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ON THE CURRENT STATUS OF
THEORETICAL MODELING OF SEISMIC WAVES
IN SATURATED SEDIMENTS

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Technical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A brief, critical discussion is given of efforts to develop theoretical models for wave propagation in saturated marine sediments. The modeling of propagation in unbounded media is considered as well as the problem of wave reflection at the water/saturated sediment interface. It is concluded that, while important and substantial progress has been made, much work remains, particularly with regard to the characterization of the viscoelastic properties of sediments at low frequencies.		

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I. INTRODUCTION

An important part of the analysis of acoustic waves in the ocean is the prediction of wave interactions with the bottom. This is a most complex problem, not only because of the irregular topography and inhomogeneity of the ocean bottom, but because the material comprising the bottom is a fluid saturated porous material having very complicated mechanical characteristics.

In this report, a summary is given of the theoretical models which have been developed for the analysis of wave propagation in saturated sediments. In Section II, theories for wave propagation in the unbounded medium are considered. The single component approach is treated briefly, and then a more extensive discussion is given of the mixture theory due to Biot. In Section III, some recent progress on the reflection and refraction of waves at a plane interface between water and a water saturated sediment is described.

II. WAVES IN UNBOUNDED MEDIA

A. The Equivalent Continuum

The simplest approach to analyzing waves in saturated sediments is to model the saturated sediment as a single continuous medium. The mechanical properties of the continuous medium are chosen so that its behavior is equivalent, in a necessarily limited sense, to that of the saturated sediment. Since waves in saturated sediments in general exhibit dispersion and attenuation, the equivalent continuous medium must be viscoelastic.

Models of this type have been discussed by Hamilton.¹⁻⁵ He suggests the use of the particularly simple linearly viscoelastic model in which the Lamé constants λ and μ of an isotropic, linearly elastic material are replaced by complex moduli $\lambda+i\lambda'$, $\mu+i\mu'$. The moduli λ , λ' , μ , and μ' are assumed to be frequency dependent and are to be determined from experiment. This type of model is equivalent to a Voigt material.⁶ Hamilton cites developments of the model by Ferry⁷ and White.⁸

Such a purely empirical approach has substantial advantages and disadvantages. The primary advantage is its simplicity. Once the coefficients in the theory have been evaluated as functions of frequency, then the large body of literature and many existing computer programs on wave propagation in viscoelastic materials can be used to obtain solutions to specific problems. On the other hand, since the model does not explicitly incorporate the physical properties of the saturated sediment, the coefficients in the theory must be measured anew for each change in the properties of the material. More important, the theory does not have the ability to predict the effects on wave propagation of changes in the material properties.

B. The Biot Theory

In order to introduce the physical properties of the saturated sediment, the material can be modeled as a binary mixture of fluid and solid constituents. By retaining the individual identities of the fluid and solid, it is possible to express at least part of the coefficients in terms of the physical properties of the two constituents.

A theory of this type was developed for application to fluid saturated, porous elastic media by Biot.⁹⁻¹² While he derived his equations on a somewhat intuitive basis, many subsequent studies have confirmed that they are consistent with the principles of continuum mechanics (see, for example, Bowen¹³ and Bedford and Drumheller¹⁴).

Biot's equations can be written

$$(1-\phi) \rho_s \ddot{u}_{(s)m} = -m(\ddot{u}_{(s)m} - \ddot{u}_{(f)m}) + A e_{(s)kk,m} + 2\mu_b e_{(s)mk,k} + Q e_{(f)kk,m} - b(\dot{u}_{(s)m} - \dot{u}_{(f)m}) \quad , \quad (1)$$

$$\phi \rho_f \ddot{u}_{(f)m} = m(\ddot{u}_{(s)m} - \ddot{u}_{(f)m}) + Q e_{(s)kk,m} + R e_{(f)kk,m} + b(\dot{u}_{(s)m} - \dot{u}_{(f)m}) \quad , \quad (2)$$

where ϕ is the porosity, ρ_s and ρ_f are the mass densities of the solid and fluid, $u_{(s)m}$ and $u_{(f)m}$ are the displacement vectors of the solid and fluid, the notation $_{,m}$ denotes partial differentiation with respect to the coordinate x_m , $e_{(s)mk}$ and $e_{(f)mk}$ are the linear strains of the solid and fluid $[e_{(s)mk} = 1/2(u_{(s)m,k} + u_{(s)k,m})]$, and A , μ_b , Q , R , c , and b are constitutive coefficients.

