EARTHQUAKE ENGINEERING

COURSE OUTLINE

The course on Introduction to Earthquake Engineering provides the fundamental concepts, principles and application of earthquake engineering in seismic analysis and design of structures. The course begins with the Seismology explaining the causes of occurrence of earthquake and its characterization. The seismic analysis of the structures under earthquake excitation is developed. The structural system modeled as discrete and continuous system. The concept of response spectrum analysis procedure to determine structure response and design earthquake forces is explained. The codal provisions for earthquake resistant design of structures as per **IRAQI SEISMIC CODE** and IBC and other standards are explained. Finally, the course also covers the soil structure interaction and inelastic response spectra. The advanced course material on Earthquake Engineering will be very useful to post-graduate students. A number of chosen problems will be solved to illustrate the design and analysis concepts clearly.

REFERENCES

1. EARTHQUAKE ENGINEERING THEORY AND IMPLANTATION, NAZZAL S. ARMOUTI, 2ND EDITION.
2. EARTHQUAKE RESISTANT DESIGN OF STRUCTURES, PANKAJ AGARWAL AND MANISH SHRIKHANDE.
3. FUNDAMENTAL CONCEPTS OF EARTHQUAKE ENGINEERING, ROBERTO VILLAVERDE.
4. Clough R.W. and Penzien J., Dynamics of Structures.
5. A.K. Chopra ,Dynamics of Structures – Theory and Application to Earthquake Engineering.
6. STRUCTURAL/SEISMIC DESIGN MANUAL, VOL.1, 2, 3, INTERNATIONAL CODE COUNCIL (ICC).
7. IS-1893:1984
8. SEISMIC DESIGN USING STRUCTURAL DYNAMICS, S.K. GHOSH.
9. ASCE-7, MINIMUM DESIGN LOADS AND ASSOCIATED CRITERIA FOR BUILDINGS AND OTHER STRUCTURES.
10. INTERNATIONAL BUILDING CODE (IBC).
11. UBC -97
12. مدونة المباني المقاومة للزلازل ، مدونة بناء عراقية ، م.ب.ع. 303 ، رقم الايداع في دار الكتب والوثائق ببغداد (2331) لسنة 2019.

INTRODUCTION

Earthquake engineering is the science that studies the behavior of structures under earthquake excitation and provides the rules on how to design structures to survive seismic shocks. Earthquakes are wild and violent events that can have dramatic effects on structures. In fact, many structures have collapsed during earthquakes because earthquake-induced forces or displacements exceeded the ultimate capacity of the structures. Therefore, the study of structural behavior at full capacity is a necessary element of earthquake engineering. Earthquakes are extremely random and oscillatory in nature (as shown in Fig. 1-1). Because earthquakes cause structures to largely deform in opposite directions, earthquake engineering also requires an understanding of structural behavior under cyclic loading. Figure 1-2 shows an example of cyclic loading in the inelastic range. Furthermore, the extreme randomness and uncertain occurrence of earthquakes also require the use of a probability approach in the analysis and design of structures that may experience seismic excitation.

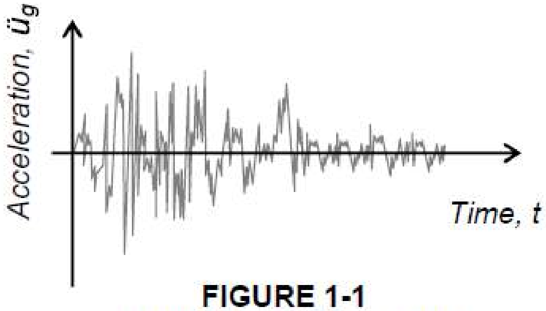


FIGURE 1-1
EARTHQUAKE RECORD

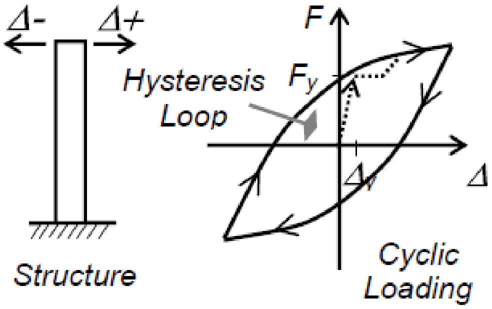


FIGURE 1-2
CYCLIC BEHAVIOR

THE INNER STRUCTURE OF THE EARTH

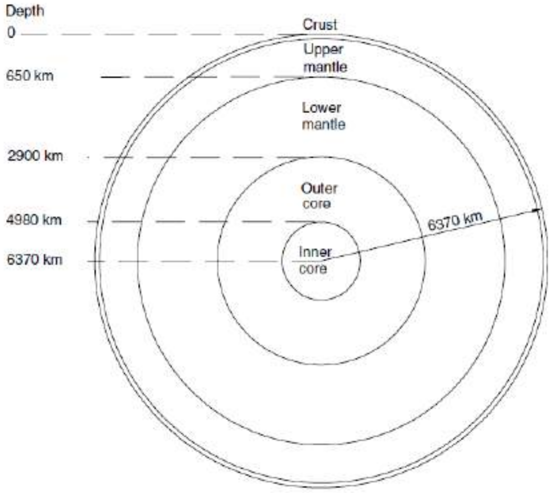
The earth is roughly spherical, with an equatorial diameter of 12,740 km and a polar diameter of 12,700 km, the higher equatorial diameter caused by the higher velocities at the equator due to the earth's rotation. Its mass is ~4.9 × 1021 kg, which implies an average specific c gravity of 5.5. As the specific c gravity of the rocks at the surface of the earth is between 2.7 and 3, it may be, thus, inferred that the materials in the interior have higher specific gravities.
The earth consists of three concentric layers having different physical properties:

1. **Crust:** The volume of the crust represents 1% of the earth's total volume.
2. **Mantle:** The volume of the mantle represents 80% of the earth's total volume.
3. **Core:** The volume of the core represents 19% of the earth's total volume.

The division of the earth into such layers has been possible by solving the inverse problem of ***geophysics***. This consists of the deduction of the physical parameters of the different layers of the earth, by starting from records of the phenomena observed on its surface. The most important of these phenomena are the ***earthquake***.

The main characteristics of the layers that constitutes the earth are (Figure 1-3):

1. The core, which has a radius R=3470 km and consists of **:(1)** ***Inner Core*** (R=1370 km) and **(2)** ***Outer Core*** (1370 km <R<3470 km). The core composed of molten iron, probably mixed with small quantities of other elements such as nickel and sulphur or silicon.
2. The mantle, which is a 2900 km thick layer, consists of: (1) ***Upper Mantle***, reaching a depth of 400 km, made up of olivine and pyroxene. (2) ***Transition Zone***, 237 km thick, constituted of olivine; (3) ***Lower Mantle*** made of more homogeneous mass of magnesium and iron oxids and of quartz. The last two zones are more rigid, owing to denser structure of the mineral that constitute them.
3. The crust or the lithosphere, which is the outer part of the earth, having a high rigidity and anisotropy. It may be considered that it has a thickness of 60 km. the crust consists on one hand of ocean basins , composed especially of basaltic rocks, and on the other hand of continents , constituted of granitic rocks.



Internal structure of the earth.

PLATE TECTONICS THEORY

The crust of the earth is divided into several large tectonic plates that sometimes encompass more than one continent. These plates include the Eurasian Plate, African Plate, North American Plate, South American Plate, Australian Plate and Pacific Plate, among others. Figure 2-1 shows the extent of some of these plates. Major geological faults are formed along the boundaries of these plates, and these faults are the main source of earthquakes. The tectonic plates are in continuous movement against each other. However, friction forces between these plates prevent differential displacements at the boundaries of the plates. This action generates energy buildup along plate boundaries in a form of strain energy that is stored in the plates.

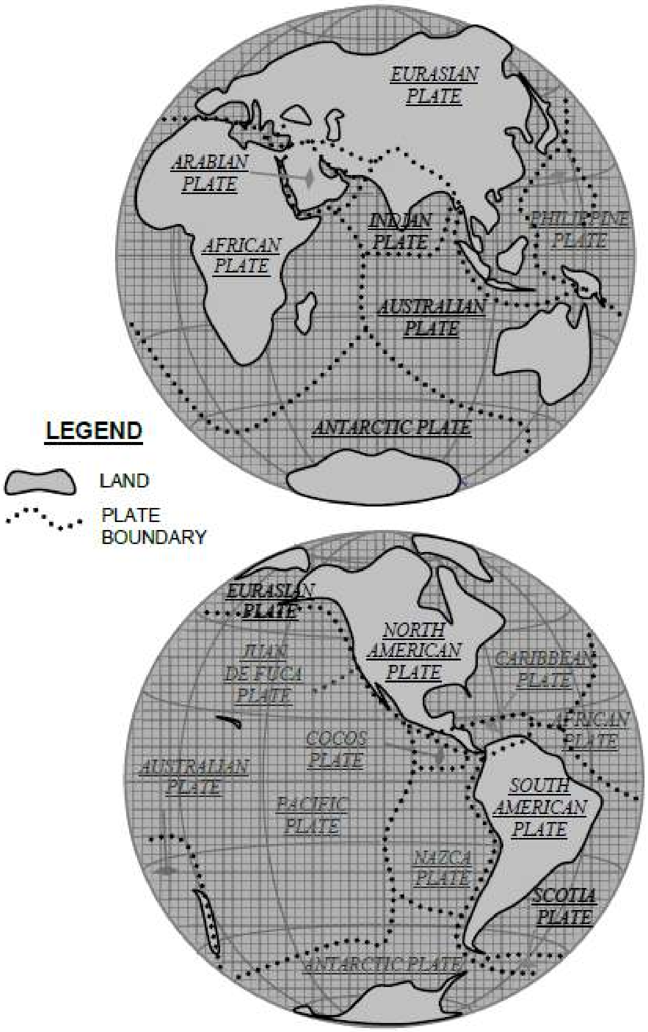
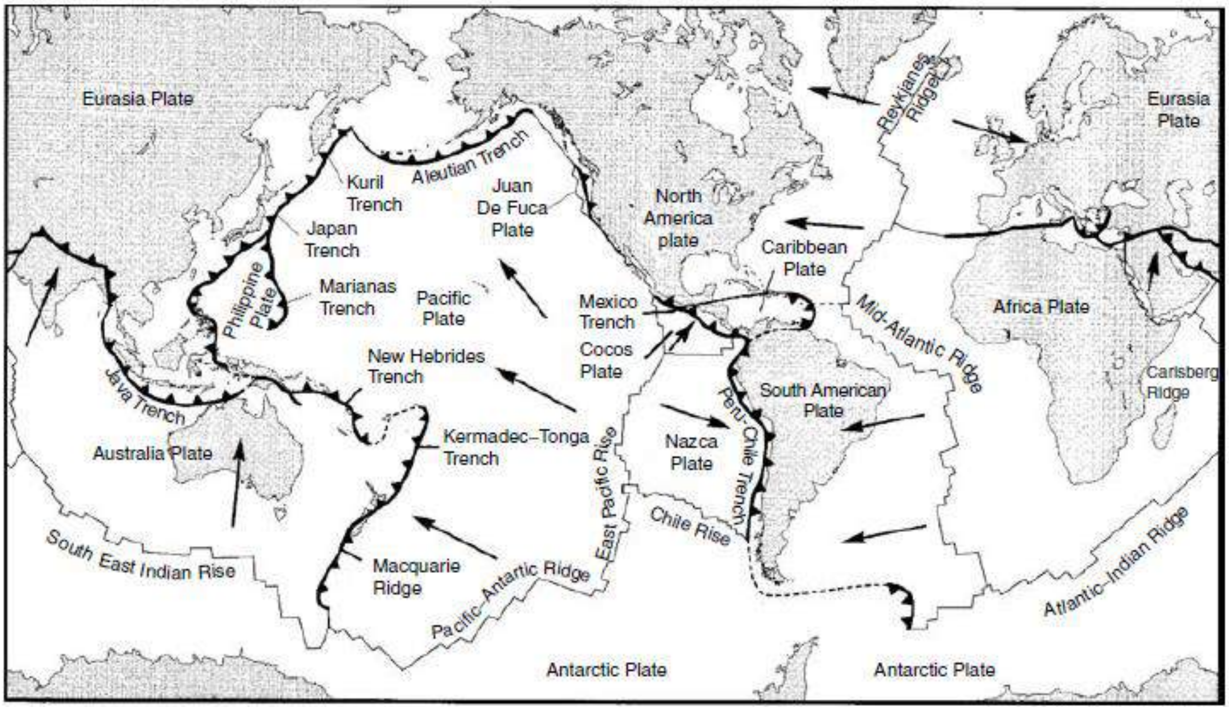


