Calculation of the acoustic target strength of elastic objects based on BEM-BEM-coupling

Based on a BEM-BEM-coupling method, the scattered pressure from elastic objects placed in water and partially buried in the sediment is calculated.

For this application, a package based on a special variant of the boundary element method (BEM) is developed. It contains a pre- and a postprocessor with 3D visualization, in order to define the geometry of the scattering objects in the interface layer between fluid and sediment and the parameters needed for characterizing the fluid and the elastic material. The solver is able to perform numerical calculations in a multiple parallel manner. For the solution of the underlying system of linear equations, we use different kinds of approximate and direct solution techniques.

Simple acoustical exterior problems e. g. the sound scattering by elastic solid cylinders and spheres placed in a fluid are treated by the BEM-BEM-coupling method. The results will be compared with analytical solutions or solutions obtained from other numerical methods.

1 Introduction

One main purpose in mine hunting is the detection and classification of objects placed on the seabed or partially buried in the sediment, especially in shallow water and port entrances. Numerical simulation provides a significant assistance and guideline for this task.

Existing studies are based mainly on time-domain formulations. Hence, numerical methods for the frequency-domain should be developed for supplementary support.

We developed an application framework including parallel working equation solvers using different methods for the calculation of the scattered pressure and the target strength in the frequency-domain.

The obtained results will be compared with analytical solutions and/or solutions obtained from other numerical methods.

2 Application framework

The application framework consists of three modules (pre-processor, calculator and post-processor) which will be described below.

2.1 Preprocessor module

The preprocessor module (with real-time 3D visualization, currently based on OpenGL) is used to define the geometric description of objects and their surrounding structures (fluid, ground).

The module currently includes the following features and options:

- Complete object-oriented design, intended to manage large and complex scenes
- Supports the import and export of 3D-structures (currently NASTRAN-, ANSYS- and CDB-format) including options to scale, translate and rotate
- Integrated mesh-generator for rippled fluid-ground-surfaces and sample structures
- Integrated mesh-combination algorithm for the generation of bonding geometric descriptions for fluid, ground and object meshes
- Supports the definition of material and acoustic properties for each structure in the scene and the surrounding fluid
- Supports the use of different types of sound sources
- Supports the definition of boundary conditions
- Enabled to use and control external computers (so-called calculator-hosts) for the calculations using a TCP/IP-based interprocess-communication
- Standalone Microsoft Windows Application using Visual C++

2.2 Calculation module

The calculation module is responsible for the real calculation processes and is optimized for large data and high performance. For portability reasons, the code will be implemented mostly independent of the underlying operating system (Win32/64, LINUX32/64).

It may be installed and used on every available and via LAN reachable computer system.

The module currently includes the following features and options:

- Implemented as a console application that can be executed standalone or as a system service
- Code-sharing between all modules reduces development time and code complexity
- Using fixed structures and pointers during the calculation process enhances performance and reduces time-consuming memory reallocations
- Enable to run multiple calculation-tasks and -steps in separate threads on different CPU cores, depending on the available hardware resources. Currently the parallelization of matrix setup and matrix vector product calculation is implemented.
- Implementation of different solving methods and solvers: plane wave approximation, Kirchhoff approximation, BEM-BEM-coupling with direct (Gauß-Pivot) and iterative solvers (GMRES)
- Uses a virtual matrix class for large systems if needed (calculates the coefficients at runtime without storing the coefficient entries in memory, optional use of internal hard disk space)
- Generation of HTML based calculation protocols
- Administration by the pre-/postprocessor

2.3 Postprocessor module

The postprocessor module which is used to visualize, export and print result data is integrated within the preprocessor, so both modules share the user interface and the visualization properties.

It currently includes the following features and options:

- Queries the status and the result data files from the calculator-hosts, assigns them to the appropriate projects and stores them locally
- Supports multiple types of result data (scalars, vectors, viewpoints) and assignments
- Supports different types of data views and exports (2D- and 3D-visualisation, screen shots, listings)
- Enable to import externally calculated result data

3 BEM-BEM-coupling method

The implemented boundary element coupling method which is based on Nolte [1] can be used for all coupling types (fluid/fluid, fluid/solid und solid/solid).

At this time constant elements (with a selectable Gauß point distribution) are used. An extension to linear / quadratic elements is intended.