Equations (1) and (2) are the equations of motion for the solid and fluid constituents, respectively. The first term on the right of each equation is a virtual mass term which is linear in the relative acceleration of the constituents. The last term on the right is a drag term which is linear in the relative velocity of the constituents. By using the solution for an oscillating cylinder containing a viscous fluid, Biot was able to evaluate the coefficient of the drag term b as a function of frequency.¹⁰

In a further important development, Biot and Willis¹⁵ showed that the coefficients A , Q , and R could be expressed in terms of the bulk modulus of the solid material, the bulk modulus of the fluid, and the bulk and shear moduli of the drained porous solid K_b and μ_b .

The Biot theory was first applied to marine sediments by Stoll and Bryan¹⁶ and Stoll.¹⁷⁻¹⁹ In order to account for dissipative effects associated with motion of the granular matrix material, these authors assumed that the moduli K_b and μ_b were viscoelastic. Based upon experimental data on dry granular media, it was assumed that K_b and μ_b were complex constants. It was shown by Stoll that the theory could correctly predict the variation with frequency of the attenuation of compressional waves in saturated sands.¹⁷

The work of Stoll and Bryan was extended by Hovem and Ingram,²⁰ who showed that Biot's technique for evaluating the drag coefficient b could be used to evaluate the virtual mass coefficient c as well. They were also able to obtain a more explicit expression for b in the case of a sediment consisting of particles of uniform size. They then presented very favorable comparisons of the theory with measurements of compressional wave attenuation in saturated sands. In addition, they presented new experimental data on compressional waves in a model sediment consisting of spherical glass beads saturated by water, and showed that the theory correctly predicted both the attenuation and phase velocity of compressional waves.

Thus the extended Biot theory has been shown to give quite accurate predictions in comparison with direct measurements of both phase velocity and attenuation in saturated sediments.

Stoll¹⁷ has used the Biot theory to show that the dominant loss mechanism at high frequencies is the drag between the solid and fluid constituents, while the dominant mechanism at low frequencies is dissipation in the viscoelastic granular matrix.

Because the scale of measurements of phase velocity and attenuation is necessarily small in a laboratory setting, the data are in the kilohertz frequency range and above. Such measurements cannot be used to verify the theory at lower frequencies. Stoll²¹ has obtained some low frequency data on the attenuation of shear waves in saturated sediments by using a resonant column technique, but he gave only qualitative comparisons with the theory.

There is a pressing need for additional data at low frequencies and for data which can shed light on the viscoelastic properties of the granular matrix.

Recently, Shirley et al.²² presented direct measurements of phase velocity and attenuation in a glass bead sediment saturated by a mixture of water and glycerine. By varying the proportion of glycerine, the viscosity of the liquid could be changed. In comparison with the extended Biot theory, the data predicted a substantially greater increase in attenuation with increasing viscosity. The measurements were made at a single frequency. Measurements made for a range of frequencies would greatly aid in characterizing the viscoelastic response of the granular matrix. This in turn could conceivably permit extrapolation of the theory to low frequency.

C. Reflection at an Interface

The ultimate objective of efforts to model wave propagation in saturated sediments is the analysis of wave interactions with the ocean bottom. Although much work remains to be done on propagation in the unbounded medium, important progress on the interaction problem has recently been made by Stoll and Kan.²³ They considered a liquid half space above a half space of saturated sediment, and solved the problem of the reflection and refraction of plane waves at the interface using the extended Biot theory. The analysis was based on the earlier work on saturated porous media by Deresiewicz and Rice.²⁴

In contrast to the results for elastic media, they showed that the reflection coefficient exhibited strong frequency dependence, and was also a function of the assumed value of permeability of the sediment. The results obviously have important implications for the modeling of bottom interactions.

The analysis of Stoll and Kan will have to be extended before realistic estimates of bottom loss can be achieved. They assumed that the sediment properties were homogeneous and isotropic. It is, of course, well known that sediment properties are strongly depth dependent.^{5,19} There is also some evidence that sediments are anisotropic.^{25,26} Both of these factors would influence the reflection and refraction of waves.