FIGURE 2-1
MAJOR TECTONIC PLATES

The theory of plate tectonics postulates that the earth’ s crust is fractured and thus divided into a small number of large and rigid pieces, referred to as plates. The size of these plates varies from a few hundred to many thousands of kilometers. Their location, as well as their given names, is shown in Figure 3.3.



The theory of plate tectonics has evolved from the theory of continental drift originally proposed by the German scientist Alfred Wegener in 1912. Wegener’ s theory of continental drift proclaimed that the earth’s surface was not static, but dynamic, and that the oceans and continents are in constant motion.

There are four interaction modes between the tectonic plates:

1. **Subduction:** it occurs especially around islands, in zones where two plates of similar thickness come into contact with each other. Plate subduction also gives rise to some of the world’ s most powerful earthquakes. In fact, almost 90% of the seismic energy released by tectonic plate movement comes from earthquakes generated in subduction zones. Earthquakes occur above the subducting plate in regions of the continental plate and at the interface between the subducting and overriding plates.

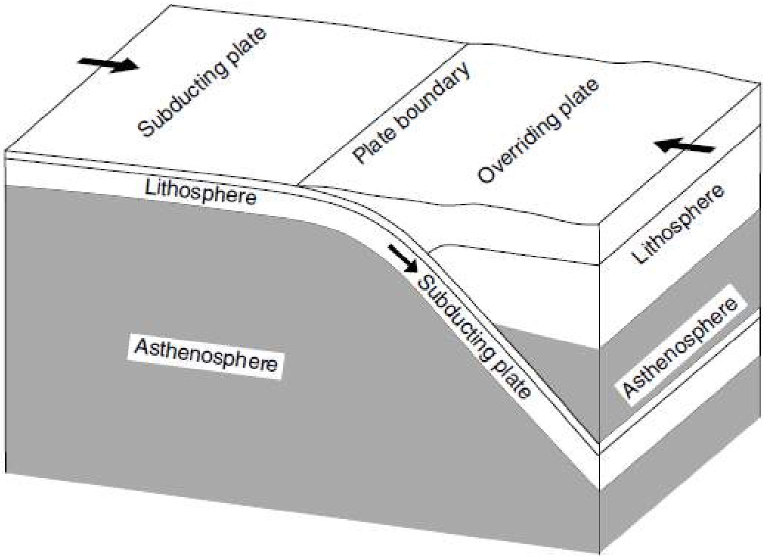


FIGURE 3.6 Subduction of oceanic plate under continental plate.

2. **Transcursion:** it occurs when two oceanic plate or an oceanic plate and a continental plate come into contact.

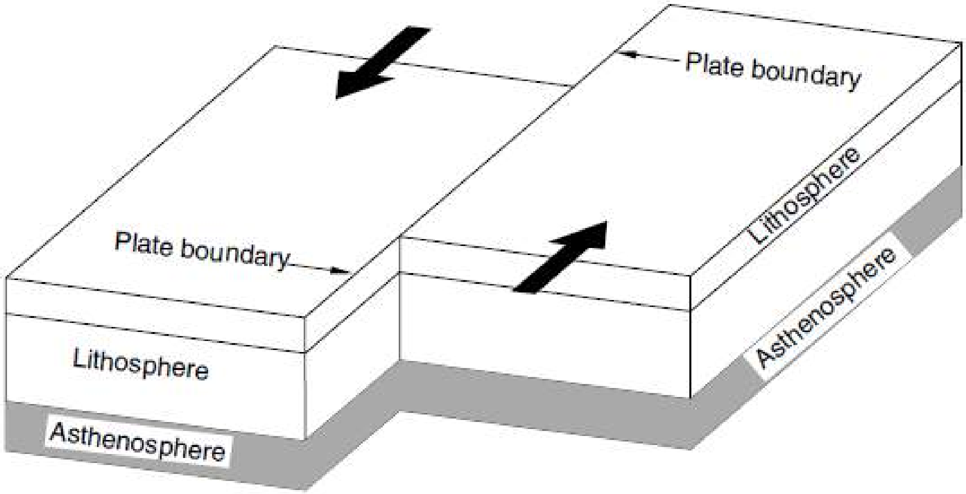


FIGURE 3.10 Plates sliding past each other and formation of transform fault.

3. **Extrusion:** it occurs when two thin tectonic plates are removed every time further from each other, that is the case of the contact of two plates in a mid-oceanic zone. Earthquake and volcano activity is involved along the boundaries of these diverging plates, although the earthquakes that occur there are usually of low magnitude.

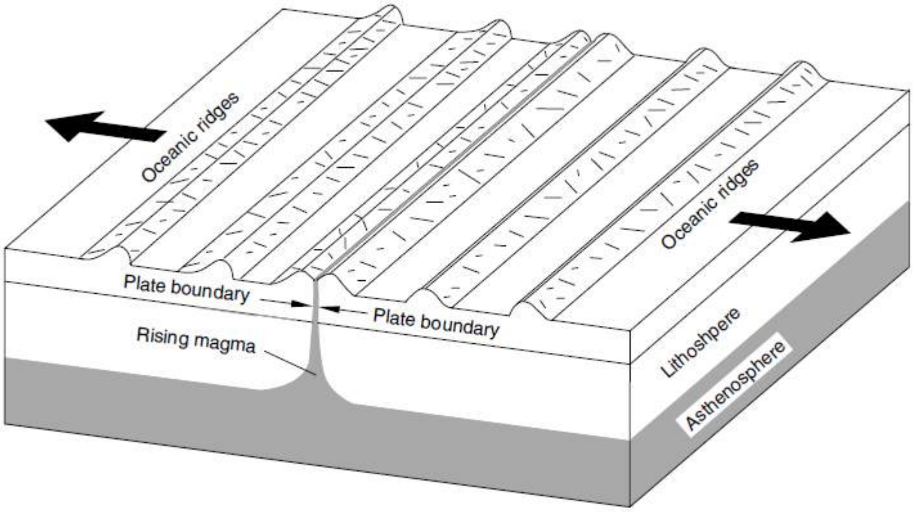


FIGURE 3.5 Schematic view of mid-oceanic ridges and spreading oceanic plates causing the rising of magma from the asthenosphere to form new ocean floor.

4. **Accretion:** it is a consequence of a slow impact between an oceanic and a continental plate.

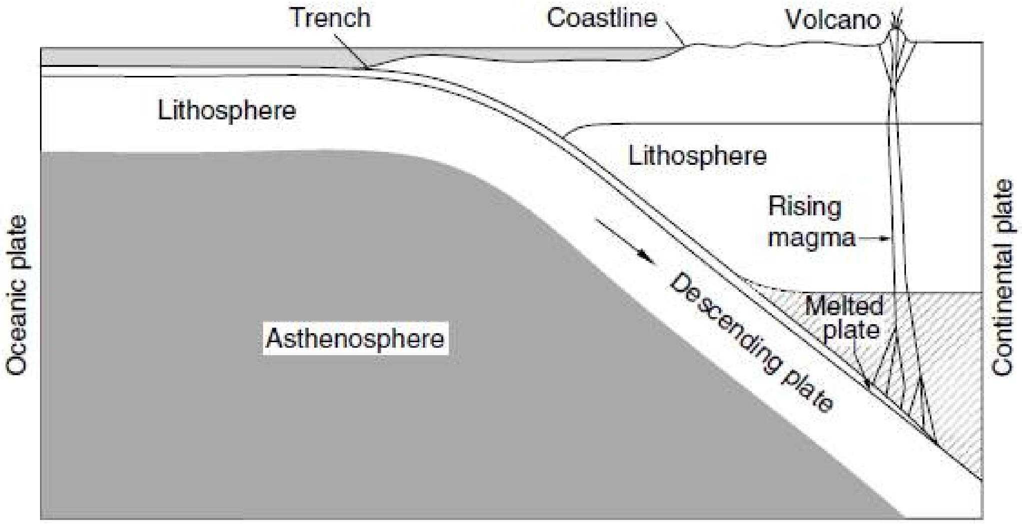


FIGURE 3.8 Formation of volcanoes in subduction zones.

Note: *It is believed that earthquakes cannot occur at depths >700 km because beyond this depth a subducting plate melts.*

Classification of the Earthquake

A classification of the earthquake according to their mechanical causes are as follow:

1. **Collapse Earthquake**: these are earthquake of low intensity that take place in zones of underground cavities and mines, and are due to collapse of these.
2. **Volcanic Shocks**: both volcanic eruption and earthquakes are phenomena that seem to have the same tectonic origin. Yet explosions of gases during eruptions can give birth to earthquakes that generally affect small surfaces and have low intensities.
3. **Tectonic Earthquake**: these are the strongest and most frequent earthquake. They are caused by sudden break of the rock layer along fractured surfaces called faults.
4. **Earthquake Generated by Explosions**: man has often produced explosions, especially underground nuclear ones, capable of generating ground motions that can be felt at certain distances. Sometimes such earthquakes can birth to strong vibrations in structures.

