Effective Geo-Acoustic Model for Sand-Silt Bottoms in Shallow Water

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Award Number: N00014-06-1-0655

LONG-TERM GOALS

The long-term goals of this work are: to develop a practical seabed geo-acoustic model for predicting transmission loss (TL), reverberation level (RL) and signal-reverberation ratio (S/R) in shallow water with sand and silt bottoms; to characterize sea bottom geo-acoustic parameters (sound speed and attenuation) and bottom scattering strength from both sound propagation and reverberation measured in a low frequency (LF) range of 100-3000Hz, and to reveal the physics of LF sediment acoustics and bottom scattering through data analyses.

OBJECTIVES

The scientific objectives of this year's research include: (1) To analyze and review both sound propagation and reverberation data collected from different locations in shallow water with sand and silt bottoms. (2) To find an effective seabed geo-acoustic model to predict low-frequency sound propagation and reverberation in shallow water.

APPROACH

Strong seabed interaction, multi-path transmission and water column variability characterize sound propagation and signal fluctuations in shallow water. The acoustic properties of the seabed usually dominate the problem. Reliable predictions of transmission loss, reverberation level, echo to reverberation ratio, spatial coherence loss, and time/angle spreading of signals, all require a reliable seabed geo-acoustic model and bottom scattering model as well as knowledge the physics of acoustic interaction with the bottom. Two well-known seabed geo-acoustic models are now widely accepted: the Hamilton visco-elastic model and the Biot-Stoll poro-elastic model. The Hamilton model suggests that the attenuation of sound waves in marine sediments increases linearly with frequency over the full frequency range of interest in ocean acoustics, and that the sound speed in sediments is almost frequency independent. The Biot model, however, predicts strong dispersion and non-linear frequency dependence of attenuation, particularly in sandy and silty bottoms at low frequencies. The debate between proponents of these two models has persisted for decades. To develop a practical seabed acoustical model for predicting TL, RL, S/R ratio in shallow water, a lot of effort has been spent developing seabed geo-acoustic inversion methods. Several good inversion methods were developed and used to make data-model comparisons. Unfortunately, these methods have yet to yield a reliable data base over a broad range of frequencies that can be used for practical applications. The current work has involved an analysis and review of LF field measurements at different locations around the world to determine whether these measurements, taken as a group, can throw additional light on this subject.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE
Effective Geo-Acoustic Model For Sand-Silt Bottoms In Shallow Water

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Georgia Institute of Technology,School of Mechanical Engineering,Atlanta,GA,30332-

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESULTS

(1) Low-frequency field measurements conducted at 18 locations in different coastal zones around the world have been analyzed and reviewed. This analysis resulted in nonlinear frequency dependences of sound attenuation in sand-silt sea bottoms. The relevant LF measurements include bottom reflection loss at small grazing angles, matched field processing, transmission loss, dispersion analysis, normal-mode spatial filtering, transition ranges of sound propagation decay laws, vertical coherence of propagation and reverberation, signal time series/spreading, and Hankel transforms.

(2) The effective sound speed and attenuation in the sand-silt sea bottoms have been inverted from LF field measurements in a frequency range of 50-2000 Hz. Although all the inversion methods unavoidably involved uncertainties, the sound attenuations inverted from different field characteristics at 18 sites, all exhibited similar magnitude and similar non-linear frequency dependence. This fact casts serious doubt on a universal assumption of linear frequency dependence of sound attenuation in seabed. The sound velocity ratios at the water-sediment interface, inverted from the LF field measurements at 8 locations, are in a range of 1.04-1.08.

(3) Both the LF field-derived sound velocity and attenuation in the sand-silt bottoms can be well described by the Biot-Stoll model with the parameters that are justified on the basis of either theoretical considerations or past experimental measurements on sand and silt seabeds. In the basic Biot theory, three parameters largely control the fluid motion that results in the nonlinear dispersion that is important in coarse granular sediments. These are the permeability k_s, the porosity β, and the tortuosity α_0. Data/model comparisons (trials) tell us that the LF sound velocity ratio is most sensitive to the porosity of sediment, and less sensitive to the permeability and tortuosity; the LF sound attenuation is most sensitive to permeability of sediment, less sensitive to the porosity and tortuosity. Thus, the porosity and the permeability are easily obtained by finding values that provide the best match between the Biot model and the LF field-inverted velocity ratio and attenuation.

