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# Basic Earthquake Engineering

## From Seismology to Analysis and Design

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# Preface

## Objectives

Earthquake engineering is generally considered as an advanced research area in engineering education. Most of the textbooks published in this field cover topics related to graduate education and research. There is a growing need, however, for the use of basic earthquake engineering knowledge, especially, in the earthquake resistant design of structural systems. Civil engineering graduates who are concerned with structural design face the fundamental problems of earthquake engineering more frequently in their professional careers. Hence, an introductory level textbook covering the basic concepts of earthquake engineering and earthquake resistant design is considered as an essential educational instrument to serve for this purpose.

This book aims at introducing earthquake engineering to senior undergraduate students in civil engineering and to master's students in structural engineering who do not have a particular background in this area. It is compiled from the lecture notes of a senior level undergraduate course and an introductory level graduate course thought over the past 12 years at the Middle East Technical University, Ankara, Turkey. Those students who take the course learn the basic concepts of earthquake engineering and earthquake resistant design such as origin of earthquakes, seismicity, seismic hazard, dynamic response, response spectrum, inelastic response, seismic design principles, seismic codes and capacity design. A prior knowledge of rigid body dynamics, mechanics of vibrations, differential equations, probability and statistics, numerical methods and structural analysis, which are thought in the second and third year curriculum of undergraduate civil engineering education, is sufficient to grasp the focus points in this book. Experience from the past 12 years proved that students benefitted enormously from this course, both in their early professional careers and in their graduate education, regardless of their fields of expertise in the future.

The main objective of the book is to provide basic teaching material for an introductory course on structural earthquake engineering. Advanced topics are intentionally excluded, and left out for more advanced graduate courses. The authors believe that maintaining simplicity in an introductory textbook is a major challenge while extending the coverage to advanced topics is trivial. Hence, the majority of the information provided in the book is deliberately limited to senior undergraduate and introductory graduate levels while a limited number of more advanced topics are included as they are frequently encountered in many engineering applications. Each chapter contains several examples that are easy to follow, and can mostly be solved by a hand calculator or a simple computational tool.

## Organization of Chapters

Chapter 1 discusses the basic physical and dynamic factors triggering earthquakes; global tectonics, fault rupture, formation of ground shaking and its effect on the built environment. Measurement of earthquake size and intensity is also defined in this chapter.

Chapter 2 introduces basic elements of probabilistic and deterministic seismic hazard assessment. Uniform hazard spectrum concept is the last topic covered in Chap. 2.

Chapter 3 presents dynamic response of simple (single degree of freedom) systems to earthquake ground motions. Analytical and numerical solutions of the equation of motion are developed. Response spectrum, inelastic response and force reduction concepts in seismic design are discussed herein.

Chapter 4 introduces linear elastic earthquake design spectra and the inelastic (reduced) design spectra. This chapter also presents the fundamentals of seismic hazard map concept employed in seismic design codes, particularly in Eurocode 8 and NEHRP provisions, together with ASCE 7 standards.

Chapter 5 develops the dynamic response analysis of building structures under ground shaking. Modal superposition, equivalent lateral load analysis, response spectrum analysis and pushover analysis are presented progressively. Analysis of base isolated structures is also included.

Chapter 6 extends the analysis methods in Chap. 5 to three-dimensional, torsionally coupled buildings. Basic design principles and performance requirements for buildings in seismic design codes are presented.

Chapter 7 is particularly devoted to the capacity design of reinforced concrete structures in conformance with the modern design codes including Eurocode 8 and ASCE 7. Ductility in concrete and capacity design principles are discussed in detail. This chapter is concluded with a comprehensive example on the design and detailing of a reinforced concrete frame.

## Suggestions for Instructors

The material in this book may serve for developing and teaching several courses in the senior undergraduate and graduate levels of civil engineering education during a 13- or 14-week semester of about three lecture hours per week.

