Investigation of Ultrasonic Wave Interaction with Fluid-Saturated Porous Rocks

Final Report
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Summary

During the period of this grant we have conducted an investigation of ultrasonic wave propagation in fluid-filled porous materials. The acoustical properties of fluid-saturated porous media are of interest to the geophysical community because measurements of the various wave velocities (fast and slow compressional waves, shear wave, surface waves, Lamb wave, etc.) and attenuation can lead to important parameters of fluid-filled rocks, e.g. elastic properties, tortuosity, permeability, internal damping, porosity, etc. Several of these parameters are especially related to the so-called slow wave velocity and attenuation, and one of our major efforts was to develop techniques to measure slow wave parameters.

First we studied the feasibility of using different surface modes to characterize both synthetic and natural rocks. We introduced several new techniques: corrugated surface wave technique, and direct generation of surface waves by edge excitation. We have reported the first observation of the so-called "true" surface wave on the free surface of fluid-saturated rocks. We have developed analytical solutions to the reflection and transmission of ultrasonic waves at boundaries between fluid and fluid-saturated porous solids. An experimental system was also developed to verify analytical predictions. These analytical treatments led to the development of a general solution for thin fluid-saturated porous plates and the dispersion curves of Lamb modes. Additional dispersion curves were predicted due to the presence of slow waves. Based on theoretical prediction, a new method was developed to detect slow waves in the frequency domain by measuring the Lamb wave spectrum.

In addition to the investigation of guided acoustic waves (surface waves, Lamb waves) in water-saturated porous media, we also studied bulk wave propagation in air-saturated specimens. We developed an experimental technique, which is based on the transmission of airborne ultrasonic waves through air filled porous plates. This technique provided irrefutable evidence of slow wave propagation in natural rocks and lends itself quite easily to tortuosity measurements in such materials. This technique was further developed to a high-resolution slow wave imaging system, to study the inhomogeneous pore structure of permeable formation.

Our research efforts – supported through this grant – should find application to the geophysical evaluation of fluid-bearing rocks where conventional techniques are difficult to apply. During this period thirty-four (34) research papers were published on the subject of this work supported by the Department of Energy. In addition two Ph.D. dissertations and one M.Sc. thesis covered this subject.

A list of publication and copies of published manuscripts will be given in this report.

Publications

1. M. J. Mayes, P. B. Nagy, L. Adler, B. P. Bouves, and R. Strict: "Excitation of surface waves of different modes at fluid-porous solid interface. J. Acoust. Soc. Am. 79, p.249, 1986.
2. L. Adler, Q. Xue, A. Jungman, and G. Quentin: "Measurements of ultrasonic parameters in fluid-filled porous metals with different grain size," J. Acoust. Soc. Am. Suppl. 1, 82, p.520, 1987.
3. A. Jungman, Q. Xue, and L. Adler: "Ultrasonic bulk and surface wave measurements in fluid-saturated porous materials," Technical Report No. 18. The Ohio State University, Columbus, Ohio, 1988.
4. A. Jungman, L. Adler, and G. Quentin: "Ultrasonic velocity measurements in porous materials," Nondestructive Characterization of Materials, pp.122-130, eds. P. Holler, V. Hank, G. Dobmann. Springer-Verlag, Berlin, Heidelberg, New York, 1989.
5. A. Jungman, G. Quentin, Q. Xue, and L. Adler: "Ultrasonic waves interaction with fluid-saturated porous plates," 13th International Congress on Acoustics Proceedings. Ed. P. Pravica, Vol. 1, pp.313-316, Sava Centar Pub., 1989.
6. A. Jungman, G. Quentin, L. Adler, and Q. Xue: "Elastic property measurements in fluid-filled porous materials," J. Appl. Phys. 66 (11), pp.5179-5184, 1989.
7. P. B. Nagy, L. Adler, K. Lewis, and B. Bonner: "Ultrasonic NDE of Fluid Saturated Porous Solids," Characterization of Materials and Flows 1988 ASNT Spring Conference. [Abstract Book p.51].
8. Q. Xue, K. Wu, L. Adler, A. Jungman, and G. Quentin: "Generalized Lamb Mode in Fluid-Saturated Porous Plate," Review of Progress in Quantitative QNDE, Vol. 8, eds. D. O, Thompson and D. E. Chimenti, Plenum Press, New York, 1989.
9. L. Adler, K. Wu, and Q. Xue: "Ultrasonic Wave Mode Conversion in Fluid-Saturated Porous Materials," Proc. Ultrasonics International 89, 1013, 1989.
10. L. Adler, P. B. Nagy, and Q. Xue: "A Study of Surface Waves and Lamb Waves in Fluid-Saturated Porous Materials," Proceedings of II International Symposium on Surface Waves in Solids and Layered Structures, 1989.
11. K. Wu, Q. Xue, and L. Adler: "Reflection and transmission of elastic waves from a fluid-saturated porous solid border," J. Acoust. Soc. Am. 87 pp.2349, 1990.
12. P. B. Nagy, L. Adler, and B. P. Bonner: "Slow wave propagation in air-filled porous materials and natural rocks," Appl. Phys. Let. 56, 2504, 1990.
13. Q. Xue, and L. Adler: "Assessment of bulk wave velocities in fluid-filled porous media from Lamb wave spectrum," 60th Annual International SEG Meeting, SEG, Tulsa, Vol. 1, pp.791-793. 1990.
14. B. P. Bonner, P. B. Nagy, Q. Xue, L. Adler, and F. Berryman: "Biot's slow wave in Massilon and Berea Sandstone," 60th Annual International SEG Meeting, SEG, Tulsa, Vol. 1, pp.791-793, 1990.
15. P. B. Nagy, and L. Adler: "Observation of slow compressional waves in natural rocks," J. Acoust. Soc. Am. 87, S145, 1990.