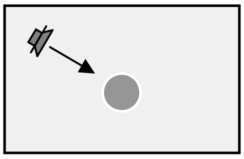

Fig. 1: object in a fluid (p_{inc} affects the whole surface).

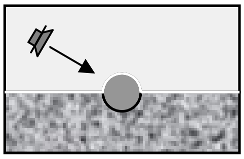

Fig. 2: partially buried object (p_{inc} affects only the "illuminated" surface parts)

The particular coupling type is determined by the existing geometry and the associated material parameters and is used to define the appropriate matrix coefficients.

Transition conditions exist at the structural interface points instead of boundary conditions. Further on one has to take into account the incident pressure of the sound source(s).

The resulting coupling matrix is complex, dense and not symmetric. This requires large computational costs for the solution.

4 Methods and results

To verify the code of the calculation module and the implemented BEM-BEM-coupling method, the results for cylinders and spheres placed in water were compared with analytical solutions and experimental results of Faran [2]. Also, an expansion into spherical wave functions is considered (according to Holford).

Additional results were obtained by the use of commercial software for acoustical / physical problems (FEMLab, MatLab).

In the following figures the back scattered pressure is shown in N/m², using a linear scale.

4.1 Rigid cylinder (placed in water)

In the following figures, the results for a rigid cylinder placed in water are shown based on the geometrical dimensions and material parameters by Faran [2]. A plane wave is impinging the test structure in x-direction.

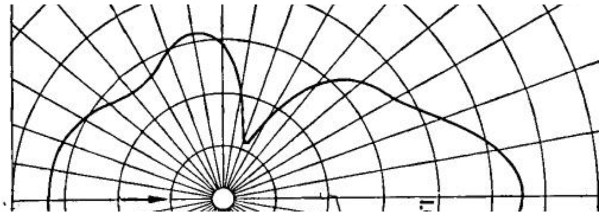

Fig. 3: J. J. Faran ([2], p. 413, Fig. 9):
$r = 0.793\times10^{-3}$ m, $l \rightarrow \infty$, f = 1 MHz, rigid

To obtain comparable results, we scaled the geometric dimension by 1000 and the frequency by 1/1000 within our calculations.

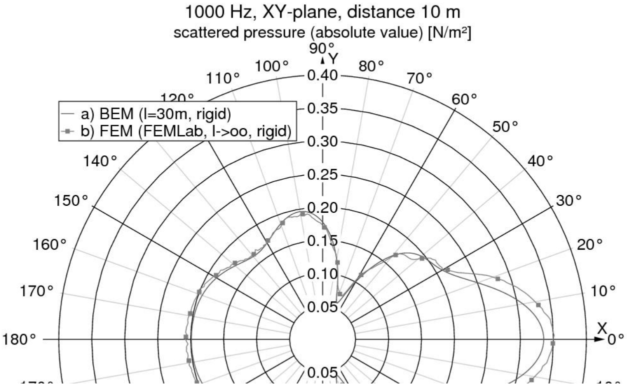

Fig. 4
a) BEM (SFGSim):
r = 0.793 m, l = 30m, f = 1 kHz, rigid

b) 2D-solution (FEMLab):
r = 0.793 m, $l \rightarrow \infty$, f = 1 kHz, rigid

A good agreement in quality and quantity is achieved.

4.2 Brass cylinder (in water)

The results for a brass cylinder placed in water are shown in the following figures:

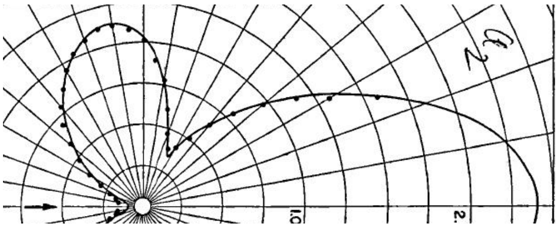

Fig. 5: J. J. Faran ([2], p. 412, Fig. 6):
$r = 0.793\times10^{-3}$ m, $l \rightarrow \infty$, f = 1.020 MHz, brass

