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Book review

'Theoretical Global Seismology' by F.A. Dahlen and Jeroen Tromp

Dahlen and Tromp have succeeded in writing an excellent treatise on theoretical global seismology, with a strong emphasis on the free oscillations of the Earth. We very much appreciate the systematic and exhaustive approach that is followed by the authors. After an extensive treatment of the physical and mathematical foundations, the book continues with the discussion of the free oscillations of a non-rotating, spherically symmetric elastic Earth. This forms the basis for the final part of the book, in which the authors discuss generalizations accounting for the Earth's rotation, ellipticity, lateral variations and anelastic losses. The first two parts mainly deal with well-established theories and results whereas the final part provides an up-to-date account of the developments in this field. The book is very clearly written by two authors with great authority in their field and it is richly illustrated. The mathematical aspects are discussed carefully but never become inaccessible. The more esoteric material is discussed in sections denoted with a star*, which can be skipped without disturbing the main line of argumentation. On many occasions alternative derivations are presented that lead to the same result. This aspect, together with the fact that many internal cross-references are given, makes this book an invaluable guide for advanced courses in global seismology for graduate geophysics students. Undoubtedly it will also be an important reference for many professionals involved in geophysics.

Let us substantiate our enthusiasm for this book with a brief chapter-by-chapter discussion.

Chapter 1 is a historical introduction to the theoretical analysis of the Earth's normal modes, starting with a memoir of Poisson presented to the Paris Academy of Sciences in 1828. The list of cited great physicists of the past further includes Lord Kelvin, Lamb, Hooke, Lord Rayleigh, Love and Stoneley. On the following pages, that discuss the developments since the late 1950s, the work of Gilbert and many others is reviewed. In this way the reader gets a bird's eye view on the literature on global seismology of the recent past.

Chapter 2 is actually the first chapter of Part I: 'Foundations'. This chapter deals with continuum mechanics in a more thorough way than most seismology textbooks. The Eulerian and Lagrangian approaches are clearly introduced and their mutual relations are discussed. These two approaches are consistently employed throughout all chapters of Part I. Important for the topic of this book is that the momentum equations are presented in non-rotating as well as rotating reference frames.

In Chapter 3 the equations of motion are derived in three ways: by linearization of the Eulerian conservation laws, by linearization of the Langrangian conservation laws and, finally, by application of Hamilton's variational principle. The main results are clearly summarized in four tables, which we consider very useful.

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Chapter 4 introduces the normal modes, for the cases of a non-rotating and a rotating Earth model. Furthermore, the alterations are discussed that are required when a hydrostatic initial stress is assumed.

Chapter 5 deals with the important subject of seismic source representations. Earthquake fault sources are represented by equivalent body and surface force distributions. One of the approaches, due to Burridge and Knopoff, is based on Betti's reciprocity theorem, which is adapted here for a rotating Earth by introducing the concept of an anti-Earth (i.e., an Earth with reversed rotation). This has an interesting analogy with the acoustic reciprocity theorem for flowing liquids or gases, which states that the acoustic response at B from a source at A is identical to the response at A from a source at B, under the condition that the direction of flow is reversed in the second experiment.

In Chapter 6 the authors discuss seismic attenuation from a macroscopic phenomenological point of view. Their treatment accounts for the causality of the relaxation function, which leads in the frequency domain to the Kramers–Kronig relations between the real and imaginary parts of the relaxation function. These relations imply that constant Q models are strictly impossible. Again, the results are generalized from a non-rotating to a rotating Earth model and the alterations for a hydrostatic initial stress are discussed as well.

The Rayleigh–Ritz method discussed in Chapter 7, the final chapter of Part I, provides an alternative and simple way of computing the eigenfrequencies and eigenfunctions of the Earth. The fact that the derivations are given for, respectively, a non-rotating elastic, a rotating elastic, a non-rotating anelastic, a rotating anelastic and a hydrostatic Earth model demonstrates the authors' feel for systematicness.

