The Penetrable Wedge as a Three Dimensional Benchmark

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Abstract: In 1989, members of the Acoustical Society of America developed a suite of range-dependent benchmark geometries, allowing the underwater acoustics community to compare the performance of analytical and numerical solutions to two dimensional propagation problems. With recent advances in analytical and numerical solutions to three dimensional propagation problems, establishing three dimensional benchmarks is a timely development. The three dimensional Green's function for the penetrable wedge has already been studied by a number of investigators, and measured with scale-model tank experiments. The state of modeling and measurement for the wedge will be discussed in the context of its usefulness as a three dimensional benchmark.

THE PROPERTIES OF A THREE DIMENSIONAL BENCHMARK

Tolstoy (1) has recently reviewed the capabilities and limitations of currently available, three dimensional (3D) range-dependent propagation models. The review highlighted the need to compare and determine the accuracy of 3D models. One of the most important reasons for establishing benchmarks is to allow such comparisons by giving interested parties a well posed canonical problem that can be solved by a variety of analytical and numerical methods. Felsen (2) discussed this issue in connection with the Acoustical Society of America benchmark wedge established in 1990 to allow comparison of two dimensional, range-dependent propagation models.

To serve their intended purpose, benchmark geometries will ideally have a primary benchmark, which is an exact analytical solution to the problem. A secondary benchmark is a method of solution with more general applicability than, but which agrees closely with, the primary benchmark (3). The desire for a primary benchmark usually results in the removal of real-world complexities from benchmark geometries, resulting in a 'canonical' problem tractable to analytical analysis. Care must be taken with canonical geometries to ensure that the essential physical phenomena of interest are retained in the chosen problem. Thus choice of a benchmark requires some a priori knowledge of the physical relevant effects.

Clearly, any geometry chosen for a 3D benchmark should exhibit some clearly identifiable feature which cannot be reproduced by 2D models. Variable bathymetry and horizontal refraction in the water column both lead to 3D features in the sound field. The acoustic wedge is arguably the simplest geometry that shows 3D propagation effects caused by variable bathymetry. Variable bathymetry results in refraction of acoustic energy and is the cause of the shadow zones observed in the 3D solution of propagation in a wedge (4). Sufficient along-shore translation from a source eventually finds a caustic associated with the fundamental mode for any frequency and off-shore range. The acoustic field decays rapidly beyond the caustic. This feature of the sound field cannot be reproduced by N×2D acoustic models that compute transmission loss along radials from the source (5).

THREE DIMENSIONAL SOLUTIONS OF THE PENETRABLE WEDGE

The Green's function for a wedge with impenetrable boundaries has a primary benchmark (6), but geometries with idealized boundaries are often difficult to handle with numerical models developed for real-world environments. This difficulty restricts the number of models that can be compared and makes the ideal wedge less useful as a benchmark.

Both mode and ray-based analytical solutions are available for an acoustic wedge with a penetrable basement (7-9). The acoustic wedge with a two-layer, elastic basement has been studied experimentally by Glegg and his colleagues (10). Fig. 1 shows a best-case comparison between Glegg's transmission loss measurements and Deane's source image model. The agreement is good until the noise floor of the measurement instrumentation is reached at around -10dB. Not all frequencies showed such good agreement, indicating a problem with either the experiment or model. The final, local maximum and decay of the curves in Fig. 1 beyond 1 meter is the caustic of the fundamental mode discussed earlier.
FIGURE 1. The agreement between experimental (solid line) and theoretical (broken line) transmission loss curves for across-slope propagation in a wedge with a two-layer, elastic basement at 110kHz. From Glegg et. al. (10).

The penetrable wedge is readily solved by a number of currently available, 3D numerical models (for example, see Fawcett (5) ). Secondary benchmark analytical models, the availability of a high-quality data set, and tractability to numerical modelers makes the penetrable wedge a good candidate for a three dimensional benchmark. Another factor in favor of the wedge is its relevance to real-world problems of interest. Many beaches exhibit a wedge-like geometry.

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