Laboratory Investigations and Numerical Modeling of Loss Mechanisms in Sound Propagation in Sandy Sediments.

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LONG-TERM GOALS

To develop accurate models for high frequency sound propagation within shallow water sediments.

OBJECTIVES

The scientific objectives are to: 1) quantify the relative importance of scattering and frictional losses in the attenuation of sound in the sediment, 2) evaluate and improve existing models of sound propagation and, 3) develop more complete models of sound propagation that can account for the complexity of shallow water sediments.

APPROACH

Recent experiments have suggested that at high frequencies in unconsolidated, granular media, the attenuation of sound may be due to both dissipation mechanisms at the grain contacts and scattering losses due to presence of heterogeneities in media [1,2]. While this may explain the attenuation observed at high frequencies in ocean sediments, such as that observed during the Sediment Acoustics Experiment 1999 (SAX99) and 2004 (SAX04) [3,4], a majority of the theories that have been developed to date have focused solely on losses at the grain contacts [5,6]. The work performed here examines the role of heterogeneities in the sediment which may scatter energy from the coherent fast compressional wave into slow compressional and shear waves, increasing the attenuation.

To understand the role of the heterogeneous nature of unconsolidated media, efforts will be made to develop models that account for the presence of force chains and porosity variations. These heterogeneities will be incorporated into a Biot description of a sand sediment using perturbation theory. Central to any attempt to incorporate heterogeneities into Biot theory is a statistical description of the variations in the medium. In studies of force chains, a majority of measurements made by the granular physics community have focused on determining the probability distribution of the forces between the grains. Very little work has been done to determine the statistics of the *spatial* distribution of the chains. Describing factors such as the correlation length of the bulk and shear moduli variations, is extremely important in determining the degree to which they will produce scattering in the medium. Likewise, for porosity variations, very little work has been done to determine the spatial statistics of the porosity in either real ocean sediments or in idealized glass bead sediments.

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14. ABSTRACT
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Since the development of a proper statistical description of the medium is essential to the propagation modeling, efforts are being undertaken to determine these statistics in sand and glass bead sediments. The primary effort underway is being conducted in conjunction with Joseph Calantoni, at NRL-Stennis, to perform molecular dynamics simulations of random packings of glass beads and composite particles from which the porosity and force chain statistics can be determined. These simulations represent an idealized medium in which we can control the factors that affect the interactions between the grains, including normal and shear friction, the force laws governing the contact dynamics, and the size distribution of the particles. These results will provide the statistical description of a glass-bead medium necessary to compare the theory to the results of laboratory measurements taken in glass-bead sediments [6].

WORK COMPLETED

The initial efforts to account for scattering due to bulk modulus heterogeneities incorporated the modulus variations into the scalar Biot theory using perturbation theory. This theory has been developed in collaboration with Darrell Jackson at APL-UW and was presented at the meeting of the Acoustical Society of America in Providence, RI [7]. In this model, the scalar form Biot's poroelastic equations could be used since the variations did not affect the shear wave and therefore the wave equations could be decoupled and solved in terms of potentials.

While this greatly simplified the solution, a full solution that incorporates bulk modulus, shear modulus, and porosity variations, requires the vector form of the poroelastic equations. In order to apply perturbation theory to these equations, the poroelastic Green's tensor is also required. The proper form of the Green's tensor has been determined and applied to the perturbed poroelastic equations allowing for the complete solution to be derived. The initial efforts to incorporate variations in the porosity were presented at the meeting of the Acoustic Society of America in Honolulu, HI [8]. Subsequent work has found that those results were incorrect and the proper theory has since been developed. A manuscript that presents this theory is currently in preparation. A full theory incorporating both bulk and shear moduli variations is also near completion and the initial results from this theory were presented at the meeting of the Acoustic Society of America in Paris, France [9].

In order to apply these theories to laboratory and field data, the statistics of the heterogeneities must be measured or estimated. Work is ongoing with Joe Calantoni using molecular dynamics simulation of granular materials to estimate the porosity and moduli variations. The most straightforward of these statistics, is the correlation function for the porosity and this has been determined for the simplest case of a random packing of perfect spheres. The more difficult problem of estimating the variations in the frame moduli is being approached using the methods developed by Bagi for examining the stress and strain in a granular material at the length scales of the grains themselves [9]. This technique involves creating a Voronoi tessellation of the medium and determining the stress in each Voronoi cell as well as the strain between groups of neighboring spheres that sit at the vertices of the cell. An example of this tessellation is shown in Fig. 1. This technique is currently being refined for a simulation of 260 spheres and will be extended to larger simulations once it has been tested.