Chapter 8 is the first chapter of Part II: The Spherical Earth. It deals with spheroidal and toroidal oscillations in a spherically symmetric, non-rotating, perfectly elastic, isotropic (SNREI) Earth model. The chapter is illustrated with many relevant examples of eigenfunctions. A starred section is dedicated to the modifications that are required for a transversely isotropic Earth model with a radial symmetry axis.

In Chapter 9 the effects of spherically symmetric elastic and anelastic perturbations on the eigenfrequencies of the SNREI model are investigated. Again the authors demonstrate their craftsmanship by their systematic approach, the alternative derivations and the extension for transverse isotropy. The many illustrations clearly show the effects of the different types of perturbations on the eigenfunctions.

In Chapter 10 it is discussed how to construct synthetic seismograms by superposition of normal modes. This results in simulations of the familiar wiggly lines that are plotted by seismometers as a function of time after the occurrence of an earthquake. The illustrations show the arrival of all kinds of events for different locations of the seismometer. These simulation results are an important aid for explaining the seismograms recorded by real seismometers after a real earthquake.

Thus far in the book, the response of the Earth to an earthquake has been described in terms of a superposition of normal modes. In Chapter 11 an alternative representation is introduced, based on a decomposition of the response in travelling waves. This is analogous to decomposing the standing wave pattern in an organ pipe into upward and downward travelling waves in such a way that the superposition of these wave constitutes the actual standing wave pattern. The travelling waves that constitute the Earth's normal modes can be divided into two categories: body waves and surface waves. The surface waves (Love and Rayleigh waves) receive special attention in this chapter, because they account for the largest amplitude arrivals on most seismograms.

In Chapter 12 the body waves in the far-field of an earthquake are examined in more detail, using a ray-theoretical approach. The various ray-paths are classified with respect to their 'life history' (analogous to Feynman diagrams). The high-frequency correspondence between ray-theoretical solutions (JWKB) and the normal mode representation gets ample attention This mode-ray duality is considered from two perspectives 'from rays to modes' and 'from modes to rays'.

Chapter 13 is the first chapter of Part III: The Aspherical Earth. It deals with the effect of the Earth's rotation, hydrostatic ellipticity and lateral heterogeneity. The perturbations to the spherically symmetric Earth model are arbitrary. The Rayleigh–Ritz method, introduced in Chapter 7, is employed to account for eigenfrequency splitting and quasi-degenerate mode coupling The eigenfrequency perturbations are found by diagonalizing a perturbation matrix. In a number of tables a very clear overview is given of the perturbation matrix, the properties of its diagonalized form, the renormalization of its eigenvectors and their orthonormality properties, all for a non-rotating elastic, a rotating elastic, a non-rotating anelastic and a rotating anelastic Earth.

Mode splitting and coupling is further worked out in Chapter 14 where a number of useful approximations is introduced, which lead to simpler expressions. For example, it is observed that first-order Coriolis splitting (as a result of the Earth's rotation) is analogous to the Zeeman splitting of the quantum energy levels of a hydrogen atom in a magnetic field. This chapter is illustrated with many numerical examples that aid the interpretation of actual earthquake observations.

Chapter 15 discusses body-wave ray theory (including JWKB theory) for a laterally heterogeneous, non-rotating, elastic and anelastic isotropic Earth model. The lateral variations are arbitrary large but sufficiently smooth. The treatment is based on what is called the slow variational principle. Apart from the theoretical aspects, the authors also pay attention so the practical numerical implementation and present numerical examples.

In Chapter 16, the final chapter, a similar approach as in Chapter 15 is followed for analyzing the propagation of surface waves (Rayleigh and Love) for a laterally heterogeneous, non-rotating, elastic and anelastic isotropic Earth model. The discussion above of Chapter 15 applies just as well for Chapter 16.

The last two-hundred pages of the book are dedicated to rigorous appendices on vectors and tensors, ordinary and generalized spherical harmonics and mathematical background for Chapter 13, as well as a bibliography and a valuable subject index.

We hope that we have given the reader a flavor of the structure and contents of this excellent book and that we have succeeded in conveying at least some of our enthusiasm. In our opinion, these impressive thousand-and-something pages are a must for anyone involved in seismology!

Jacob Fokkema and Kees Wapenaar,
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