### *Earthquake Engineering at Senior Undergraduate Level*

A selected coverage of topics is suggested from the book for an introductory course on earthquake engineering at the undergraduate level. Chapter 1 can be summarized in a week in a slide presentation form. Chapter 2 may also be summarized in a week through describing the fundamentals of seismic hazard analysis methodology. Sections 3.6.3–3.6.7 can be excluded from Chap. 3 in teaching an undergraduate course. Chapter 4 is advised to be given in a practical manner, with more emphasis on defining the design spectra directly according to Eurocode 8 and ASCE 7. Sections 5.8 and 5.9 can also be excluded from Chap. 5. Full coverage of Chaps. 6 and 7 is necessary for introducing the basics of earthquake resistant building design.

### *Earthquake Engineering at Graduate Level*

The entire book can be covered in a first course on earthquake engineering at the graduate level. Chapter 2 can be shortened by introducing the classical probabilistic and deterministic hazard assessment methods with emphasis on their elementary components, while step-by-step descriptions of probabilistic and deterministic hazard assessment methods can be ignored. Assuming that the students have already taken structural dynamics, Sects. 3.1, 3.2, 3.4.1 and 3.4.2 can be skipped in Chap. 3. Similarly Sects. 5.1, 5.2 and 5.5 can be excluded from Chap. 5.

### *Engineering Seismology and Hazard Assessment at Graduate Level*

The first four chapters of the book can be good teaching sources for a graduate level engineering seismology course for civil engineering students. The content of the Chap. 1 can be extended by the cited reference text books and can be given to the student in the first 3 weeks of the course. Seismic hazard assessment covered in Chap. 2 can be taught in 4–5 weeks. The instructor can start refreshing the basics of probability before the main subjects in seismic hazard assessment. The elastic response spectrum concept that is discussed in Chap. 3 can follow the seismic hazard assessment and simple applications on the computation of uniform hazard spectrum can be given to the students from the materials taught in Chaps. 2 and 3. The last 2 or 3 weeks of the course can be devoted on the code approaches for the definition of elastic seismic forces that are discussed in Chap. 4.

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# Contents

# Chapter 1
# Nature of Earthquakes

**Abstract** This chapter introduces some of the basic concepts in Engineering Seismology that should be familiar to earthquake engineers who analyze and design structures against earthquake induced seismic waves. The majority of these concepts are also used as tools to assess seismic hazard for quantifying earthquake demands on structures. The chapter begins with a summary of the main components of Earth's interior structure and their interaction with each other in order to describe the physical mechanism triggering the earthquakes. These introductory discussions lead to the definitions of earthquake types, their relation with global plate movements and resulting faulting styles. The magnitude scales for determining the earthquake size as well as primary features of seismic waveforms that are used to quantify earthquake intensity follow through. The characteristics of accelerograms that are mainly used to compute the ground-motion intensity parameters for engineering studies as well as the macroseismic intensity scales that qualitatively inform about the earthquake influence over the earthquake affected area are discussed towards the end of the chapter. The chapter concludes by a brief overview on the effects of earthquake shake on the built and geotechnical environment to emphasize the extent of earthquake related problems and broad technical areas that should be focused by earthquake engineers.

## 1.1 Dynamic Earth Structure

The internal structure of the Earth is one of the key parameters to understand the major seismic activity around the world. The Earth may be considered to have three concentric layers (Fig. 1.1). The innermost part of the Earth is the core and it is mainly composed of iron. The core has two separate parts: the inner core and outer core. The inner core is solid and the outer core is liquid. The mantle is between the crust (outermost layer of the earth) and the core. The abrupt changes in the propagation velocity of seismic waves (Fig. 1.2) differentiate the mantle, the outer core and the inner core. The sudden variation in the seismic wave velocity close to the

