Source Mechanisms of Earthquakes

Theory and Practice

Recent, disastrously large and tsunami-generating earthquakes, from Sumatra in 2004 to Chile in 2010 and Japan in 2011, have underlined the need to better understand the origins, dynamics, and source mechanisms of earthquakes. This book presents an innovative new approach to studying source mechanisms, combining theory and observation in a unified methodology, with a key focus on the mechanics governing fault failures.

The authors explain source mechanisms by building from fundamental concepts, such as the equations of elasticity theory, to more advanced problems including dislocation theory, kinematic models, and fracture dynamics. The theory is presented in a student-friendly form, using consistent notation throughout and with full, detailed mathematical derivations that enable students to follow each step. The topics covered include point source models, the seismic moment tensor, the determination of point sources and source dimensions, and kinematic extended sources.

The later chapters present the simple and advanced dynamic fracture models used for source mechanism determination, clearly establishing their theoretical foundations. These chapters highlight the processing of data results from cutting-edge dynamic models and are fully supported with up-to-date seismograms and illustrative data plots.

Providing a unique balance between application techniques and theory, this is an ideal guide for graduate students and researchers in seismology, tectonophysics, geodynamics, and geomechanics, and a valuable practical resource for professionals working in seismic hazard assessment and seismic engineering.

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Preface

A key problem in seismology is the study of the processes that give rise to earthquakes. It is well established now that earthquakes, with rare exceptions, are caused by shear fracture on pre-existing faults in the Earth. Thus, the modern study of earthquakes and their source mechanisms should be based on the application of dislocation theory and fracture mechanics; this is the point of view taken in this book. General textbooks of seismology have dedicated chapters to this subject, for example, Aki and Richards (1980), Ben Menahem and Singh (1981), Dahlen and Tromp (1998), Gubbins (1990), Lay and Wallace (1995) and Udías (1999). A few books have been written specifically on the subject, for example, Kasahara (1981), Kostrov and Das (1988) and Scholz (1990). Each of these three books has a different approach: Kasahara presents the state of the study of earthquake mechanisms as it was 30 years ago, before modern developments, and does not give details of the mathematical developments. Scholz' approach is that of rock mechanics, with an emphasis on qualitative descriptions and applications to Earth faulting. Finally, Kostrov and Das (1988) gives an excellent presentation of earthquake dynamics, but it may be difficult for students to follow. None of these books includes a detailed presentation and discussion of practical methods for the determination of the earthquake mechanisms together with the theory on which they are based.

At present it is very common to find, in publications and on the web, results from different methods of determination of the source mechanisms of earthquakes, for example, centroid moment tensor (CMT) solutions. The use of these results is today standard practice in the study of tectonics and seismic hazard, often without knowledge of the methods and theory behind them. Thus the novel approach of this book is to present the theory of the source mechanisms of earthquakes and also the methods used for their determination in particular cases. The theory on which the methods are based is made clear. As nowadays digital data are used in the analysis of observations, the practical processing of seismograms, accelerograms and high-rate GPS data is also presented. A further novelty is the structure of the book as a textbook, that is, having in mind its use by students. Thus topics are presented in a gradual form, starting from the basic principles and developments and progressing to more advanced and difficult problems. In many cases mathematical developments are given in detail, and throughout the book a unified terminology and notation are used. This is an important point since in articles different authors use differing notation, and this makes it difficult, sometimes, to get a unified grasp of the subject. Above all, considerable efforts have been made towards clarity in the presentation and an emphasis on the fundamentals; therefore some more advanced and difficult problems have been omitted.

The book is divided into 12 chapters. An introduction, in which very basic concepts are explained (Chapter 1), is followed by a presentation of the basis of digital data processing,

an often neglected subject (Chapter 2). The fundamentals of the elastodynamic theory of earthquake source representation are given in detail in Chapter 3. In the following chapters three types of source representation or model are considered. These are point sources, including the first-order moment tensor (Chapters 4 and 5), extended kinematic sources (Chapter 7) and dynamic sources, both homogeneous and heterogeneous (Chapters 9–11). In these last few chapters the more complex concepts of seismic source dynamics are presented. After the presentation of each type of source model, some methods used for determination of the corresponding model parameters from seismic wave observations are discussed, namely, point source inversion, including fault-plane solutions and moment tensor inversion (Chapter 6), the determination of source dimensions and slip distribution on the fault plane (Chapter 8) and the determination of dynamic parameters (Chapter 12). In these chapters, the methods are explained in detail and references are given to web addresses where computer programs for them can be found.

The authors' aim is that the book should be both a user-friendly textbook and also a standard reference for source mechanism studies of earthquakes and their applications, for graduate students and researchers. An comprehensive list of references is given. The book is based on the long teaching and research experience of the authors.

The authors wish to thank to all our students, to whom we are indebted for their questions and suggestions. A. U. and E. B. specially thank C. Pro (University of Extremadura), S. Cesca (GFZ, Potsdam) and C. del Fresno (Instituto Geográfico Nacional, Madrid). R. M. thanks M. Lancieri (IRSN, France), S. Ruiz (University of Chile in Santiago), C. Holden (New Zealand) and S. Di Carli (France) for their help and Drs J. Virieux, K. B. Olsen, R. Archuleta, S. Peyrat, E. Fukuyama, T. Tada and H. Aochi for their long-standing collaboration on the dynamic modeling and inversion of earthquakes.