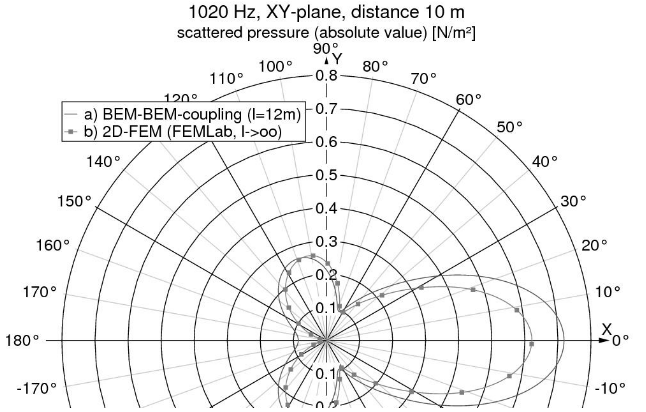

Fig. 6
a) SFGSim (BEM-BEM-coupling):
r = 0.793 m, l = 12m, f = 1.020 kHz, brass

b) 2D-solution (FEMLab, FEM-coupled):
r = 0.793 m, l → ∞, f = 1.020 kHz, brass

Here one can see small differences in the coupled case which results from differences of the model geometry (infinite length of a 2D solution compared to a limited length of 12 m of the modeled cylinder).

4.3 Aluminium sphere (in water)

The results for an aluminium sphere placed in water are shown in the following figure:

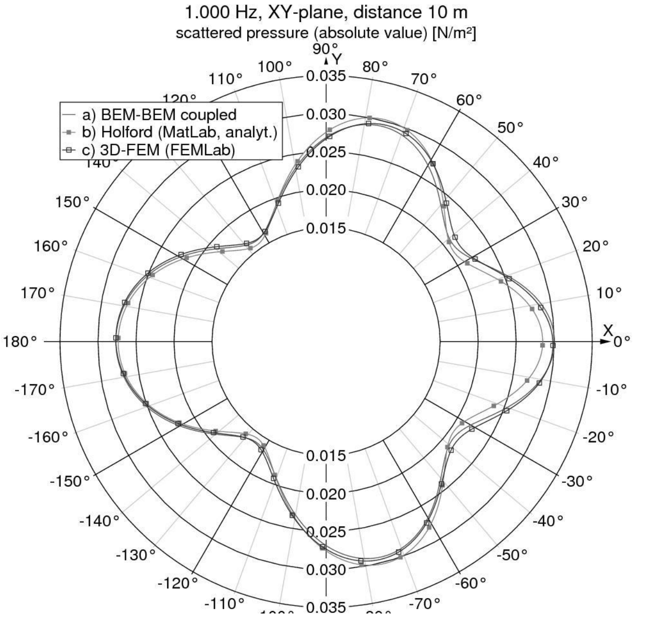

Fig. 7
a) SFGSim (BEM-BEM-coupling):
r = 0.5 m, f = 1 kHz, aluminium

b) Holford solution (MatLab, analytic):
r = 0.5 m, f = 1 kHz, aluminium

c) 3D-FEM-solution (FEMLab, FEM-coupled):
r = 0.5 m, f = 1 kHz, aluminium

An almost exact agreement could be achieved here; some minor differences may result from discretization errors.

5 Summary / Outlook

In case of identical geometries the results of the BEM-BEM-coupling method agrees well with the results of other solving methods.

The limiting value in solving the whole present complex matrix directly consists in about 20,000 unknowns (approx. 6 GB RAM) using a “pc-workstation”, the equivalent structure size is 5,000 elements (for the fluid/solid coupled case).

The use of iterative solvers is required for solving major problems.

In future we will focus on:

- More test calculations with larger and more complex structures
- Preconditioning and optimization of iterative solvers
- Use of alternative solution methods (e. g. Fast Multipole Method)
- Improvements of the postprocessor

Acknowledgements

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Literature

[1] Nolte, B.: Randelementberechnungen und Nahfeldmessungen zur akustischen Fluid-Struktur-Interaktion, Dissertation 1998, Universität der Bundeswehr Hamburg

[2] Faran, James. J.: Sound Scattering by Solid Cylinders and Spheres, JASA Vol. 23, Nr. 4, July 1951, p. 405ff

[3] Burgschweiger, R., Ochmann, M., Nolte, B. and Schäfer, I.: A boundary element package containing approximate solvers for treating high frequency acoustic scattering, Proceedings of the 14th International Congress in Sound & Vibration (ICSV14), 2007, Cairns, Australia