The most important of all of these is the tectonic earthquake; therefore, every time that we refer to an earthquake in the following lines, it will be one of this type.

Classification of the Tectonic Earthquake

The classification of tectonic earthquakes can be made according to the criterion of the focal depth. According to this, tectonic earthquakes can be divided into;

1. **Normal or Surface Earthquakes**, whose focal depth is H=5-70km.
2. **Medium Earthquakes**, whose focal depth is H=70-300km.
3. **Deep Earthquakes**, whose focal depth is H>300km.

Note: *The maximum depth that the focus of an earthquake can reach is 700 km.*

EARTHQUAKE FAULTS

When the boundaries between the earth's tectonic plates manifest themselves on the surface of the earth, they are seen as long uneven fractures or fissures on a rock formation whose sides have moved relative to each other. Geologists call these fractures or fissures as faults and identify them by the abrupt discontinuities on the structure of the adjacent rock and the irregularities on the earth's surface features along the fault line. Faults may range in length from several meters to hundreds of kilometers, extend to considerable depths, and exhibit displacements of several meters.

The four main types of fault related to the tectonic earthquakes are classified in the following group:

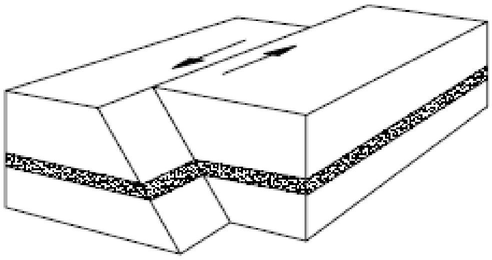
(1) **Normal Faults**, which correspond to zones where the earth's crust is in extension; one of the blocks separated by fault moves downwards.

(2) **Thrust or Inverted Faults,** which correspond to compressed zones; they are of two types:

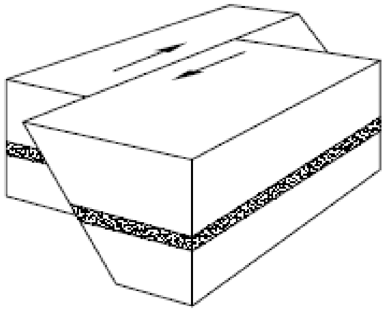
  (a) **Underthrust faults:** one of the interacting plates thrusts under the other, which generally is a continental plate.

  (b) **Overthrust faults**: the upper of the two blocks moves upwards.

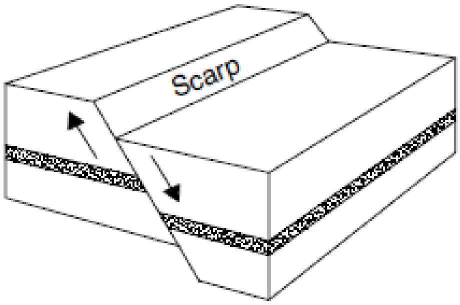
(3) **Transcurrent Faults,** which involve horizontal relative displacement the two sides of a fault.



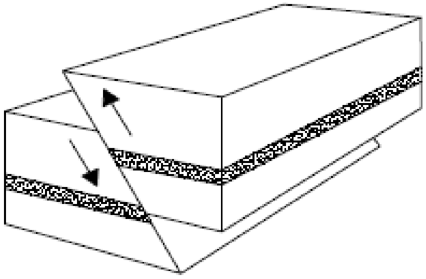
Left lateral strike-slip fault



Right lateral strike-slip fault



Normal dip-slip fault



Reverse or thrust dip-slip fault

EARTHQUAKE-GENERATION MECHANISM: ELASTIC REBOUND THEORY

The elastic rebound theory formulated by Harry F. Reid of Johns Hopkins University shortly after the 1906 San Francisco earthquake in California.

Thus, according to the elastic rebound theory, earthquakes are generated according to the following process (see Figure 3.17):

1. Stresses are generated and gradually accumulated along the sides of a fault as a result of the relative motion between such two sides and the friction forces that resist this motion.
2. Stresses along the sides of the fault overcome the frictional resistance of the fault.
3. Fault suddenly slips.
4. The two sides of the fault rebound to an unstressed state causing a disturbance.
5. Disturbance is propagated in the form of radial waves.

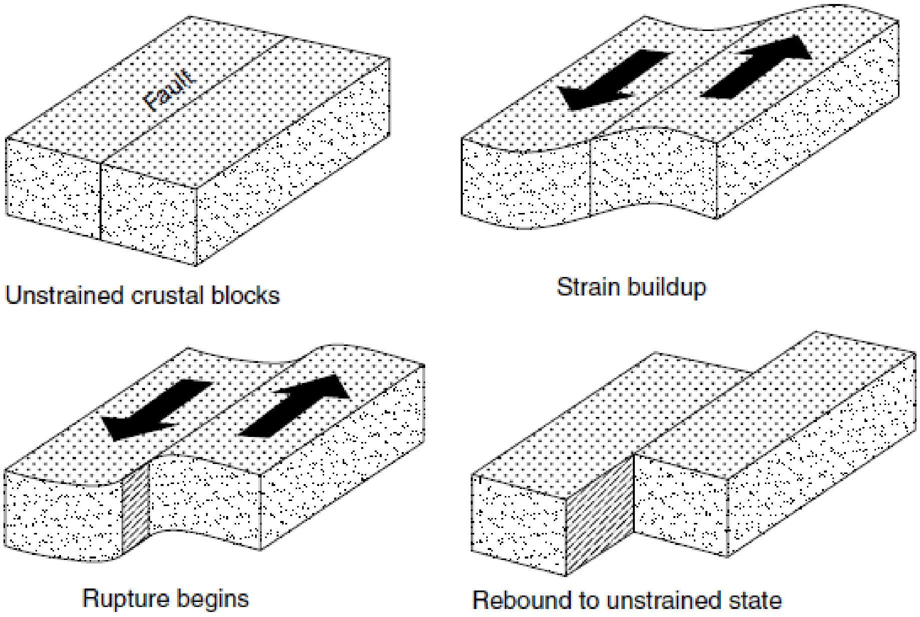


FIGURE 3.17 Earthquake-generation process according to elastic rebound theory.

The concepts behind the elastic rebound theory serve not only to explain the mechanism that generates earthquakes, but also to develop a technique to determine the orientation of the causative fault. With reference to Figure 3.19, it may be noted that after the rupture of a fault and the rebound of its two sides, the rock adjacent to the fault will be subjected to the distribution of tensile and compressive stresses shown in this figure. That is, compressive stresses in two diametrically opposed quadrants and tension stresses in the other two.

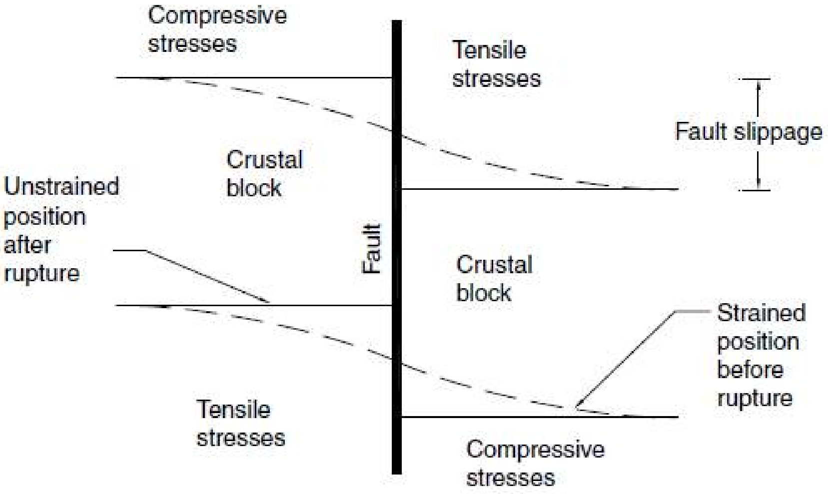
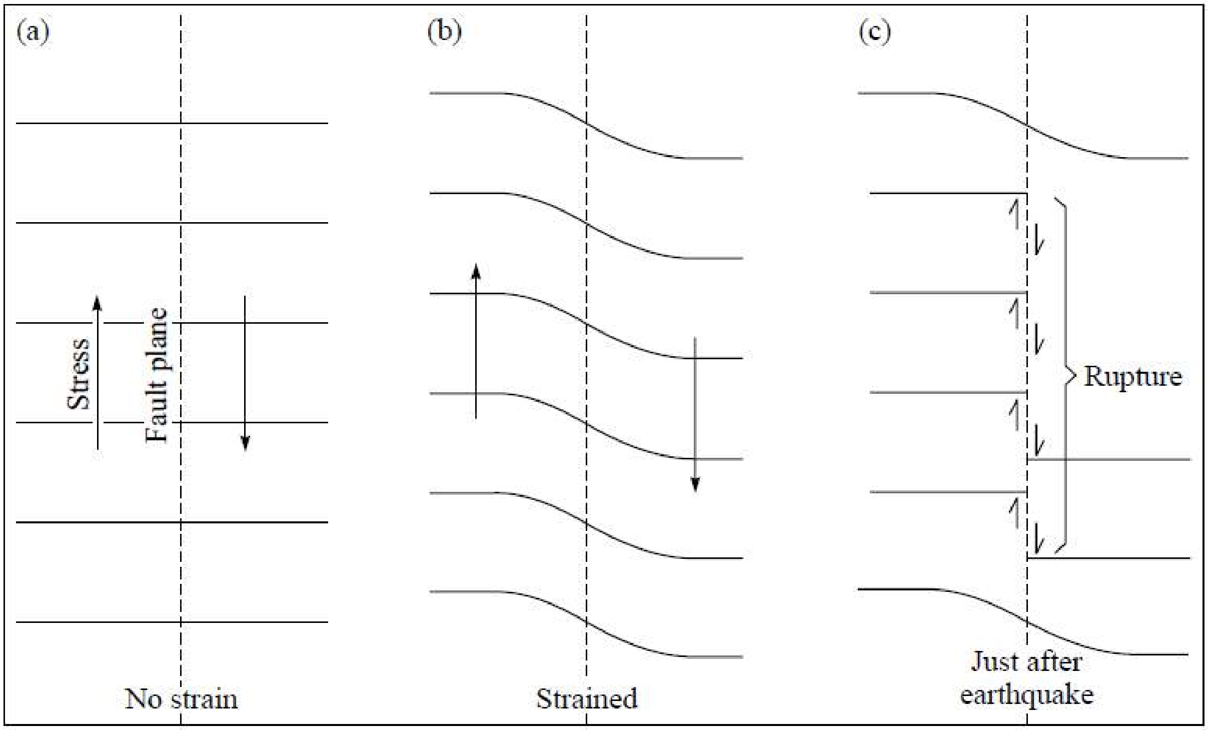


FIGURE 3.19 Distribution of stresses around a vertical earthquake fault right after the fault's rupture.