(4) The possible "velocity-attenuation coupling" problem in seabottom geo-acoustic inversions is addressed in this work. It shows that, if acoustic energy losses such as the TL or modal decay law are used to derive the sound attenuation in bottom, one should first have an accurate value of sound speed in seabed (and density), independently derived from LF measurements, as a constrained condition. A possible error in dispersion-based inversion made at one distance, caused by filter phase shift, is also analyzed.

(5) The LF field-derived seabed acoustic parameters are joined smoothly with the SAX99 benchmark data for mid- and high-frequency, and also match Hamilton's prediction on sound attenuation around 1 kHz. A combination of the LF field-inverted data with the SAX99 data as well as other HF measurements offers a reference broadband data set of sound velocity and attenuation for sand-silt bottoms in shallow water in a frequency range of 50-400,000Hz. Changing the porosity β from 0.39 to 0.46, permeability k_s from 2.5E-11 to 0.5E-11 (m^2) and tortuosity α_0 from 1.25 to 1.45, and keeping 11 other Biot parameters the same as those measured by the SAX99 group, we have obtained two attenuation curves shown in Figure 1. These two curves cover our LF field-derived sound attenuation at 18 locations as well as recent direct measured attenuation at mid- and high-frequency at 3 locations in a broadband range of 50-400,000Hz.

PUBLICATIONS

1. J.X. Zhou, X.Z.Zhang, Z.H. Peng and J.S.Martin, "Sea surface effect on shallow-water reverberation," J. Acoust. Soc.Am., **121**, 98-107 (2007).

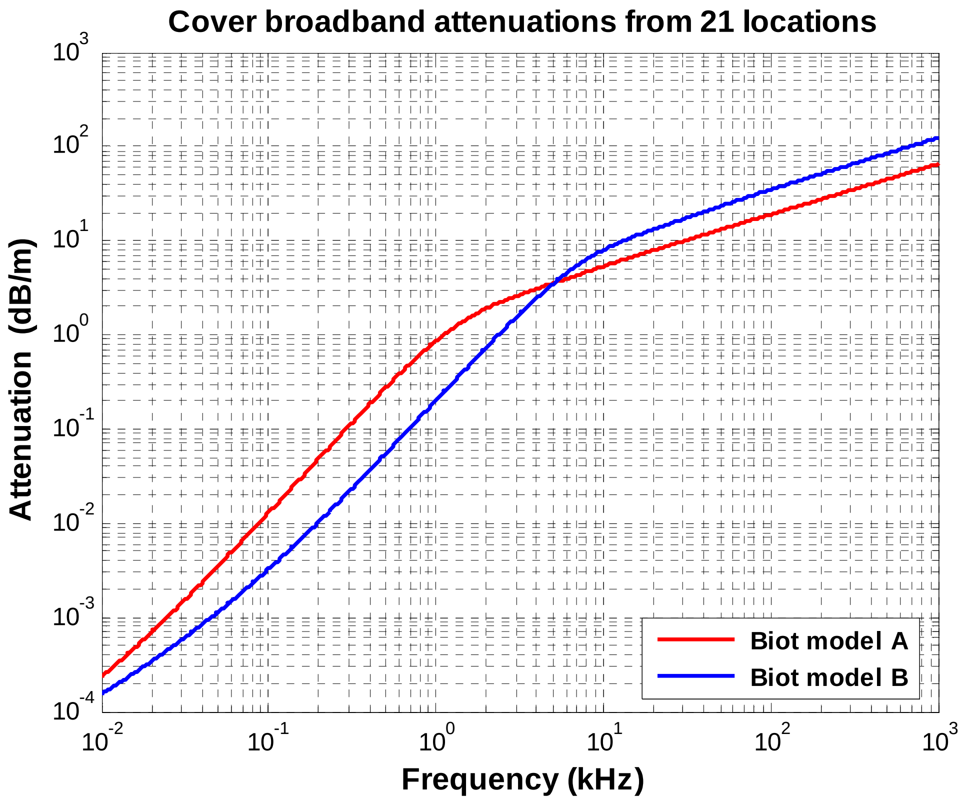

Figure 1. Two sets of the Biot parameters predict the sound attenuation in shallow water with sand-silt bottom in a broadband of 50-400,000Hz