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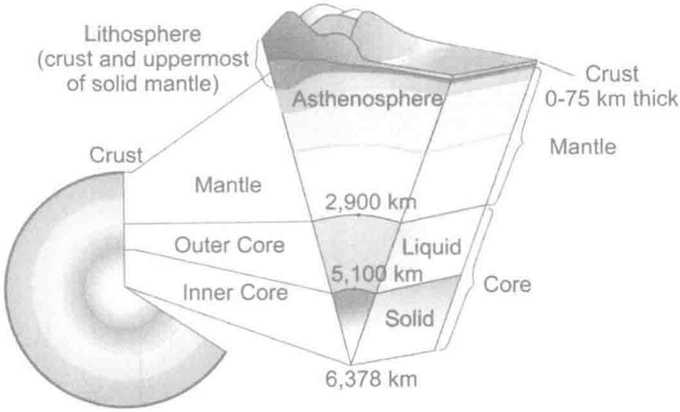
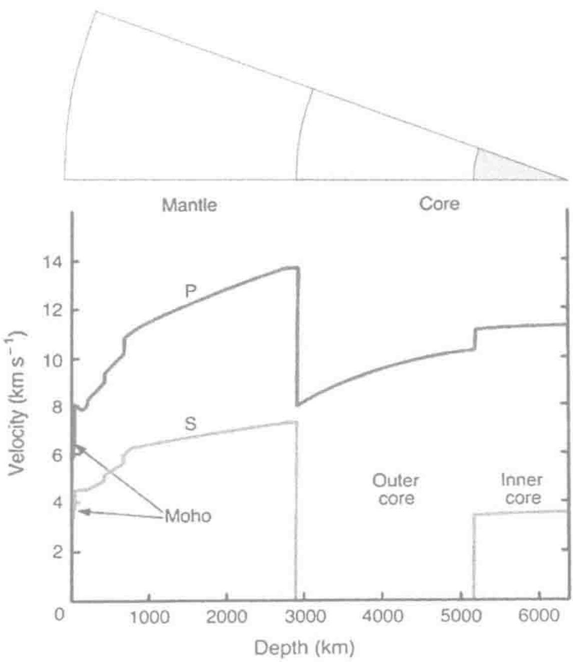



**Fig. 1.1** Earth's interior structure: major layers

**Fig. 1.2** Variation of P- and S-wave velocities along different layers of Earth (modified from Shearer 1999)




crustal surface is due to Moho discontinuity (recognized by the Croatian seismologist Mohorovičić in 1909) and it is accepted as the boundary between the mantle and the crust (Fig. 1.2). The crust thickness is approximately 7 km under the oceans. Its average thickness is 30 km under the continents and attains even thicker

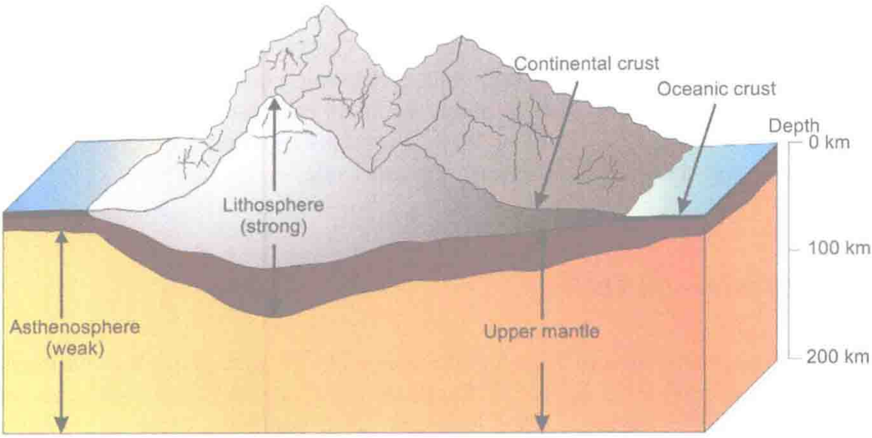
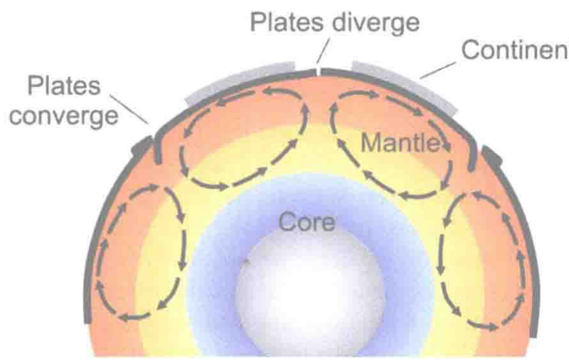