Schematic representation of elastic rebound theory

FOCUS, EPICENTER, RUPTURE SURFACE, AND FAULT SLIP

According to the elastic rebound theory, earthquakes originate right after a fault suddenly ruptures. This rupture, however, is neither instantaneous nor concentrated at a single point. Rather, it begins at a point below the earth’s surface, spreads across the fault plane with a velocity V, and finally stops after the rupture extends to cover an area with an average length L and average width W. In the process, the two fault surfaces are offset by a finite amount referred to as the fault slip. Thus, earthquakes are characterized by the location of their focus or epicenter, their focal depth, the size and orientation of the associated fault’s rupture surface, and the fault slip.

With reference to Figure 3.21 and for the purpose of this characterization (Earthquake Mechanism):

The Focus or Hypocenter of an Earthquake is defined as the point where the rupture of the associated fault originates. The focus of the earthquake may be defined as the weak point at which the first rupture occurs.

Epicenter is defined as the projection of the hypocenter on the earth’s surface.

Rupture Surface is considered to be the area within the fault plane that is displaced during an earthquake.

Fault Slip is the corresponding relative displacement between the two sides of the fault.

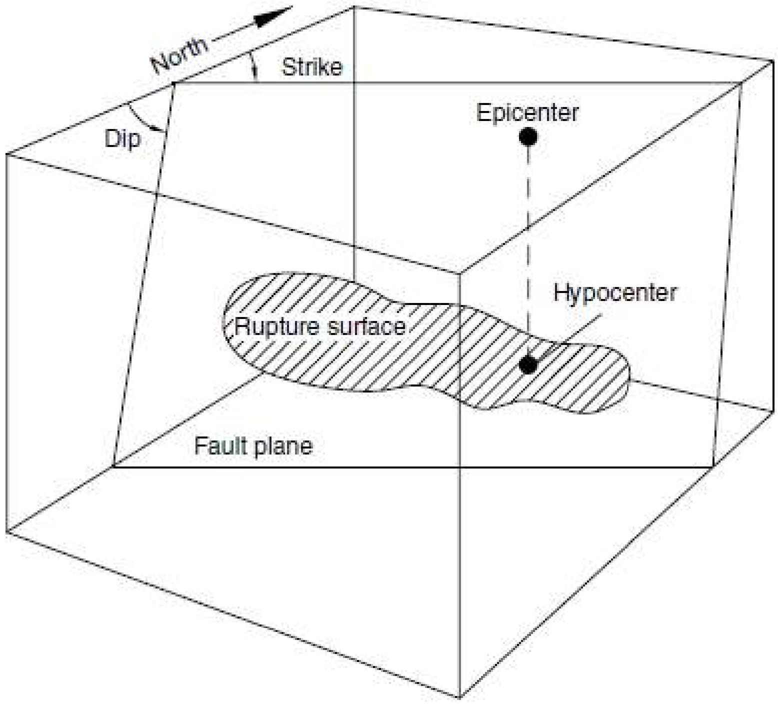


FIGURE 3.21 Hypocenter and epicenter of an earthquake and associated rupture surface.

Note :

- The ruptured area during an earthquake may range from a few to thousands of square kilometers.
- A parameter related to fault displacement that is often used to characterize the activity of earthquake faults is the **Slip Rate**. For a given fault, slip rate is calculated by dividing the cumulative displacement of the fault, determined from offset geological or geomorphic features, by the estimated age at which the earliest displacement took place. Thus, slip rate is an average value over a geological time interval. The slip rates for a few selected faults are listed in Table 3.1. Note that, as expected, highly active faults such as the San Andreas Fault have a much higher slip rate than minor faults.

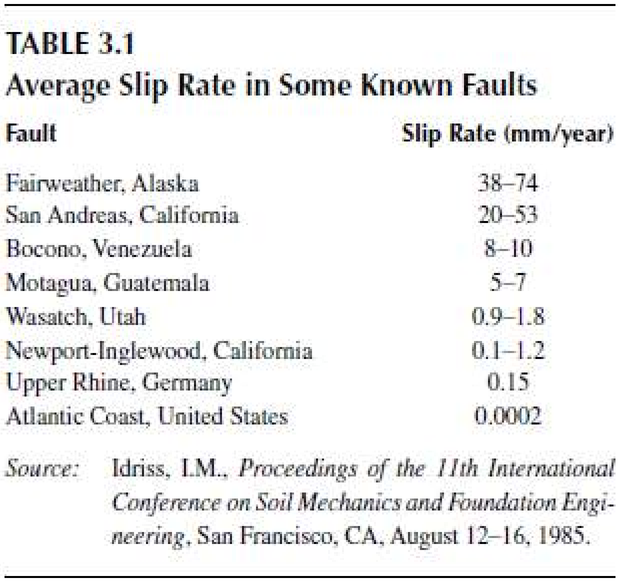


TABLE 3.1
Average Slip Rate in Some Known Faults

Fault	Slip Rate (mm/year)
Fairweather, Alaska	38–74
San Andreas, California	20–53
Bocono, Venezuela	8–10
Motagua, Guatemala	5–7
Wasatch, Utah	0.9–1.8
Newport-Inglewood, California	0.1–1.2
Upper Rhine, Germany	0.15
Atlantic Coast, United States	0.0002

Source: Idriss, I.M., *Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering*, San Francisco, CA, August 12–16, 1985.

FORESHOCKS AND AFTERSHOCKS

Large earthquakes are usually preceded and followed by a sequence of tremors of smaller size that originate at approximately the same location. The tremors preceding the so-called main shock are known as **Foreshocks**. Those following the main shock are called **Aftershocks**. Foreshocks are normally small in size and only a few occur before an earthquake. Moreover, not all earthquakes are preceded by a foreshock. Aftershocks may be relatively large in number and size, but their frequency and size gradually decreases with time. Foreshocks are believed to be the precursors of the fault rupture that generates the main earthquake, whereas aftershocks are considered to be the result of adjustments to the stress imbalances produced by such rupture. Aftershocks almost as large as the main event have been observed in the past.

Seismic Waves

The large strain energy released during an earthquake travels in the form of seismic waves in all directions (Fig. 1.8), with accompanying reflections from earth's surface as well as reflections and refractions as they traverse the earth's interior (Fig. 1.9).

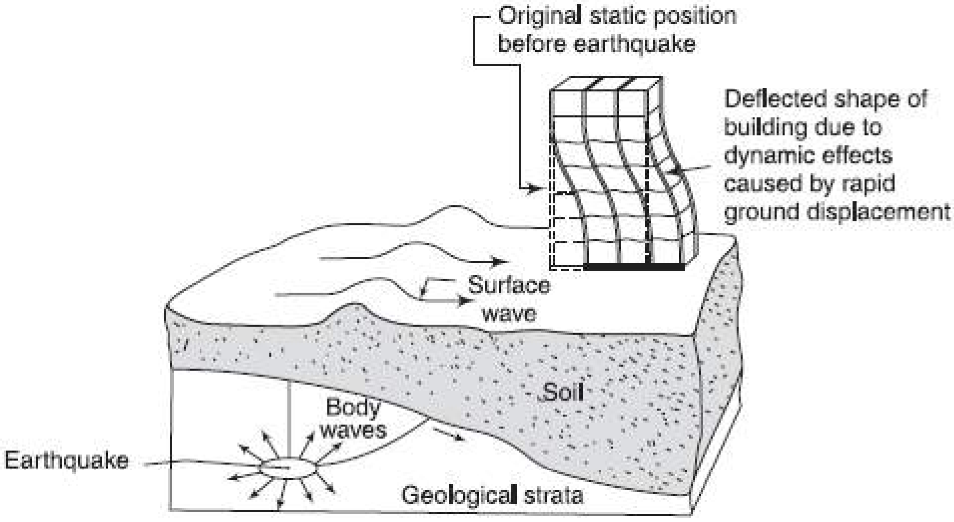


Fig. 1.8 Arrival of seismic wave

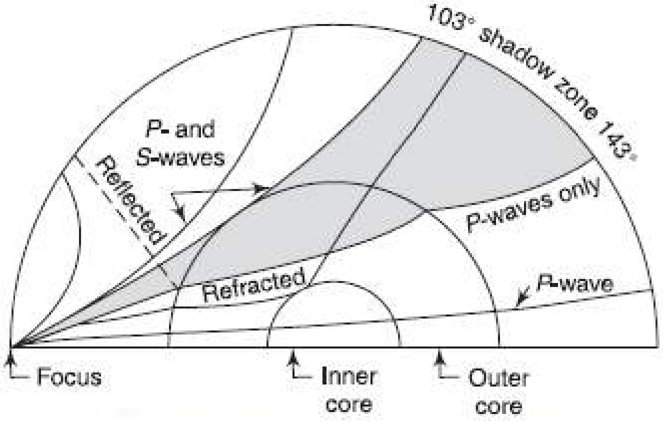
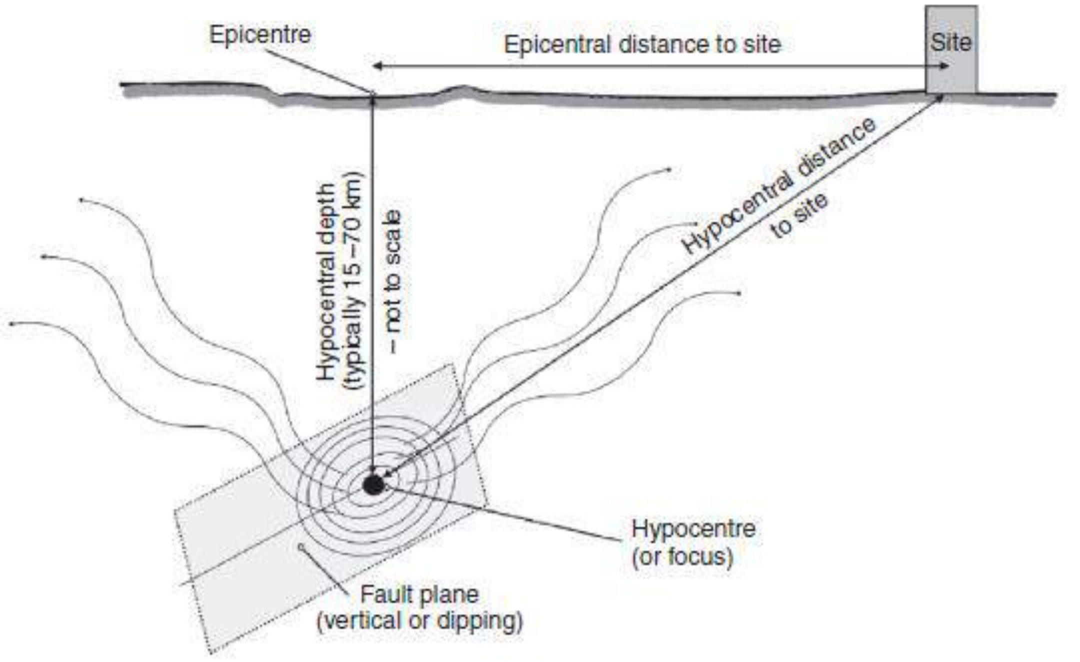


Fig. 1.9 Seismic wave paths (Richter 1958)



The seismic waves have as their theoretical origin the focus of the earth and propagate in spherical wave fronts through the earth up to surface.

