# SEABED TOPOLOGY AND MATERIAL COMPOSITION EFFECTS ON UNDERWATER SOUND RADIATION OF A 70M STEEL HULL VESSEL

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***Abstract:*** *In the marine industry, simulation starts to occupy a key role in product design as NVH and environmental requirements are becoming increasingly demanding. This paper discusses new advances in marine vibro-acoustic predictions and in particular the effect of seabed topology and material composition on the underwater noise radiation of a steel hull. This paper introduces Fast Multipole Boundary Element Method (FMM-BEM) to predict underwater sound radiation of ships in deep or shallow waters. Finally, the effect of seabed topology and impedance on sound radiation are illustrated with several simulation examples based on a 70m steel hull vessel.*

***Keywords:*** *Seabed, Topology, Sediment, Propagation, Underwater*

## 1. INTRODUCTION

This paper describes in section 2 the traditional vibro-acoustic predictions methods in the marine industry and proposes ways to improving sound insulation representation using SEA (Statistical Energy Analysis) and in section 3 introduces an advanced method of predicting full frequency vibro-acoustic response by coupling FEM (Finite Element Method) and SEA. In section 4 a new wavelet approach to represent heavy fluid loading is described and illustrated by a numerical example. Section 5 presents numerical examples for deep and shallow waters sound radiation computation using the FMM-BEM method (Fast Multipole Boundary Element Method).

## 2. IMPROVING SOUND INSULATION REPRESENTATION USING SEA

The ship industry has relied on empirical models to predict vibration and sound pressure throughout a vessel for many years. This method has proven useful when the ship to be studied is built of similar material, has similar general arrangement plan and has conventional sources as the numerous ships used to build the empirical models. Furthermore, some shipbuilding companies also used FEM to predict first few global modes of the ship and making sure the different sources would not excite the structure with the same frequencies to avoid major resonance problems. Another application of FEM is in the design of the engine foundation. A local FEM model of the engine foundation can be built and the input impedance at the location of the engine and gearbox attachment points can be computed and compared with the impedance of the mounting system. This process ensures a strong impedance mismatch and therefore limiting the amount of vibrational energy getting into the structure [1]. Finally, local FEM models can be used to diagnose local resonance problems by visualizing the mode shapes of certain panels and stiffening or damping the problematic panel as required. One should remember that while stiffening a panel reduces vibration levels, it can significantly increase the sound radiated by the panel and care must be taken when stiffening so one does not create a new acoustic problem while trying to fix a vibration problem [2,3,4].

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 [1,5,6,7]. SEA can be applied with confidence on a wide frequency range from a few hundred hertz to 10 000Hz. Recently, model building has been greatly simplified by the use of automation. SEA models can now be automatically built from 2D general arrangement drawings. Accuracy and predictivness of SEA has been widely confirmed in publications for other industries and in the marine industry, the number of publications increases each year.

The insulation content in a yacht can be described by either a treatment layup describing each layer of a noise control treatment or as an insertion loss. Many insulation designers use a condensation model that uses an insertion loss and a damping spectrum to represent the insulation treatment. This makes model building even easier since the insulation does not have to be explicitly created in a structural model but only as a treatment applied on a base panel. All ship images and results in this paper are from a model created by ESI from a 70m luxury yacht 2D general arrangement drawing found on the internet (Fig.1). Computations and post-processing are made with the commercial software VA One.

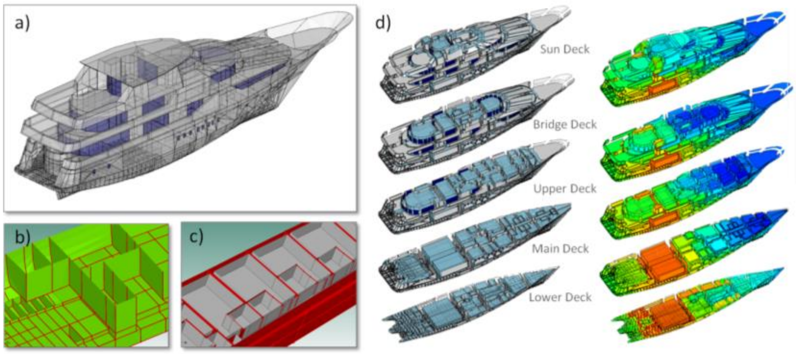


Fig. 1: a) SEA model built from 2D drawings, b) structural point and line junctions (in red) between structural panels (in green), c) area junctions (in red) between panels and acoustic cavities (in grey), d) decks and contour plot of panel velocity and cavity SPL.