**Fig. 1.3** Illustration of the lithosphere and asthenosphere (modified from Press and Siever 1986)

**Fig. 1.4** Heat convection mechanism and the relative motion of lithospheric plates due to heat convection currents (modified from Press and Siever 1986)




values under the mountain ranges. The crust has basaltic structure under the oceans whereas it is mainly comprised of basalt and granite under the continents.

The lithosphere and asthenosphere are the two outermost boundaries of the Earth that are defined in terms of material strength and stiffness (Fig. 1.3). The lithosphere is rigid and relatively strong. It is mainly formed of the crust and the outermost part of the mantle. The thickness of lithosphere is approximately 125 km. The asthenosphere lies below the lithosphere and it forms mainly the weak part of the mantle (a softer layer) that can deform through creep. The lithosphere can be considered to float over the asthenosphere.

The interior of the Earth is in constant motion that is driven by heat. The source of heat is the radioactivity within the core. The temperature gradient across the Earth sets up a heat flow towards the surface from the outer core and the mechanism of heat transfer is convection. Convection currents within the asthenosphere moves the lithospheric plates (tectonic plates) like a conveyor belt (Fig. 1.4). The movement of these plates results in two slabs diverging from each other, or converging to each other. When two slabs converge to each other, they collide and one slab descends beneath the other one.

### *1.1.1 Continental Drift*

The physical process described in the previous section also explains the continuous motion of the continents. In fact, 225 million years ago all of the continents had formed a single landmass, called Pangaea. This continent broke up, initially forming two continents, Laurasia and Gondwanaland, about 200 million years ago. By 135 million years ago, Laurasia had split into the continents of North America and Eurasia, and Gondwanaland had divided into the continents of India, South America, Africa, Antarctica and Australia. These continents have continued to move and have come to their current configuration, including the collision of India with Eurasia about 50 million years ago. The entire process is illustrated in Fig. 1.5.

The pioneering explanations about the motion of continents were done by a few geologists in the second half of the 20th century. One of these earth scientists was Richard Field who studied the geology of the ocean floor. The discovery of mountain chains (ridges) along the major oceans as shown in Fig. 1.6 and observations on the dense seismic activity along the oceanic ridges indicated that these zones are under continuous deformation. In 1960, Harry Hess proposed the theory of sea-floor spreading and suggested that the ocean floor is formed continuously by the magma that rises up from within the mantle into the central gorges of the oceanic ridges (Fig. 1.7). The magma spreading out from the gorges pushes the two sides of the ridge apart. This mechanism separates the two tectonic plates from each other as in the case of African and South American continents. Today the continuous formation of ocean floor still moves these two continents apart from each other. The separation of African and South American continents was first documented by the German meteorologist Alfred Wegener in 1915 by comparing the geological structures, mineral deposits and fossils of both flora and fauna from the two sides of the Atlantic Ocean. Wegener's hypothesis on continental drift was not appreciated by the scientific community at those days as he failed to provide the physical explanation behind the separation process.

The new oceanic crust that is formed continuously at the mid-oceanic ridges should expand the Earth unless another mechanism consumes the older material that is in excess due to the newly formed material. There are regions in the oceanic floor where the lithosphere is descending into the mantle, being consumed at the same rate that new crust is being generated at the oceanic ridges (Fig. 1.8). This process is known as subduction and it occurs where two plates collide and one is