When the stored energy increases to levels that exceed the ability of the friction forces to hold the plate boundaries together, sliding along those boundaries occurs, creating a phenomenon known as elastic rebound. Elastic rebound releases the stored energy in the form of seismic strain waves in all directions. This marks the onset of an earthquake event. Figure 2-2 shows the different types of seismic strain waves that are generated by earthquakes. Strain waves are classified into two main groups:

1. **Body Waves**, which propagate through the earth's mass. Body waves are classified as :
   (a) Fast primary waves (primary, longitudinal, or compressional waves) or P-waves. It is condensation-rarefaction waves that involve volume changes. It can travel across both solids and fluids.
   (b) Slow shear waves (secondary, transverse, or shear waves) or S-waves. It is shear waves and do not imply volume changes. It cannot travel across a fluid part of the earth. They are sometimes called secondary waves because they travel more slowly than P-waves in the same material.
2. **Surface Waves (Q)**, that propagate through the earth's crust. Surface waves are classified as:

(a) Rayleigh waves or R-waves produce, as P-wave do, volume change.
(b) Love waves or L-waves propagate, the same as S-wave, with a horizontal translation of particles, normally in the direction of the wave motion.

Note:

- Body waves can be used to estimate the distance of the site of measurement from the earthquake source. Because P-waves are faster than S-waves, a measurement of the time difference between their arrivals at the site can be converted into a distance.
- Note that these seismic strain waves travel through random media that modify the waves with an infinite number of effects, which include filtering, amplification, attenuation, reflection and refraction. These random modifications give each site a different wave profile, making it very difficult to predict the characteristics of an earthquake at a specific site. The extreme randomness and uncertainty of earthquake characteristics require the use of probabilistic means in the treatment and design of structures. Therefore, the design and survival of structures is also based on probabilistic consideration of earthquake excitations.
- The material particles in S-waves oscillate at right angles to the direction of propagation of the wave [Fig. 1.10(b)], and cause shearing deformations as they travel through a material. The direction of particle movement can be used to divide S-waves into two components, SV (vertical plane movement) and SH (horizontal plane movement). S-waves do not change the instantaneous volume of the material through which they pass. However, the instantaneous shape of the material gets distorted. The velocity of S-waves is directly proportional to the shear strength of the material through which they pass. S-waves do not travel through liquids as fluids have no shearing stiffness.
- In association with the effects of L-waves, S-waves cause **maximum damage to structures by rocking the surface in both horizontal and vertical directions**. When P- and S-waves reach the earth’s surface, most of their energy is reflected back. Some of this energy is returned to the surface after being reflected from different layers of soil and rock. Shaking due to earthquakes is more severe (about twice as much) at the earth’s surface than at substantial depths.
- L-waves cause surface motion similar to that caused by S-waves, but with no vertical component [Fig. 1.10(c)]. These are produced from the interaction of SH-waves with a soft surficial layer and have no vertical component of particle motion. L-waves are always dispersive, and are often described as

SH-waves that are trapped in by multiple reflections within the surficial layers.

- Rayleigh waves make a material particle oscillate in an elliptical path in the vertical plane (with horizontal motion along the direction of energy transmission) as shown in Fig. 1.10(d). These are produced by the interaction of P- and SV-waves with the surface of earth. The velocity of Rayleigh waves depends on Poisson's ratio of the material through which they pass. Rayleigh waves are believed to be the principal component of **ground roll**. Ground roll is a form of coherent linear noise which propagates at the surface of earth, at low velocity and low frequency.

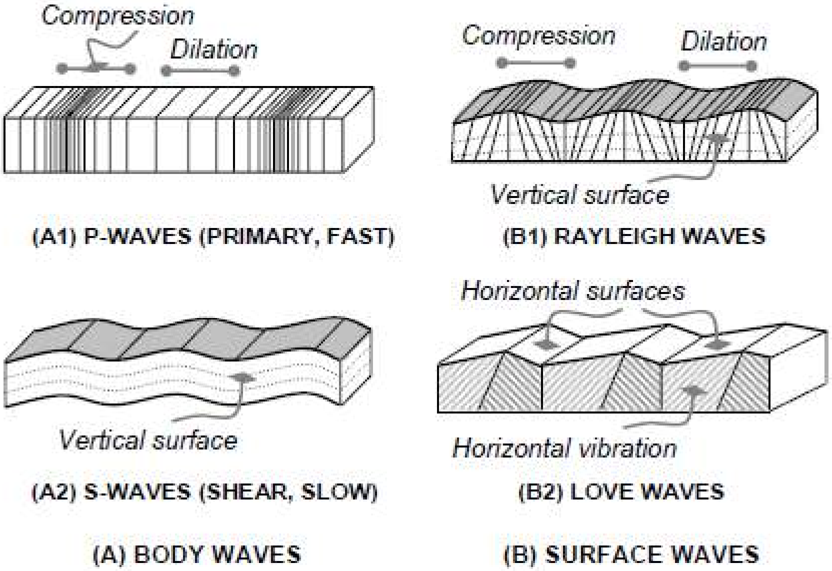


FIGURE 2-2
TYPES OF SEISMIC STRAIN WAVES

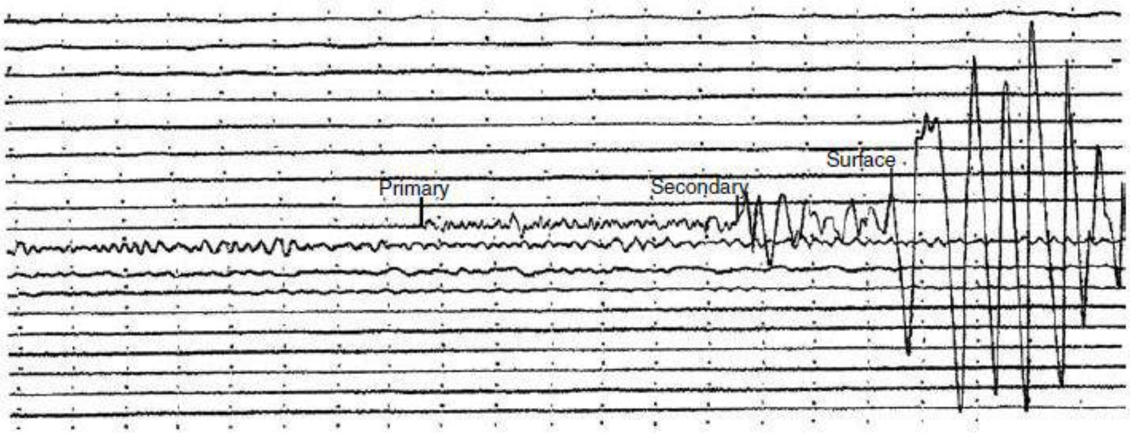


FIGURE 4.20 Ground motion recorded in Palisades, New York, generated by an earthquake in South America on May 28, 1976, showing the arrival of primary, secondary, and surface waves.

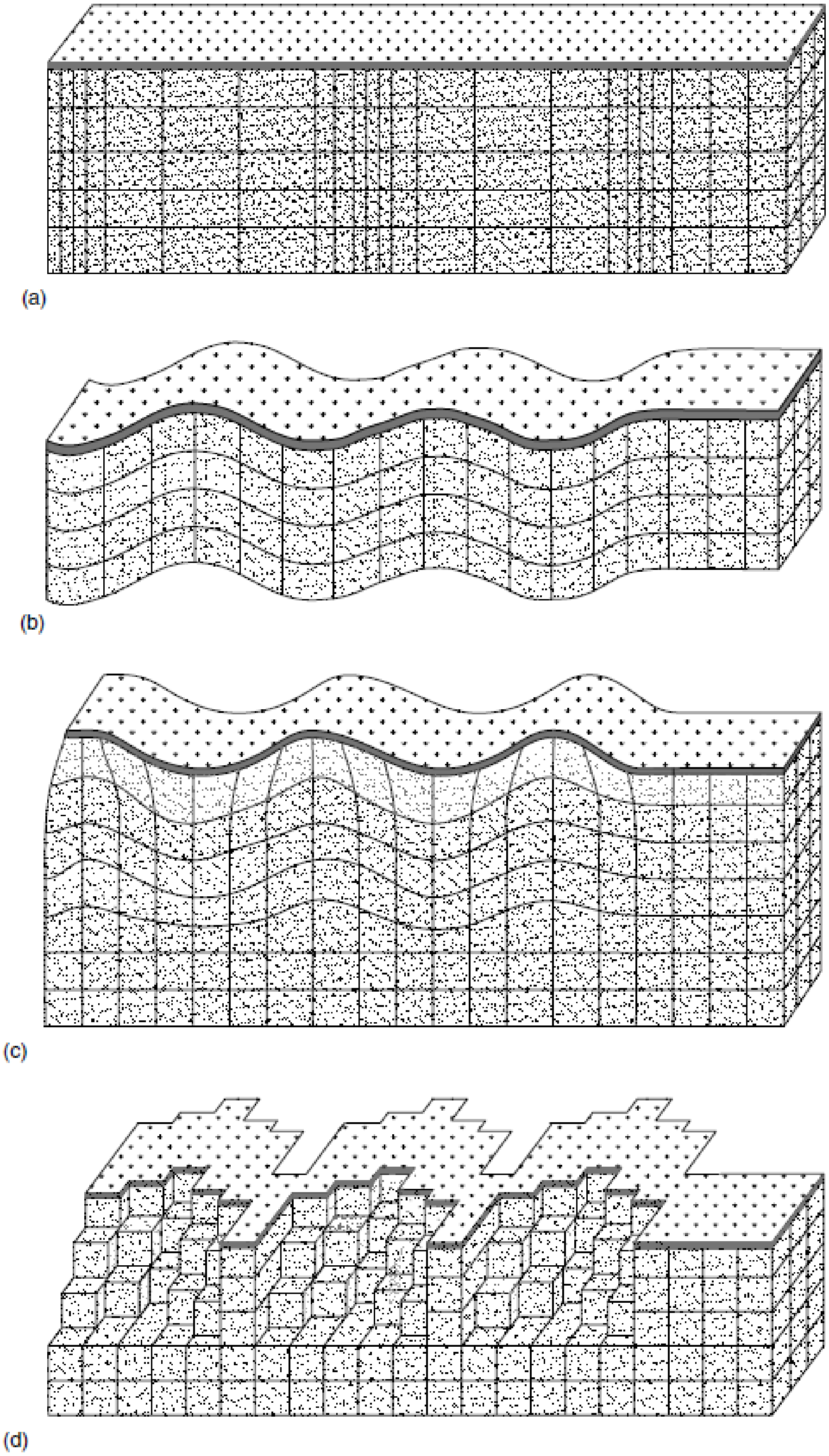


FIGURE 4.19 Motion generated by P, S, Love, and Rayleigh waves as waves propagate from left to right: (a) primary waves compress and stretch the medium, (b) secondary waves generate up-and-down and side-to-side oscillations, (c) Rayleigh waves rotate the top of the medium in an elliptic pattern like an ocean breaker, and (d) Love waves distort the top of the medium side to side.

