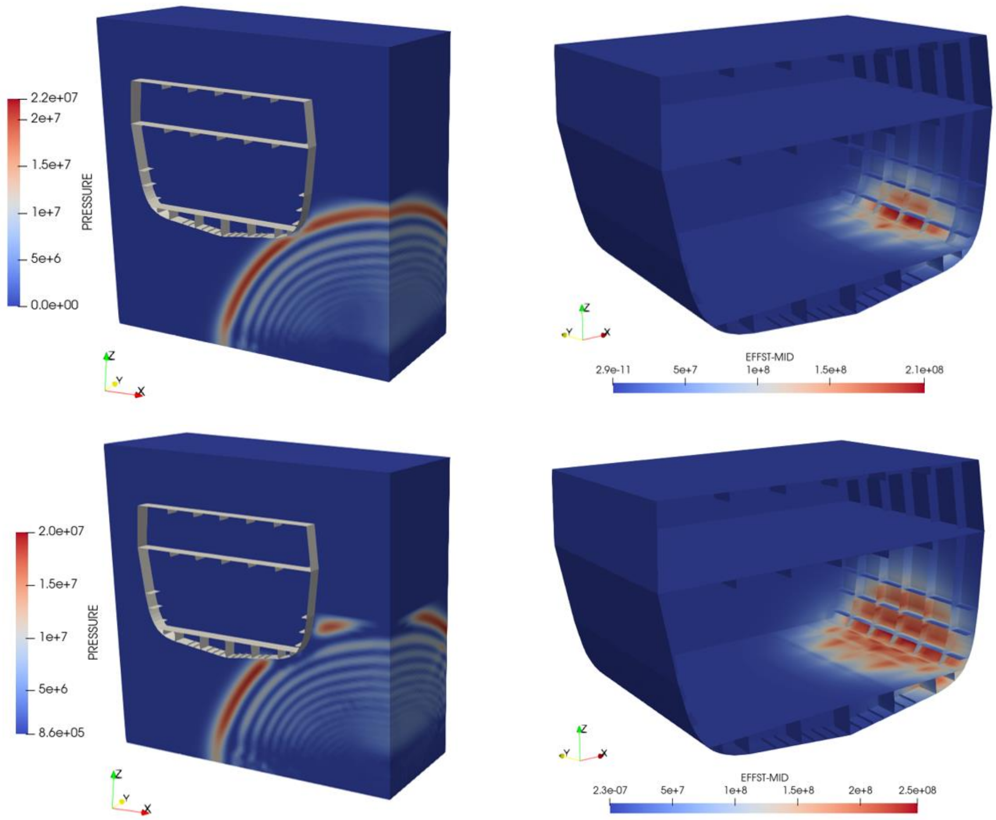


Figure 6: Pressure field and stresses at different instants.

In Actran VI the structural Root Mean Square Velocity (RMSV) (Figure 8) and the Sound Pressure Levels (SPL) (Figure 9) in different points inside the ship rooms are evaluated as a function of frequency.

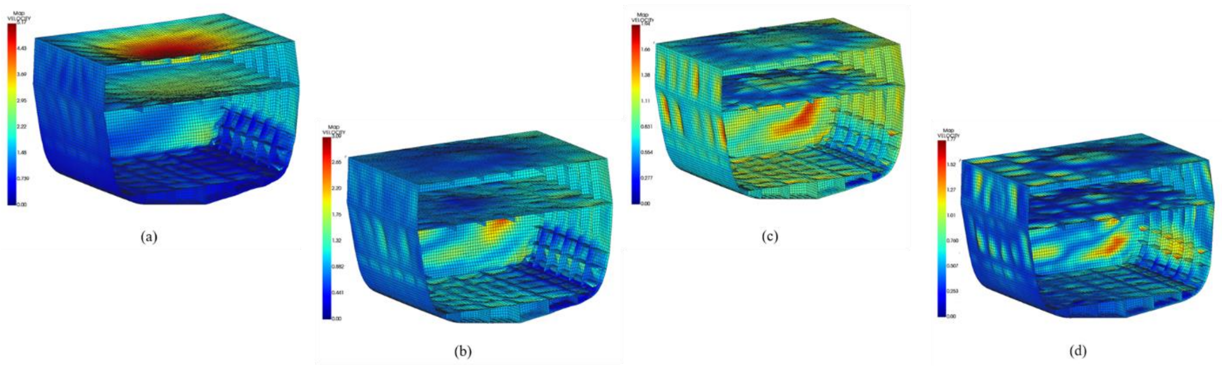


Figure 7: structural RMSV and deformations at prescribed frequency.