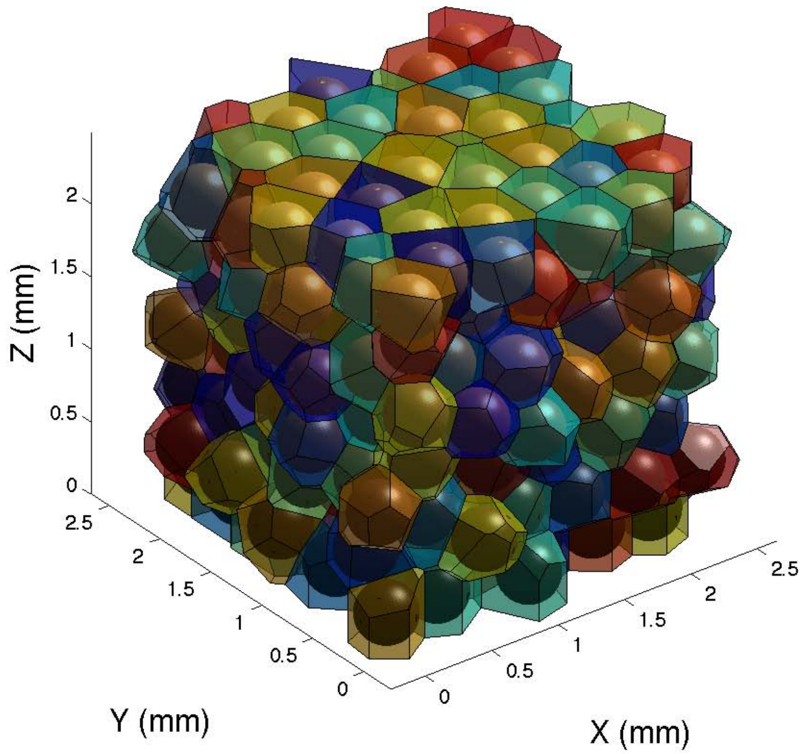

Figure 1: MD simulation of a random packing of 260 spheres and the Voronoi tesselation of the packing. The color of each cell is randomly chosen to help distinguish each cell from one another and is not related to any property of the packing.

RESULTS

To apply the perturbation theory for porosity variations to sand sediments, it is necessary to know the autocorrelation function for the spatial variations of the porosity in the medium. The magnitude of the attenuation predicted by the theory is not expected to depend strongly on the form of this function therefore we have assumed an exponential autocorrelation function since it provides an analytic solution to the theory. The exponential autocorrelation function has two free parameters: the variance, σ_β^2, and the correlation length, *r*, of the porosity variations. The upper panels in Fig. 2 show the predictions of the theory as the variance of the porosity is increased from $\sigma_\beta^2 = 0$ to $\sigma_\beta^2 = 0.115$ and the correlation length is held constant at $r = 3\ d$, where *d* is the diameter of the grains. The lower panels shows the theory predictions as the correlation length is varied from $r = 0$ to r = 8 *d*. The remaining parameters have the same values as measured during SAX99[3].

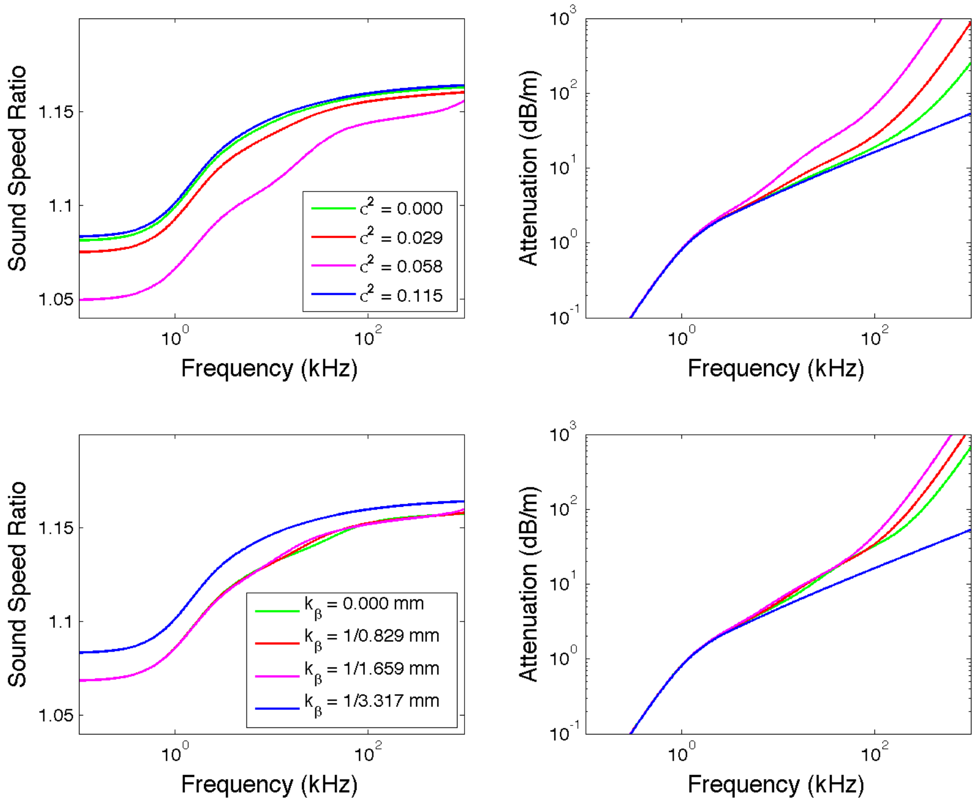

Figure 2: Predictions of perturbation theory for a poroelastic medium with spatial variations in the porosity. In the upper panels, the correlation length is r = 3 d while in the lower panels the variance is $\sigma_\beta^2 = 0.0059$.

IMPACT/APPLICATIONS

This work will potentially lead to the development of complete, physically-based models of sound propagation in sandy sediments by accounting for scattering losses which can supplement various proposed loss mechanisms such as grain-to-grain shearing.

RELATED PROJECTS

1. Title: High-Frequency Sound Interaction in ocean sediments, Grant# N00014-98-1-0040, E.I. Thorsos, PI. http://www.apl.washington.edu/projects/SAX04/summary.html The efforts of SAX04 were coordinated under this program. The measurement of sediment sound speed and attenuation at the SAX04 site was conducted under this program. The results of the analysis of this data will be used in the development of theories of sound propagation.

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