REFERENCES

1. E. L. Hamilton, "Elastic Properties of Marine Sediments," *J. Geophys. Res.* 76, 579-604 (1971).
2. E. L. Hamilton, "Prediction of In Situ Acoustic and Elastic Properties of Marine Sediments," *Geophys.* 36, 266-284 (1971).
3. E. L. Hamilton, "Compressional Wave Attenuation in Marine Sediments," *Geophys.* 37, 620-646 (1972).
4. E. L. Hamilton, "Geoacoustic Models of the Sea Floor," in Physics of Sound in Marine Sediments, edited by L. D. Hampton (Plenum Press, New York, 1974), pp. 181-221.
5. E. L. Hamilton, "Geoacoustic Modeling of the Sea Floor," *J. Acoust. Soc. Am.* 68, 1313-1340 (1980).
6. W. M. Ewing, W. S. Jardetzky, and F. Press, Elastic Waves in Layered Media (McGraw-Hill Book Co., Inc., New York, 1957) pp. 272-278.
7. J. D. Ferry, Viscoelastic Properties of Polymers (John Wiley and Sons, Inc., New York, 1961).
8. J. E. White, Seismic Waves: Radiation, Transmission, and Attenuation (McGraw-Hill Book Co., Inc., New York, 1965).
9. M. A. Biot, "Theory of Elastic Waves in a Fluid Saturated Porous Solid. I. Low Frequency Range," *J. Acoust. Soc. Am.* 28, 168-178 (1956).
10. M. A. Biot, "Theory of Elastic Waves in a Fluid Saturated Porous Solid. II. Higher Frequency Range," *J. Acoust. Soc. Am.* 28, 179-191 (1956).
11. M. A. Biot, "Mechanics of Deformation and Acoustic Propagation in Porous Media," *J. Appl. Phys.* 33, 1482-1498 (1962).
12. M. A. Biot, "Generalized Theory of Acoustic Propagation in Porous Dissipative Media," *J. Acoust. Soc. Am.* 34, 1254-1264 (1962).
13. R. M. Bowen, "Theory of Mixtures in Continuum Physics," in Continuum Physics, Vol. III, Mixtures and EM Field Theories, edited by A. C. Eringen (Academic Press, New York, 1976).
14. A. Bedford and D. S. Drumheller, "A Variational Theory of Porous Media," *Int. J. Solids Structures* 15, 967-980 (1979).
15. M. A. Biot and D. G. Willis, "The Elastic Coefficients of the Theory of Consolidation," *J. Appl. Mech.* 24, 594-601 (1957).

16. R. D. Stoll and G. M. Bryan, "Wave Attenuation in Saturated Sediments," J. Acoust. Soc. Am. 47, 1440-1447 (1969).
17. R. D. Stoll, "Acoustic Waves in Saturated Sediments," in Physics of Sound in Marine Sediments, edited by L. D. Hampton (Plenum Press, New York, 1974).
18. R. D. Stoll, "Acoustic Waves in Ocean Sediments," Geophys. 42, 715-725 (1977).
19. R. D. Stoll, "Theoretical Aspects of Sound Transmission in Sediments," J. Acoust. Soc. Am. 68, 1341-1350 (1980).
20. J. M. Hovem and G. D. Ingram, "Viscous Attenuation of Sound in Saturated Sand," J. Acoust. Soc. Am. 66, 1807-1812 (1979).
21. R. D. Stoll, "Experimental Studies of Attenuation in Sediments," J. Acoust. Soc. Am. 66, 1152-1160 (1979).
22. D. J. Shirley, A. Bedford, and S. K. Mitchell, "Wave Propagation in a Saturated Model Sediment with Varied Liquid Properties" (in preparation).
23. R. D. Stoll and T. K. Kan, "Reflection of Acoustic Waves at a Water-Sediment Interface," J. Acoust. Soc. Am. 70, 149-156 (1981).
24. H. Deresiewicz and J. T. Rice, "The Effect of Boundaries on Wave Propagation in a Liquid Filled Porous Solid: III. Reflection of Plane Waves at a Free Plane Boundary (General Case)," Bull. Seismol. Soc. Am. 52, 595-625 (1962).
25. R. T. Bachman, "Acoustic Anisotropy in Marine Sediments and Sedimentary Rocks," J. Geophys. Res. 84, 7661-7663 (1979).
26. M. H. Manghnani, S. O. Schlanger, and P. D. Milholland, "Elastic Properties Related to Depth of Burial, Strontium Content and Age, and Diagenetic Stage in Pelagic Carbonate Sediments," in Bottom Interacting Ocean Acoustics, edited by W. A. Duperman and F. B. Jensen (Plenum Press, New York, 1980) pp. 41-51.

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