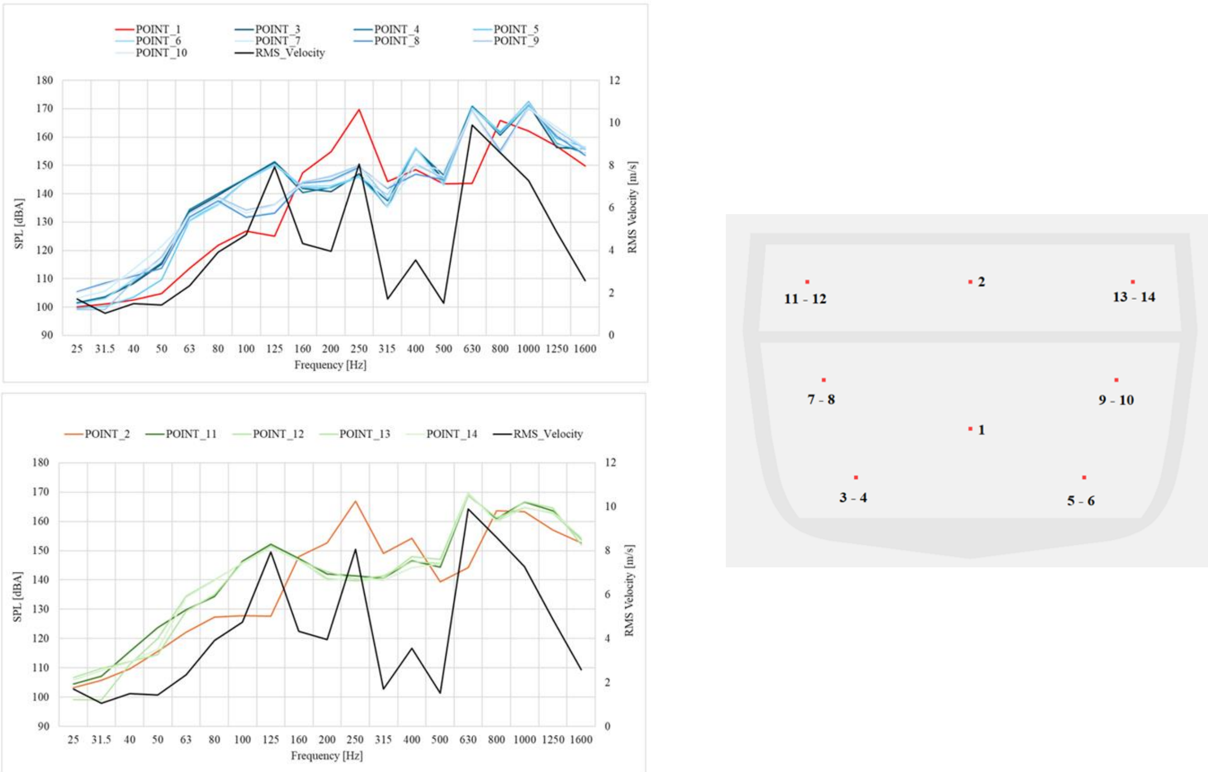


Figure 8: SPL inside the ship rooms.

Conclusions

Understanding the effects of UNDEX is crucial for the design of both ship hull and protection systems for machinery, equipment and crew.

The study evaluates the applicability of the proposed methodology, which combine the use of Dyran and Actran VI, in the preliminary design of military vessels, ensuring the operability during and after far-field UNDEX.