## 3. FULL FREQUENCY ANALYSIS: COUPLING FEM AND SEA

A critical aspect of ship design is the modeling of the structure location where the structureborne sources are attached. Since this part of the ship is usually stiff and composed of small thick panels, FEM 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). A SEA model can cover the high frequency domain. For mid-frequency, (20 to 200 Hz for our 70m luxury yacht example) a FEM/SEA model provides a good representation of the ship's physics: FEM for stiff structure below water line and SEA for the remainder of the structure. All acoustic cavities (cabin volume of air) can be modelled as SEA (Fig. 2).

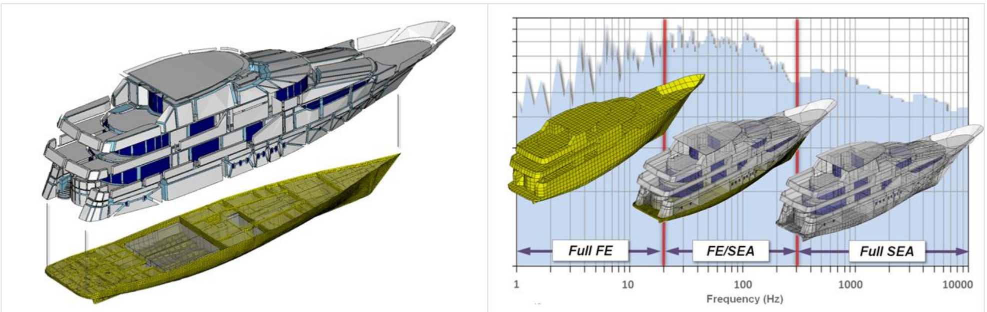


Fig. 2: Left: FE/SEA Coupled: SEA subsystems in gray and FEM stiff panel network in yellow. Right: full frequency vibro-acoustic analysis: FEM for low frequency, FE/SEA Coupled for mid-frequency and SEA for high frequency.

This new formulation has been published in [5,8,9]. It is a full coupling formulation where the global modes of the stiff parts are represented with FEM using natural frequencies and mode shapes and the local modes are represented with SEA using modal densities. The SEA panels actually have 2 effects on the FEM content. First the SEA panels add impedance onto the FEM content loading the FE modes with an averaged impedance. The second effect is to excite the FEM content with the reverberant field of each SEA subsystem coming from either the FEM content or external excitation applied directly on SEA subsystems. This new formulation allows for a full frequency vibro-acoustic analysis of a ship using FEM for low frequency, FE/SEA coupled for mid-frequency and SEA for high frequency.

## 4. FLUID LOADING

Fluid loading plays an important role in the vibration of the hull, especially at low frequency. The loading actually changes natural frequencies and mode shapes in a significant way. Therefore, one cannot ignore the fluid loading in any predictive model of vibration and noise radiation for hull panels as well as all tanks (water, fuel, waste) in a ship. A new efficient fluid-structure analysis method [10] makes use of wavelets to compute the acoustic radiation from baffled, unbaffled, or partially baffled planar structures. The surface displacement and the surface pressure are expressed in terms of wavelets, and the acoustic dynamic stiffness (baffled case) or the acoustic receptance (unbaffled case) between any two wavelets is derived in closed form. This formulation is implemented into the commercial software VA One. In the present work, this formulation is only used to compute velocity on the hull panels. Underwater radiation computation is done using FMM -BEM and is presented in the following section.

## 5. UNDERWATER RADIATION: SHALLOW WATER

To represent underwater sound radiation from the yacht hull, the FMM-BEM method has been selected. This method provides a detailed description of waves propagating from the vibrating hull into the environment, the scattering of waves around the complex contour of the hull and is therefore appropriate to predict underwater radiated noise. The FMM-BEM formulation from Gumerov and Duraiswami [12,13] has been used. It is an advanced algorithms designed to solve large scattering and radiation problems and is well suited for forced response computation. The solver is based on a multilevel Fast Multipole Method to solve the Helmholtz boundary integral equation for the acoustic unknowns of pressure and velocity. The FMM BEM solver is intended for mid to large-sized scattering and radiation problems, typically problems involving approximately 10,000 to 2,000,000 nodes in the rigid and elastic faces defining the fluid domain. The solver is expected to give accurate results for $0.0025 < kD < 500$, which corresponds to 4E-4 to 80 acoustic wavelengths throughout the BEM domain. The symbol $k$ is the acoustic wavenumber in the fluid and $D$ is the largest distance in the fluid domain. The solving time is expected to scale in $(kD)^3$; part of this behavior is due to the expected increase of GMRES iterations as $kD$ increases. The FMM-BEM is coupled to an ILUT pre-conditioner to compute the SPL at a virtual microphone array and to generate the contour plots of underwater pressure distribution.