Velocity of the Seismic Waves (propagation velocities)

The seismic waves reflect and refract when they hit an earth discontinuity. This involves changes of the velocity of the waves. The propagation velocities *Vp* and *Vs* of P-waves and S-waves, respectively, are expressed as follows:

$$V_P = \left[\frac{E}{\rho} \times \frac{1-\nu}{(1+\nu)(1-2\nu)}\right]^{1/2}$$

$$V_S = \left[\frac{G}{\rho}\right]^{1/2} = \left[\frac{E}{\rho} \times \frac{1}{2(1+\nu)}\right]^{1/2}$$

where E is the Young's modulus, G is the shear modulus, ρ is the mass density, and υ is the Poisson's ratio (0.25 for the earth) that it is provide:

$$V_P = \sqrt{3}\, V_S$$

Near the surface of the earth, VP = 5–7 km/s and VS = 3– 4 km/s.

The time interval between the arrival of a P-wave and an S-wave at the observation station is known as **duration of primary tremors**, Tsp and is given by

$$T_{SP} = \left(\frac{1}{V_S} - \frac{1}{V_P}\right)\Delta_{P\text{–}S}$$

where ΔP–S is the distance from the focus to the observation point. The epicenter can thus be located and the depth of the focus obtained graphically if earthquake records are made at least at three different observation points.

Seismographs

The seismic wave are recorded by means of seismographs. Generally these are instruments that record three orthogonal components of ground motion, two horizontal ones and a vertical one. Seismographs can be designed to record the acceleration, the velocity or the displacements of the seismic ground motion. The most used for earthquake engineering purpose are those which record acceleration, named accelerometers. The components of the recorded ground acceleration a (t), named ax (t), ay (t) and az (t). The records obtained from a seismograph are called seismograms. A seismogram is thus a record of the variation with time of the displacement of the ground, magnified by the magnification factor of the seismograph, at the location where the seismograph is installed.

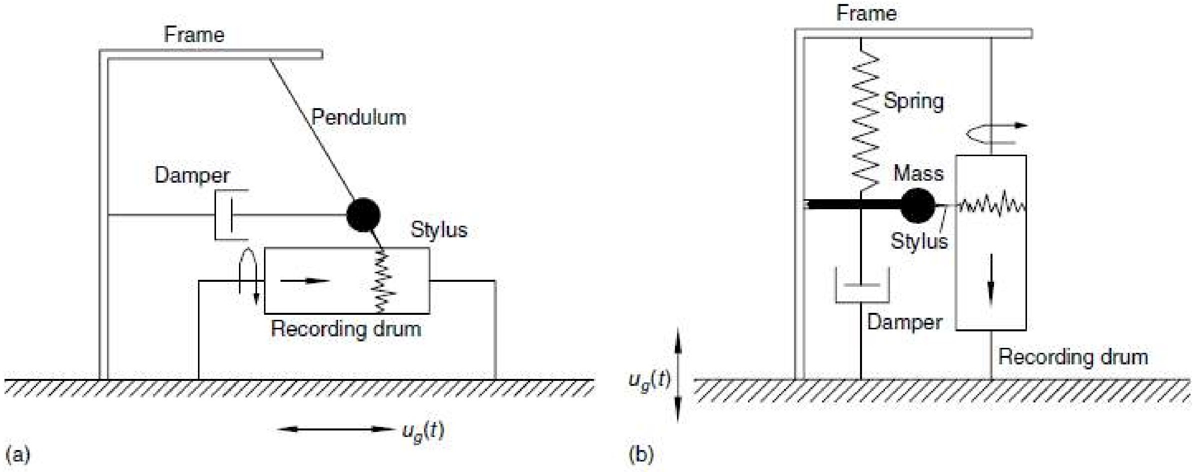


FIGURE 5.3 Schematic representation of (a) horizontal and (b) vertical seismographs.

These are the basic elements of a seismograph:

1. **The sensor**, a device capable of providing a measurable signal of its base motion.
2. **The signal conditioning device**, which is amplifies and filters the output of the sensor. It may consist of a mechanical, optical or electronic system, in accordance with the nature of the mentioned output.
3. **The recorder**, a device that turns the conditional signal into a form that can be used in seismology or in the earthquake engineering calculus. The output of the recorder can be expressed on a magnetic tape, a recording paper or film, or a digital record on a magnetic tape.

The arrival of P, S, and surface waves may be detected in a seismogram by considering that the P, S, and surface waves arrive at different times, have different amplitudes, and have different dominant periods (i.e., interval between peaks). This way, the arrival of the P and S waves can be clearly identified in the seismogram

Measures of Earthquakes

Earthquake measures quantify the size and effect of earthquakes. The size of an earthquake is measured by the amount of energy released at the source, its magnitude, whereas the effect of an earthquake at different locations is measured by its intensity at a specific site. Figure 2-3 defines the relevant components of an earthquake with its measures at the source and at any site.

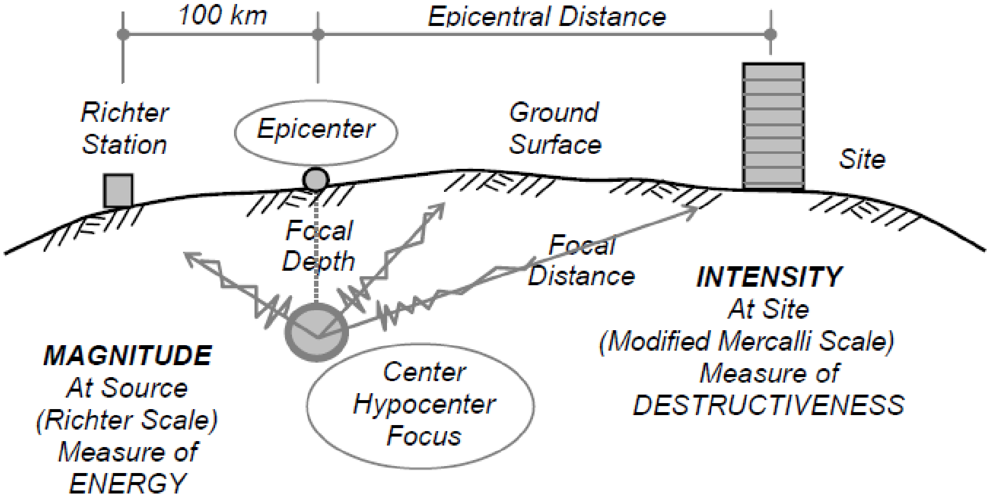


FIGURE 2-3
MEASURES OF EARTHQUAKES

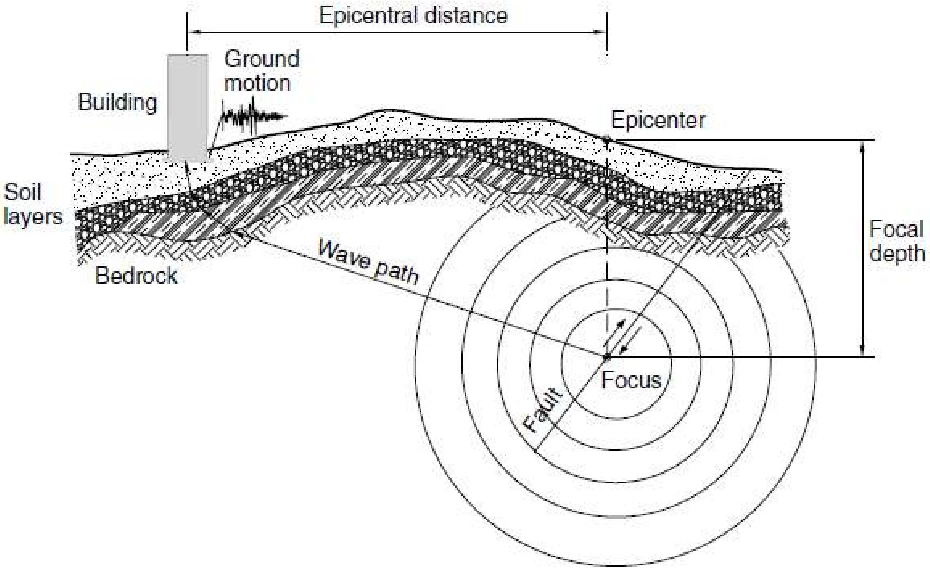


FIGURE 7.9 Schematic representation of factors affecting characteristics of ground motion at building site.

Magnitude

The size of an earthquake at its source is known as the magnitude of the earthquake and is measured by the Richter scale. The magnitude, M, is given as

$M = \log A$

where:

A = Amplitude in mm measured on a Wood-Anderson type seismometer.

The earthquake may be described in general terms according to the value of M as follows:

$M = 1$ to 2: Earthquake is barely noticeable.

$M < 5$: Earthquake is not expected to cause structural damage.

$M > 5$: Earthquake is expected to cause structural damage.

$M = 8, 9$: Earthquake causes the most structural damage recorded.

Note that ground motion intensity decreases with the distance from focus.

Therefore, M does not measure local destructiveness of earthquakes.

The M-value is only an indication of the energy released.

