11. Research Projects under Lane Johnson

11.1 Effect of damage on explosion generated elastic waves

L. R. Johnson and C. G. Sammis

A basic study was completed on the effect that rock damage has on the elastic waves generated by explosions. This work was done in collaboration with Charles Sammis at the U.S.C.. The basic idea of this research was to study the effects of pre-existing cracks in the region of high stresses immediately surrounding explosive sources. Such cracks are present in almost all rocks and occur at a variety of scales. Sammis, working with Ashby at Cambridge Univ., has developed a quantitative micromechanical model of how such cracks could grow as a function of the local stress field. The first step was to calculate the stress field surrounding an explosive source and this was accomplished with an equivalent elastic method. Comparisons with data from the 1 kt chemical explosion of Non-Proliferation Experiment showed that the stress levels and the waveforms generated with this method were reasonable simulations of realistic observations in the field. Then it was shown that these stresses were capable of causing a growth of pre-existing cracks in a fairly large volume surrounding the explosion, with a radius up to ten times that of the original explosion cavity. The effects of the density of pre-existing cracks and their size was studied, with the main conclusion being that the volume of crack growth increases with the initial size of the cracks. The second main result of this research was to develop a method for calculating the secondary elastic waves generated by the growth of pre-existing cracks, which involved developing the appropriate moment tensor representation of the cracks and then summing the contributions of all the cracks using Green functions. It was found that, while the contribution from an individual crack is small, the combined effect of many cracks in a large volume can generate secondary waves that are comparable in amplitude to the primary waves generated by the explosion. Most importantly, provided there is some asymmetry in the pattern of crack growth, this process is quite effective in generating S waves, thus providing a quantitative explanation of how S waves can be generated by an explosion. Two types of asymmetry, a shear pre-stress and a preferred orientation, were investigated and both proved to be effective in generating S waves in the far field.

11.2 Dynamic composite media theory

B. Kaelin and L. R. Johnson

Considerable progress has been made on the basic problem of characterizing the elastic and anelastic properties of a material from a knowledge of the relative proportions of its components. In the past this approach has been successful in estimating elastic properties in the quasi-static limit, where it goes by the names of effective media theory or composite media theory. However, such approaches are not sufficient for the high frequencies that are commonly encountered, so we have been developing a more complete theory which is applicable over a broad frequency range. So far the results are quite promising with respect to the handling of the elastic moduli, density, porosity, and pore fluids. Two papers describing the general approach have been published. The first paper describes a dynamic composite elastic medium theory for one-dimensional media. The method is self-consistent, is valid for all frequencies, and agrees with known solutions at both low and high frequencies. The comparison with complete numerical solutions for the one-dimensional problem allows a rigorous evaluation of the method. The second paper extends the dynamic composity elastic medium theory to three-dimensional media. In this case the method is also self-consistent, is valid for all frequencies, and agrees with known solutions at low frequency. The method requires the calculations of complete scattering solutions, and such calculations have been done for the case of spherical inclusions.

11.3 Source parameters of small earthquakes

C. G. Sammis, R. M. Nadeau, and L. R. Johnson

Our earlier studies of the source parameters of small earthquakes estimated from moment release rates has been extended in a collaborative study with Professor Charles Sammis at the University of Southern California. Laboratory results concerning the strength of rocks and asperity models of friction were studied and compared with the earthquake data. The study shows that these two different types of data are consistent and imply a discrete hierarchical fractal distribution of asperities having a fractal dimension of 1.0 and a discrete rescaling factor of 10.

11.4 Three-dimensional velocity structure of the earth

D. W. Vasco, O. Marques, and L. R. Johnson

Our recent studies of the 3D structure of the earth have relied upon the tomographic inversion of large amounts of high frequency seismic travel time data. Although various approaches to this type of problem have been used, with the major differences involving the parameterization of the model and regularization, all of the methods require the solution of a very large inverse problem. Unfortunately, these problems are so large that the available computer resources are generally sufficient to provide an estimate of the solution only, and it is rare that these solutions can be provided with formal estimates of resolution and uncertainty. Various approximate estimates of resolution and uncertainty have been proposed and used, but it can be demonstrated that these are not entirely adequate. We have been able to overcome this deficiency by developing a procedure where the eigenvalues and eigenvectors associated with a singular value decomposition of the problem can now be calculated for problems with the order of 10^5 model parameters. The procedure makes use of an iterative Lanczos algorithm, and has been implemented for both work stations and large parallel computers.

11.5 Use of Genetic Algorithms in Geophysical Inverse Problems

P. B. Parker and L. R. Johnson

Genetic algorithms offer an attractive approach for many geophysical inverse problems in that they can explore the entire model space, are not dependent upon an initial estimate, require no derivatives, and are much more efficient than completely random search methods. An understanding has been lacking of how this approach performs on realistic geophysical inverse problems and how the control parameters influence the performance. It has been found that a particular choice of parameters consistently produces optimal results for a broad range of problem difficulties. At least for problems of the type encountered in geophysics, the choice of a low mutation rate of about half the inverse of the population size was the most critical factor, with the crossover method and rate having a relatively minor effect upon performance. Tournament selection was found to be the most effective and robust selection method. In addition to an investigation of the general performance of genetic algorithms, the method has been applied to practical problems of modeling receiver functions and interpreting gravity data.

11.6 Calculation of waveforms in three-dimensional media

H. Keers and L. R. Johnson

In order to model elastic wave propagation in 3D heterogeneous media, there is a need for approaches which are intermediate between expensive numerical methods such as finite differences and overly-simplified methods such as geometrical ray theory. The WKBJ approach is such a method, but it is suitable only for media inhomogeneous in 1D. We have been investigating semi-analytical methods of the Maslov type in an attempt to develop an approach which includes most of the relevant wave phenomena and also makes reasonable demands upon computing resources. We are developing a method which uses Kirchoff-Helmholtz theory, includes non-stationary ray paths, and properly accounts for caustics. Sensitivity functions have also been generated, which allows the method to be used in waveform inversion problems. Both forward and inverse applications of this method have been studied and it has been tested with a tomographic inversion of data collected in the laboratory. Including the waveforms leads to a significant improvement over inversions that use only travel times.

11.7 References

Dicke, M., *Seismicity and Crustal Structure at the Mendocino Triple Junction, Northern California*, M.S. Thesis, University of California, Berkeley, 79 pp., 1998.

Glaser, S. D., G. G. Weiss, and L. R. Johnson, Body waves recorded inside an elastic half-space by an embedded, wideband velocity sensor, *J. Acoust. Soc. Am.*, **104**, 1404-1412, 1998.

Kaelin, B., and L. R. Johnson, Dynamic composite elastic medium theory. Part I., One-dimensional media, *J. Appl. Phys.*, **84**, 5451-5457, 1998.

Kaelin, B., and L. R. Johnson, Dynamic composite elastic medium theory. Part II., Three-dimensional media, *J. Appl. Phys.*, **84**, 5458-5468, 1998.

Kaelin, B., and L. R. Johnson, Using seismic crosswell surveys to determine the aperture of partially water-saturated fractures, *Geophysics*, **64**, 13-23, 1999.

Parker, P. B., *Genetic Algorithms and Their Use in Geophysical Problems*, Ph.D. Thesis, University of California, Berkeley, 202 pp., 1999.

Sammis, C. G., R. M. Nadeau, and L. R. Johnson, How strong is an asperity?, *J. Geophys. Res.*, **104**, 10,609-10,619, 1999.

Vasco, D. W., L. R. Johnson, and O. Marques, Global earth structure: inference and assessment, *Geophys. J. Int.*, **137**, 381-407, 1999.