Design of Acoustic Insulation in Ships Based on Predictive vibro-acoustic Models

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Abstract

The marine industry has used empirical models to predict transfer functions between source locations and noise sensitive cabins extensively in the past. These empirical methods work well for standard construction types, material and small number of cabins. Today's tendencies are to use complex construction methods, exotic material such as composite and build larger and larger yachts with cabin layouts and numbers not easily represented in an empirical way. This paper presents an approach to build predictive vibro-acoustic models for full frequency analysis (0-10 000 Hz). The approach makes use of several modeling methods and coupling such as FEM (Finite Element Method), FMM-BEM (Fast Multipole Method- Boundary Element), SEA (Statistical Energy Analysis) and "FE/SEA Coupled" to represent the yacht structure, interior cabins, fluid tanks, underwater fluid loading and noise radiation. This approach also permits the representation of the acoustic insulation and the optimization of its content to achieve required targets while reducing mass and insulation cost. This paper also discusses the source models to be used to represent the airborne, structureborne and waterborne contribution of major excitations. This approach is applied on a 70m luxury yacht where these vibro-acoustic concepts are discussed and illustrated.

Full Frequency Challenge

SEA has been established in space, aircraft, automotive and train industry for many years now, and this method is increasingly used in the marine sector to design interior insulation [1,2,3]. SEA can be applied on a wide frequency range from a few hundred hertz to 10 000Hz. A critical aspect of ship modeling is the modeling of the structure where the structureborne sources are attached.

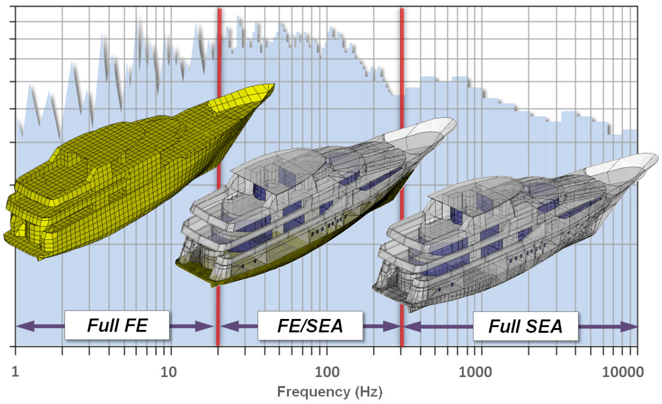


Figure 1: Full frequency analysis concept: From deterministic/narrowband low frequency FE model to statistical 1/3rd octave band high frequency SEA model.

Since this part of the ship is usually stiff and composed of small thick panels, FE is more appropriate for frequencies up to ~200Hz. This paper proposes a method that allows engineers to build predictive models for the full frequency domain (0-10000Hz). In the marine industry, it is common to build a FE model of the ship for low frequency structural analysis. A SEA model can cover the high frequency domain. For mid-frequency, (20 to 200 Hz for 70m yacht example) a FE/SEA model provides a good representation of the ship's physics: FE for stiff below water line structure and SEA for the remainder of the structure. All cavities can be modeled as SEA (Figure 1).

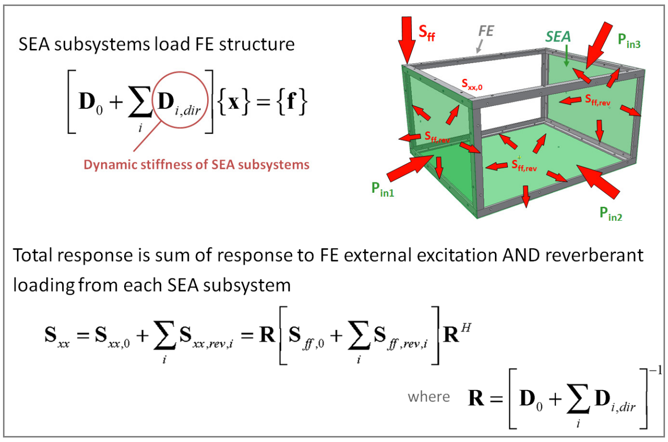
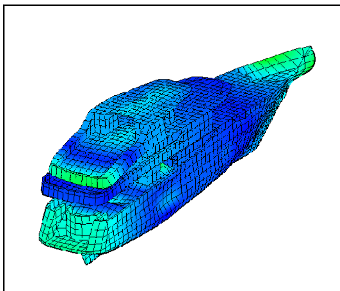


Figure 2: FE/SEA Coupled: SEA subsystems load FE structure (top left) and total response at FE node equals sum of FE external excitations and SEA reverberant energy

In such a model, the SEA structure and cavities are loading the FE content and the total response on a FE node is the sum of FE external excitations and the reverberant field of any SEA subsystem attached to this node (Figure 2). Rigorous formulations have been developed and published to describe coupling between FE and SEA [4,5].

Fluid Loading and Underwater Radiation

Fluid loading plays an important part in the behavior of the hull, especially at low frequency. The loading actually changes natural frequencies and mode shapes in a significant way (Figure 3).