Intensity

Intensity is a subjective measure of the local destructiveness of an earthquake at a given site. Intensity scales are based on human feelings and observations of the effect of ground motion on natural and man-made objects. The most popular scale of intensity is called the Modified Mercalli scale (MM). This scale is divided into twelve grades (I to XII) as follows:

I. Not felt except under exceptionally favorable circumstances.
II. Felt by persons at rest.
III. Felt indoors; may not be recognized as an earthquake.
IV. Windows, dishes and doors disturbed; standing motor cars rock noticeably.
V. Felt outdoors; sleepers wakened; doors swung.
VI. Felt by all; walking unsteady; windows and dishes broken.
VII. Difficult to stand; noticed by drivers; fall of plaster.
VIII. Steering of motor cars affected; damage to ordinary masonry.
IX. General panic; weak masonry destroyed, ordinary masonry heavily damaged.
X. Most masonry and frame structures destroyed with foundations; rails bent slightly.
XI. Rails bent greatly; underground pipes broken.
XII. Damage total; objects thrown into the air.

Note that MM depends on the magnitude of the earthquake and on the distance between the site and the source. This scale may be expressed as a function of magnitude and distance from the epicenter by the following expression:

MM = 8.16 + 1.45 M - 2.46 ln r

where:

MM = Modified Mercalli scale intensity grade.

M = Earthquake magnitude (Richter scale).

R = Distance from epicenter (km).

A plot of this relation is shown in Figure 2-4.

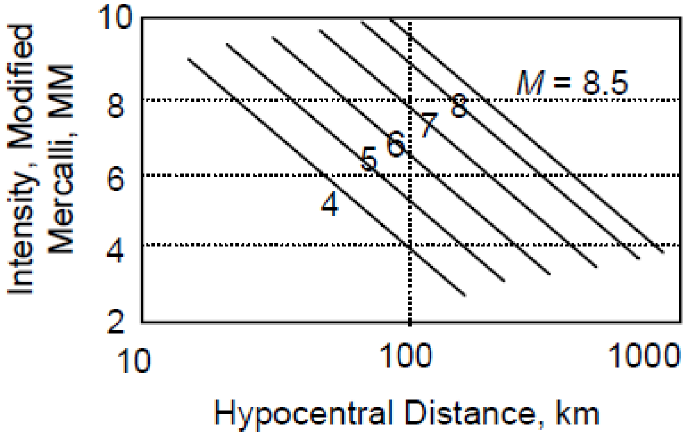


FIGURE 2-4
RELATIONSHIP BETWEEN MAGNITUDE AND SEISMIC INTENSITY
(mile ≈ 1.609 km)

Example :

A maximum amplitude of 1.2 m is recorded on a Wood-Anderson seismometer at a standard Richter station. Describe the expected damage in a city located at 160 km from the earthquake epicenter.

Solution

1. Richter scale magnitude

$$M = \log A = \log 1.2 \times 10^6 = 6.08$$

2. MM scale intensity

$$\mathrm{MM} = 8.16 + 1.45\,M - 2.46 \ln r$$

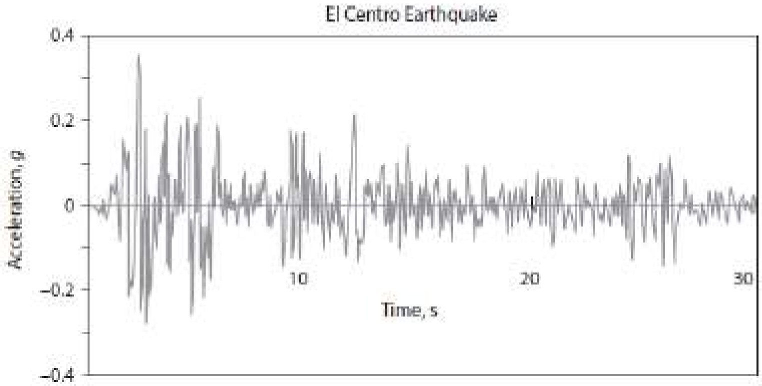
$$\mathrm{MM} = 8.16 + 1.45\,(6.08) - 2.46 \ln (160)$$

$$\mathrm{MM} = 4.5 \approx \text{grade V}$$

Therefore, the damage in the city may be described as grade V according to the MM scale: the earthquake was felt outdoors, sleepers wakened, and doors swung.

Instrumental Scale

In general, both magnitude and intensity scales of earthquakes are useful in estimating the size and severity of earthquakes. However, they are not useful for engineering purposes, especially in structural engineering. Structural engineers need a quantitative measure that can be used in analysis and design. This measure is provided in an accelerogram, which is a record of the ground acceleration versus time.



A correlation between the peak ground acceleration and the MM scale has been observed. Statistical analysis shows that the following approximate relations may be used for estimate purposes.

1. ***On the average, PGA (in g) is given as***

$$\mathrm{PGA}_{\mathrm{avg}} = 0.1 \times 10^{-2.4 + 0.34\,\mathrm{MM}}$$

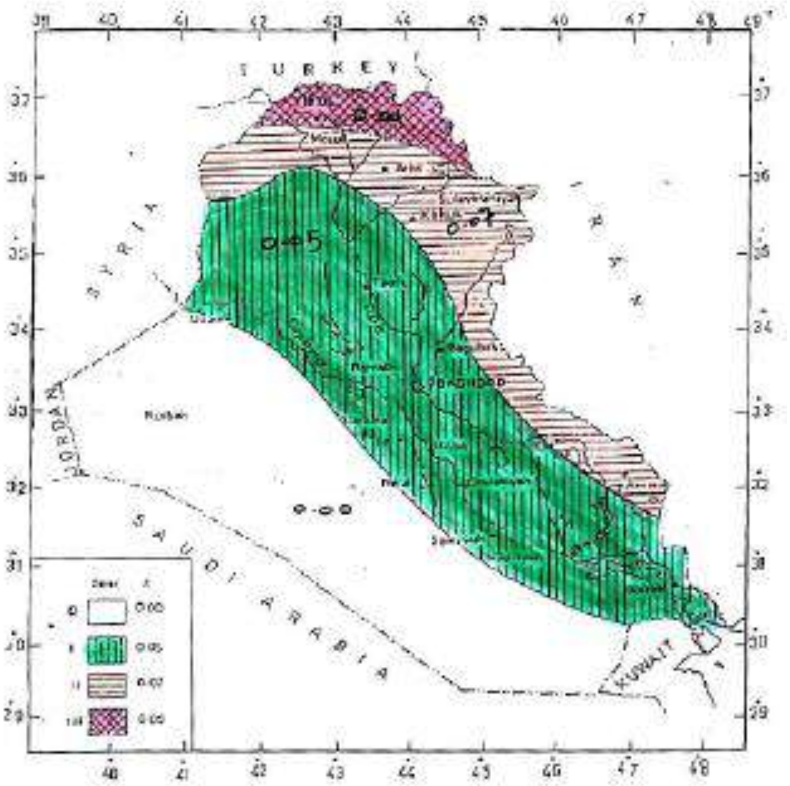
2. ***A conservative value of PGA (in g) is given as***

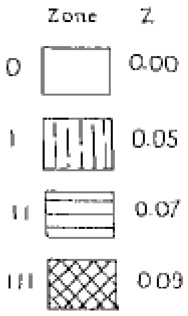
$$\mathrm{PGA}_{\mathrm{design}} = 0.1 \times 10^{-1.95 + 0.32\,\mathrm{MM}}$$

Approximate Relationships between PGA, MM, Uniform Building Code (UBC) Zoning, and International Building Code (IBC) Zoning Criterion

MM	PGA (g)	UBC zone (Z)	IBC	
			Mapped spectral acceleration at short period (S_s)	Mapped spectral acceleration at 1-s period (S_1)
IV	< 0.03	1	around 30	around 12
V	0.03–0.08			
VI	0.08–0.15			
VII	0.15–0.25	2A	around 60	around 25
		2B	around 75	around 30
VIII	0.25–0.45	3	around 115	around 45
IX	0.45–0.60			
X	0.60–0.80	4	around 150	around 60
XI	0.80–0.90			
XII	> 0.9			

