Constructing a database of computational methods for environmental acoustics

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1. Introduction

Recent years have witnessed the widespread application of numerical methods such as FEM, BEM, and FDM to acoustical problems. Furthermore, various new related techniques are also being developed. Nevertheless, software users are sometimes confused when choosing an appropriate method among them because clear indications are lacking in regard to choice. For example, one researcher may implement a new method, but cannot sufficiently compare the numerical result with those obtained by other methods. One reason for this situation is that there have been few collaborative opportunities that allow mutual comparison of their results.

A suite of benchmark problems is arranged on the world wide web site based on a study by the authors [1] to allow the mutual comparison of computational accuracy and efficiency of various methods. A specific form for contribution of numerical results is also provided below to clarify the comparison. The web site is constructed and run by the working group on "Computational Methods for Environmental Acoustics, Architectural Institute of Japan." This paper is a revised article based on the authors' previous reports ([2,3]).

2. Platform and benchmark problems

The database on the web site consists of five parts: "Top," "Introduction," "Directions," "Benchmark Problems" and "Papers," to provide a useful benchmarking platform. Its main language is English; the Japanese pages are provided as a supplement.

Table 1 shows the latest version of benchmark problem classifications; the problems share the main part of the platform. The table is provided on the "Introduction" page of the web site.

2.1. Basic regulations

Basic regulations for the calculation of each benchmark problem are given on the "Directions" page; the air condition, time factor, and units are determined as general regulations (see Table 2). Other regulations are assigned individually for respective problems in the frequency domain and time

domain.

In frequency domain problems, a stationary state with a single frequency is considered where octave-band center frequencies are assigned ranging from 31.5 Hz to 4 kHz. In time domain problems, the sampling frequency is fixed at 8 kHz. If a filtered pulse is used as the source, it must be mentioned in the data file described below. If supplementary data are necessary, they must also be noted.

2.2. Categories and types

The benchmark problems on the platform are classified as either: A — exterior; B — interior; or C — structural-acoustic. Each category has two types of problems: 0 — basic and 1 — practical.

To construct the basic problems, simple objects are arranged individually: a cube, a sphere, and a flat panel. They are designated with the index number "0," or as A0, B0, or C0. Similarly, regarding practical problems and realistic objects, an irregularly shaped reverberation room contains a loud speaker, a panel diffuser, a noise barrier, and an auditorium, which are designated with index numbers: "1," or A1, B1 and C1.

To identify the problem properties clearly, numbers and symbols are added to the index with hyphenation, or A0-1F. Typical examples of the two types, basic and practical, are illustrated in Figs. 1 and 2.

2.3. Tasks

If necessary, several "Tasks" can be attributed to each problem to clarify details of the problem's computing conditions or settings. For example, B0-1F has two tasks: A and B. The former is to compute "Spatial distribution of sound pressure amplitude [Pa] at 101 points (R1), on the line $x = z = 0.5$, which is located at 0.01 m intervals ($y = -0.5, -0.49, -0.48, \dots, 0.5$) at the octave-band center frequencies ($f = 31.5$ Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, and 4 kHz), while the latter computes "Frequency response of sound pressure amplitude [Pa] at three points (0.5, 0.5, -0.5) (R2), (0, 0, 0.5) (R3) and (0.4, 0.3, 0.2) (R4); at frequencies with 1 Hz intervals from 20 Hz to 4 kHz, or with 10 Hz intervals from 20 Hz to 4 kHz."

As subsidiaries for the preprocessing of a computation, datasets of geometrical frames and meshes are arranged for problems with complicated shapes.

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Table 1 Classification of benchmark problems.