16. P. B. Nagy, and L. Adler: "Experimentation techniques for studying slow wave propagation in fluid-saturated porous media," J. Acoust. Soc. Am. 88, S120, 1990.
17. Q. Xue, and L. Adler: "An improved method to measure slow compressional wave in fluid-saturated porous plates," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9A, pp. 211-218, Plenum Press, New York, 1990.
18. L. Adler, P. B. Nagy, and Q. Xue: "Investigation of ultrasonic wave interaction with porous rocks," Review of Underground Imaging, Lawrence Berkeley Laboratory, Berkeley, pp.71-75, 1991.
19. L. Adler: "Ultrasonic waves in Biot Solids," Colloquium at National Institute of Physical Acoustics, Oxford, Mississippi, 1991.
20. P. B. Nagy: "On the attenuation of slow waves in air-saturated porous materials," J. Acoust. Soc. Am. 90, S2371, 1991.
21. P. B. Nagy, and L. Adler: "Nondestructive Evaluation of porous materials by airborne ultrasonic waves," Review of Progress in Quantitative Nondestructive Evaluation, Vol. 11, Plenum Press, New York, 1992.
22. P. B. Nagy, and G. Blaho: "Experimental measurements of surface stiffness on water saturated porous solids," J. Acoust. Soc. Am. 95, pp.828-835, 1994.
23. L. Adler, and P. B. Nagy: "Measurements of acoustic surface waves on fluid-filled porous rocks," J. Geophys. Res. Solid Earth 99, pp.17863-17869, 1994.
24. P. B. Nagy, B. P. Bonner, and L. Adler: "Slow wave imaging of permeable rocks," Geophys. Res. Lett. 22, pp.1053-1056, 1995.
25. P. B. Nagy, and A. H. Nayfeh: "Generalized formula for the surface stiffness of fluid-saturated porous media containing parallel pore channels," Appl. Phys. Lett. 67, pp.1827-1829, 1995.
26. P. B. Nagy: "Local variations of slow wave transmission in permeable materials," J. Acoust. Soc. Am. 99, No. 2, 1996.
27. P. B. Nagy and D. L. Johnson: "On the physical origin of the excess slow wave attenuation in air-filled permeable solids," Appl. Phys. Lett. (submitted for publication).
28. P. B. Nagy and G. Blaho: "Surface stiffness measurements on water-saturated porous solids," Rev. Progr. Quant. Nondestr. Eval., Plenum, New York, 1996, Vol. 14B, pp.1425-1432.
29. V. F. Godinez-Azcuaga and L. Adler: "Theoretical simulation of experimental observations of surface wave propagation on a fluid-saturated porous material," Rev. Progr. Quant. Nondestr. Eval., Plenum, New York, 1006, Vol. 14A, pp.243-250.
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31. A. D. Degtyar and S. I. Rokhlin: "Ultrasonic wave propagation in anisotrophic fluid-saturated porous media," J. Acoust. Soc. Am.
32. A. D. Degtyar, S. I. Rokhlin, and L. Adler: "Effect of anisotrophy on slow waves in porous media," presented at 131st Acoust. Soc. Am. Meeting, Indianapolis, May 1996.

33. L. Adler: "Ultrasonic wave propagation in Biot solids," Invited. Euromech Colloquium 354, "Shear waves in solids for materials characterization," Greece 1996.

34. L. Adler, V. F. Godinez, and P. B. Nagy: "A study of acoustic surface waves in fluid-saturated porous solids," proceeding 1995 World Congress on Ultrasonics.

Thesis and Dissertation
The Ohio State University

1. M. J. Mayes: " A Study of Ultrasonic Surface and Bulk Waves in Saturated Porous Solids," M.Sc. Thesis, Ohio State University, 1988.
2. Q. Xue: "Acoustic wave interaction with planar interfaces in fluid-saturated porous media," Ph.D. Dissertation, Ohio State University, 1990.
3. V. F. Godinez-Azcuaga: "Study of surface wave propagation in fluid-saturated porous solids," Ph.D. Dissertation, Ohio State University, 1995.