Node ID	Uncoupled (Hz)	Coupled (Hz)	Damping (-)
1	6.2	5.2	0.034
2	7.4	5.9	0.049
3	7.7	6.9	0.015
4	9.5	7.4	0.010
5	11.0	7.5	0.010
6	12.0	7.8	0.015
7	12.2	7.9	0.011
8	12.3	8.2	0.011
9	12.8	8.3	0.016
10	13.1	9.2	0.021

Figure 3: Left: First bending mode shape, Right: Uncoupled and coupled natural frequency and coupled modal damping

Today, it is also possible to visualize the coupled mode shapes. The waterloading can also impact the vibration response of the hull plating by as much as 10 to 20 dB at low frequency and only a few dB at high frequency (Figures 4 and 6).

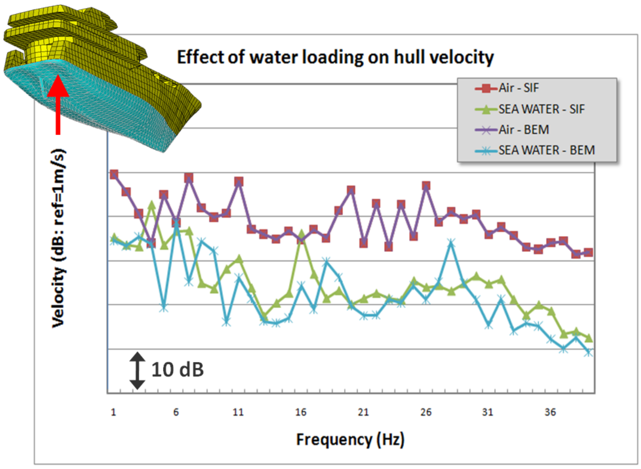


Figure 4: Effect of water loading on vibration of hull plating.

To model water loading on FE, a new formulation has been developed and implemented in the commercial software VA One. This formulation is based on “FE/SEA coupled” and is 4 to 5 times faster than conventional BEM. MFLUID approaches cannot be used on such large structures. Underwater radiation from the hull panels and wave propagation from propeller blades can be modeled using FMM-BEM (Figure 5).

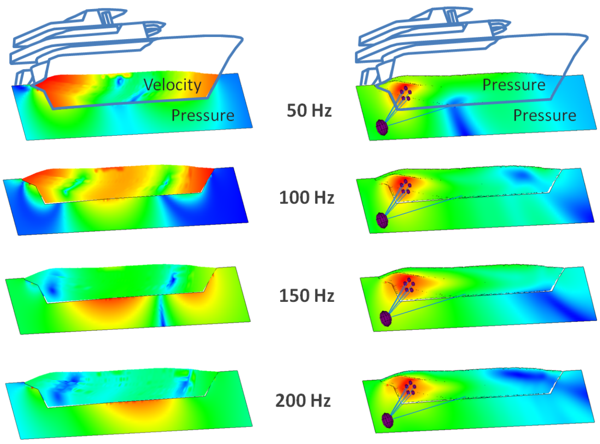


Figure 5: Left: Hull underwater panel velocity and radiation into sea water. Right: Underwater wave propagation from propeller acoustic point sources.

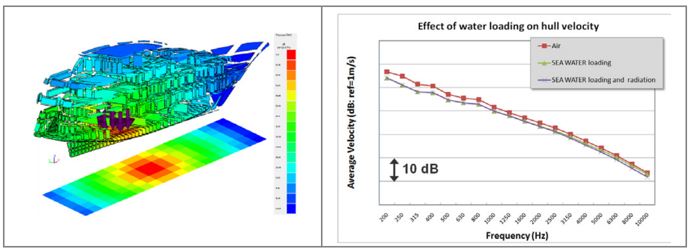


Figure 6: Left: SEA underwater radiation. Right: Effect of water loading and underwater radiation at high frequency

Modeling insulation

Modeling insulation using the Transfer Matrix Method (TMM) into a SEA model has been widely covered in the literature. The same approach can be applied on FE models as well. See [1,3] for description of method and validation.

Modeling Sources

Typical sources are of 3 types: airborne, structureborne and waterborne. The main sources of noise and vibrations are the engines, gearboxes, generators, HVAC, bow thrusters and propellers. It is critical to have the right power getting inside the structure. For low-mid frequency, a FE model of the attachment points of these sources is essential (see [1] for more details).

Typical results

Figure 7 shows typical results for full frequency domain.

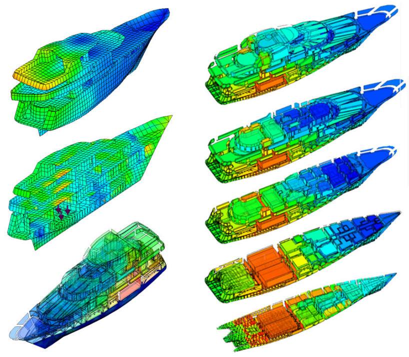


Figure 7: Left: FE & FE/SEA Coupled. Right: SEA

Conclusion

Full frequency analysis of marine vessels is possible today. Combination of FE and SEA provides an efficient way of accurately representing the system and computing the response. Water loading and underwater radiation are important physical phenomena that should not be neglected in structural analysis and insulation design.

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