To analyze shallow water problems the following approach was adopted: a half sphere with water surface at top was created. A plane that represents the seabed was created at 20m and the half sphere was cut at the intersection with the seabed surface. Impedances are used to represent seabed material, the water surface and the water at the sides of the fluid domain (Fig. 3). The benefit of this method is that one can represent the different materials composing the sea bed either by adding impedance to the bottom of the sea or by coupling the BEM fluid with a PEM (Poro-elastic material) approach.

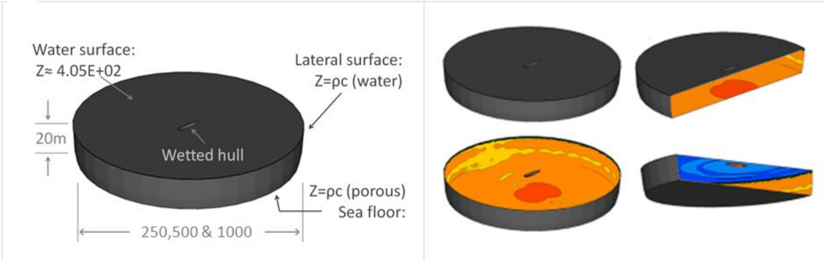


Fig. 3: Left: External view of shallow water fluid BEM domain. Right: BEM domain clipped to reveal pressure distribution on the inside of the domain.

PEM uses a modified Biot equation [14,15] to properly model waves propagating in a 2 phase medium typical of seabed content. PEM uses a Finite Element Formulation for the analysis of acoustic and elastic wave propagation through the use of Biot parameters such as flow resistivity, porosity, tortuosity, viscous and thermal characteristic lengths. Several validation cases have been published and are referenced in [16]. A full convergence study should provide the proper radius of the half sphere to use to insure the smallest possible model can be used to reduce computation time/memory usage or to increase maximum upper frequency. In this study, three different radii are compared: 250m, 500m and 1000m. One can also match the sea bed and water surface topology since the model does not use an infinite flat plane but a real meshed surface. A preliminary convergence analysis with various topology/material for the sea bed is presented here. Fig.4 shows effect of varying BEM domain size on SPL at seabed level.

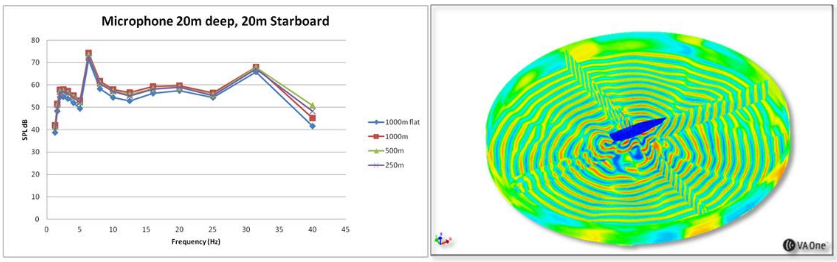


Fig. 4: Left: Effect of BEM fluid domain size. Right: Pressure field from acoustic waves radiated from vibrating hull

A reference case with 1000m diameter and flat seabed was computed. All other sizes were computed using a non-planar seabed. The effect of reducing the diameter of the BEM domain has marginal effect below 40Hz. The change in topology impacts the SPL by around 2dB. Fig. 5 shows impact of various seabed materials on SPL at seabed level. The change in material can have as much as 5 dBs effect below 40Hz.

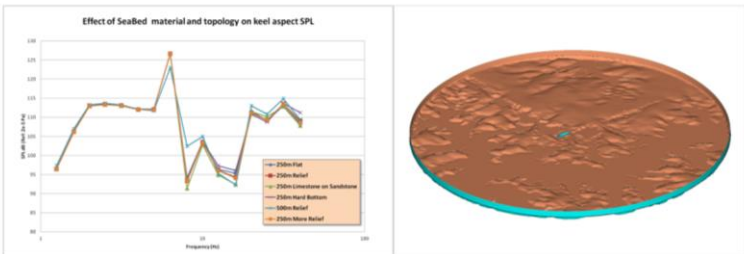


Fig. 5: Left: Effect of seabed material on SPL at seabed level Right: Seabed topology used in this work

## 6. PERSPECTIVE

Ina future paper, these results will be compared to a full FEM Biot representation of the seabed composition. Will also be included, the topology of the water surface.

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