Category	Type	Index	Domain	Object	Note
A. exterior	0. basic	A0-1F	frequency	vibrating cube	radiation
		A0-2F	frequency	cube	radiation
		A0-2T	time	cube	radiation
		A0-3F	frequency	sphere with a point source	scattering
		A0-3T	time	sphere with a point source	scattering
		A0-4F	frequency	sphere	scattering
		A0-4T	time	sphere	scattering
		A0-5F	frequency	flat panel	diffraction
		A0-5T	time	flat panel	diffraction
	1. practical	A1-1F	frequency	loudspeaker	radiation
		A1-1T	time	loudspeaker	radiation
		A1-2F	frequency	diffuser	scattering
		A1-2T	time	diffuser	scattering
		A1-3F	frequency	barrier on the ground	diffraction
		A1-4F	frequency	rigid barrier with cylindrical edge	diffraction
		A1-4T	time	rigid barrier with cylindrical edge	diffraction
		A1-5F	frequency	absorptive barrier with cylindrical edge	diffraction
		A1-5T	time	absorptive barrier with cylindrical edge	diffraction
B. interior	0. basic	B0-1F	frequency	cubic cavity	closed cavity
		B0-1T	time	cubic cavity	closed cavity
	1. practical	B1-1F	frequency	auditorium	closed cavity
		B1-1T	time	auditorium	closed cavity
		B1-2F	frequency	auditorium with seats	closed cavity
		B1-2T	time	auditorium with seats	closed cavity
		B1-3F	frequency	reverberation room	closed cavity
		B1-3T	time	reverberation room	closed cavity
C. structural-acoustic	0. basic	C0-1F	frequency	plate in baffle	insulation
	1. practical	C1-1F	frequency	plate in a room	radiation
		C1-2F	frequency	plate between rooms	insulation

Table 2 Basic regulations for calculation.

Time factor	$\exp(+i\omega t)$
Air condition	
	$c = 343.7 \text{ m/s}$
	$\rho = 1.205 \text{ kg/m}^3$
	$T = 20^\circ\text{C}$

Fig. 1 Geometry of problem (B0-1F/T) with a point source (S) and receiving points (R1–R4). Unit [m]. **Fig. 2** Geometry of problem (B1-3F/T). A point source (S) and receiving points (R1). R1 comprises 53 points on a line. Unit [m].

The CPU-time and used memory are measured and specified to evaluate computational efficiency. Note that the CPU-time does not include the time for mesh generation. Regarding additional information of a computation, such as applied mesh division, element type(s) and size(s), the number of nodes, degrees of freedom, and so on should be specified in the data file, as shown below.

2.4. Data files for contribution

A downloadable MS-Excel formatted file is provided for contributors to list their computed results. The file comprises three sheets: face items, numerical output, and computing performance. All supplementary information about a contributor's computation can be filled into the Excel-cell that is prearranged as that for "Comments" on each sheet. The data file, which is submitted to the web-administrator, is to be included in the "Contributions" section, where it is represented by the method name and contributor.

3. Example applications

Using the database, one can compare results with those obtained by other contributors listed in the data files. Figure 3 shows an example of a comparison of results of B0-1F as computed by modal summation, FEM, BEM and FMBEM. In the data files, explanations of each computational environment are given in the face items. Table 3 shows several

Fig. 3 Example application of the database. Results are compared for B0-1F computed by Modal-Summation, FEM, BEM, and FMBEM. Symbol superscripts correspond to the numbers in Table 3.

Table 3 Summary of face items submitted to B0-1F.

No.	Method	Machine
1	Modal Summation	iMac PowerPC G3
2	FEM	SunBLADE 2 x UltraSPARCIII Cu
3	BEM	Dell Precision WorkStation 610
4	FMBEM	<i>ditto</i>

exemplary items that are selected from downloaded sheets.

Regarding practical problems, an analytical solution is not obtained easily. In such cases, measured data are valuable as a reference. In this respect, some contributors have submitted their computational results with measured data. An example of one case is given in Fig. 4. The figure shows a comparison between sound pressure levels as computed by FEM and measured data on B3-1F at 1/3 octave-band centered on 250 Hz. Pearson's correlation coefficient, R , is equal to 0.89 in this case. Since, in general, a measurement at a single frequency is not easy to give meaningful sound pressure value, octave or 1/3 octave-band measurements are usually conducted. In such cases, computed values at the frequencies within the band width must be integrated to give a single number.

4. Concluding remarks

This paper introduced a world wide web database of computational methods for environmental acoustics along with several example applications. The project has just begun; contributions from various aspects of numerical methods including conventional techniques are welcomed. The progress of computing power is sufficiently rapid that extension of current computational methods is also expected. The web site address is: <http://gacoust.hwe.oita-u.ac.jp/AIJ-BPCA/>.

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Fig. 4 Comparison of sound pressure level distribution in a reverberation room (B3-1F) between FEM and measurement at 1/3 octave-band centered on 250 Hz.

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