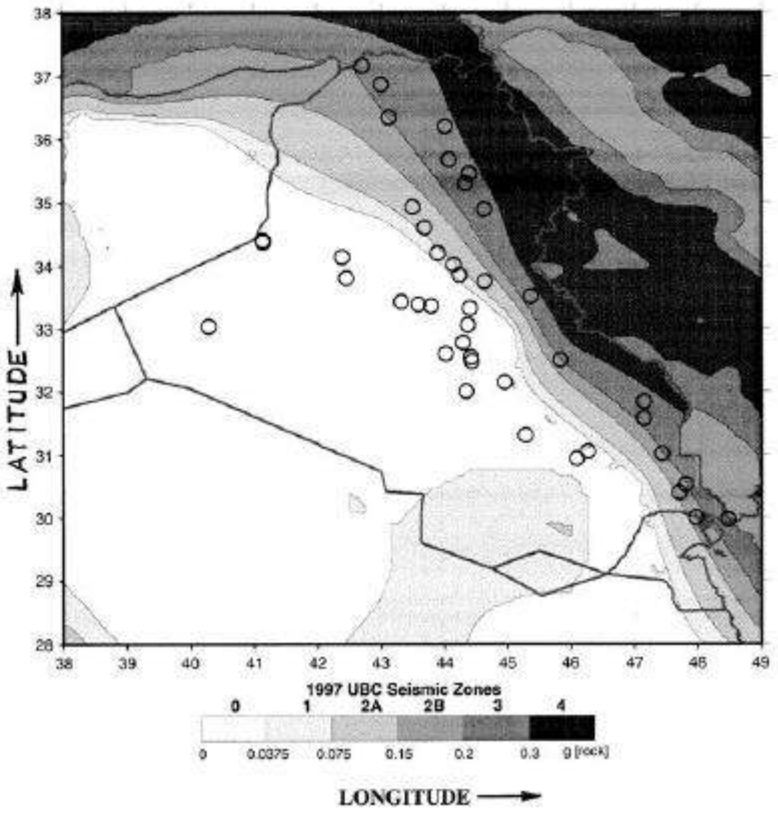
Seismic Zoning Map of IRAQ





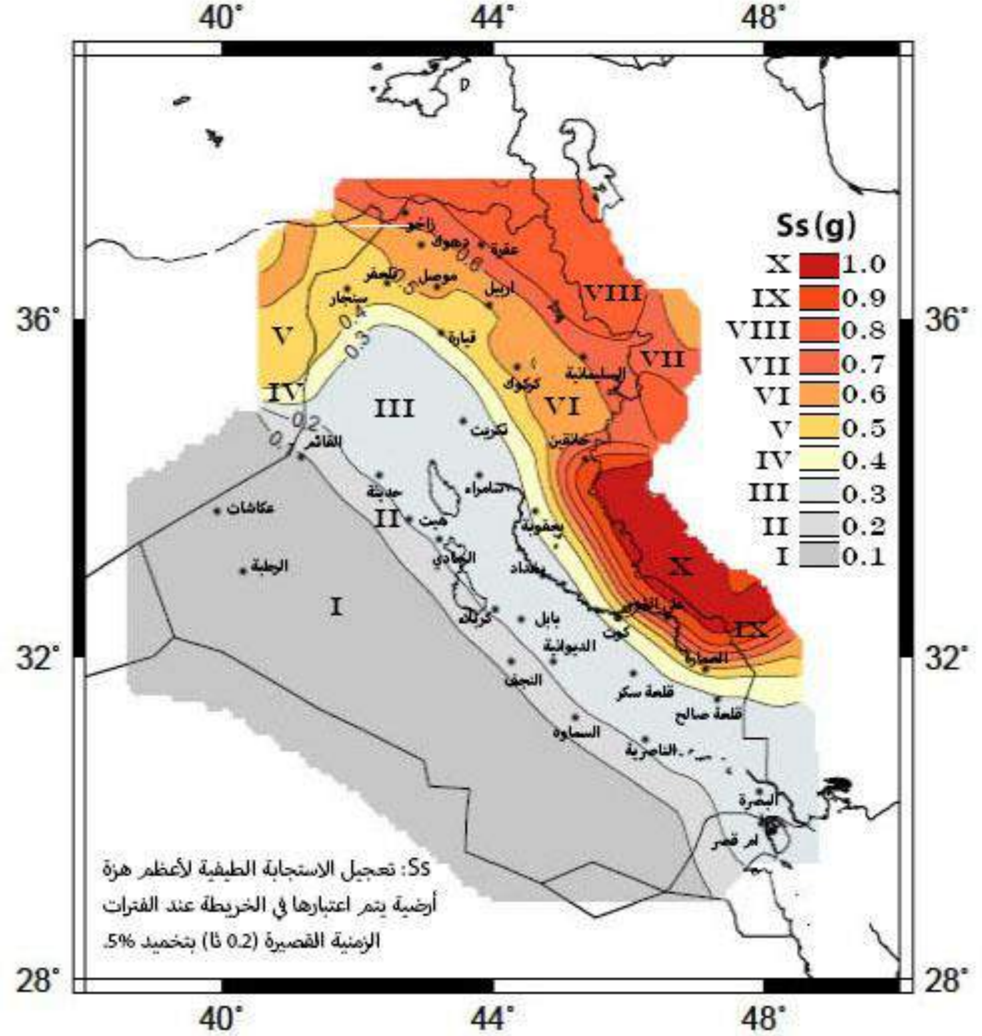
Zone		Z
0	☐	0.00
I	▥	0.05
II	▤	0.07
III	▩	0.09

Iraq Seismic Zone (Iraqi seismic Code-1997



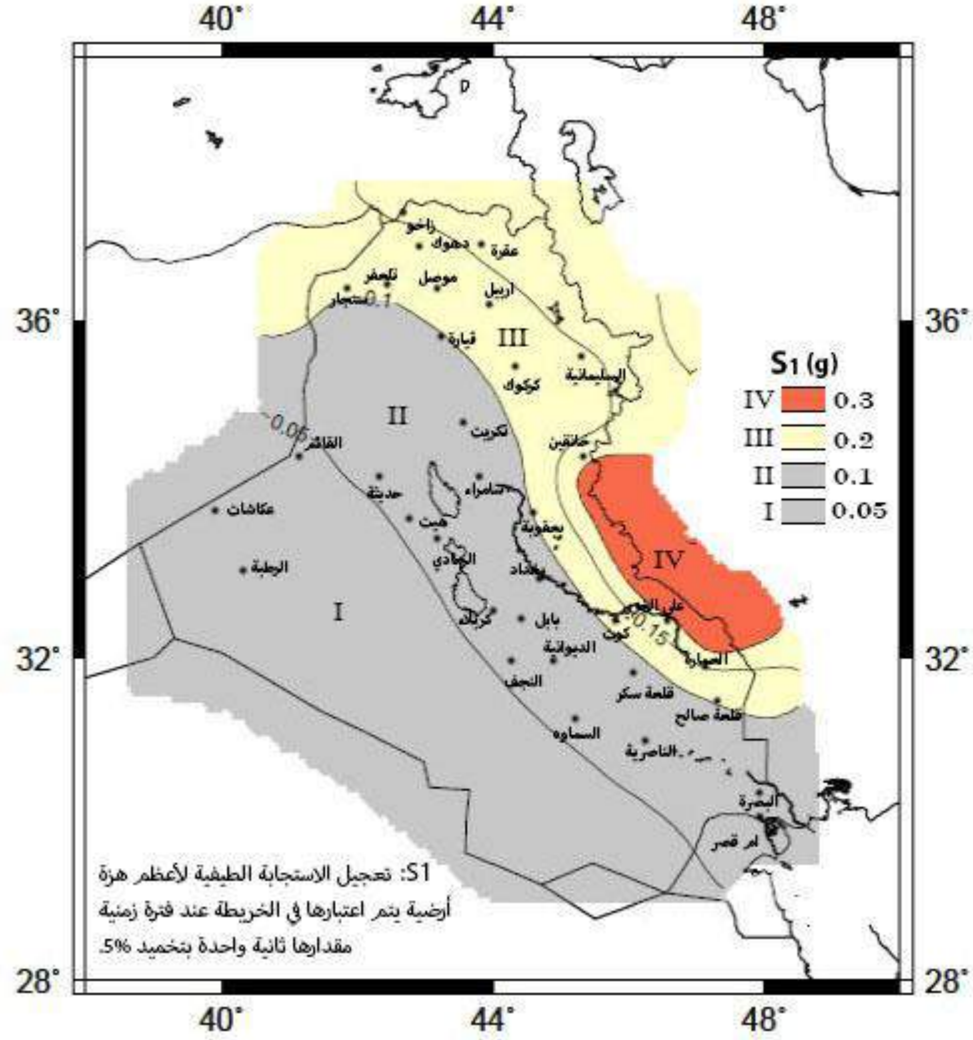
O Indicates location of different cities in Iraq

UNIFORM BUILDING CODE (UBC) 1997 SEISMIC ZONE FOR IRAQ



خارطة العراق توضح قيم التسارع الطيفي للحركة الارضية الزلزالية عند فترة زمنية قصيرة (0.2) ثانية (Ss)

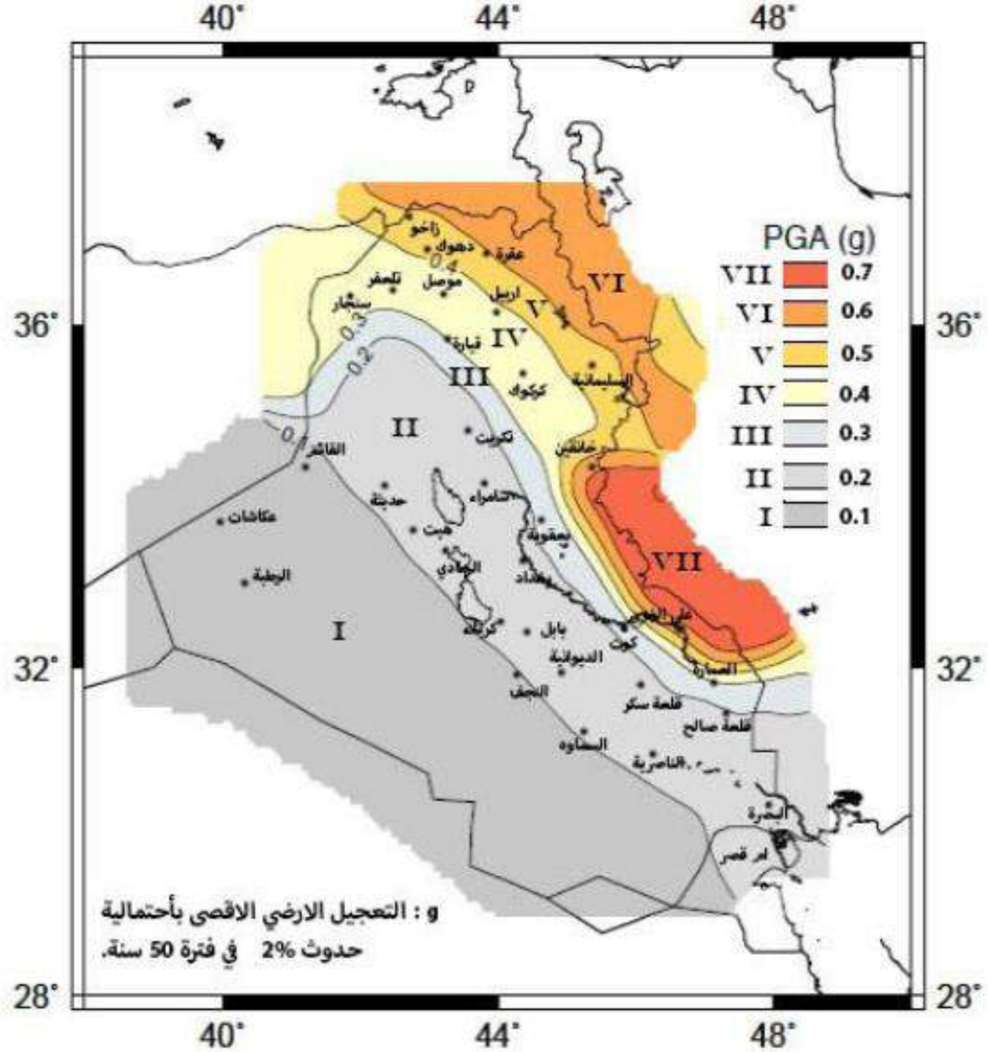
حسب مدونة الزلازل العراقية لسنة 2017(مدونة المباني المقاومة للزلازل) (مدونة بناء عراقية) م.ب.ع 303



S1: تعجيل الاستجابة الطيفية لأعظم هزة أرضية يتم اعتبارها في الخريطة عند فترة زمنية مقدارها ثانية واحدة بتخميد 5%.

خارطة العراق توضح قيم التسارع الطيفي للحركة الارضية الزلزالية عند فترة زمنية قصيرة (1) ثانية (S_1)

حسب مدونة الزلازل العراقية لسنة 2017(مدونة المباني المقاومة للزلازل) (مدونة بناء عراقية) م.ب.ع 303



خارطة العراق توضح قيم التعجيل الارضي الاقصى (PGA) لاحتمالية حصول هزة ارضية تتجاوز قيمة هذا التعجيل هي 2% لفترة 50 سنة

حسب مدونة الزلازل العراقية لسنة 2017(مدونة المباني المقاومة للزلازل) (مدونة بناء عراقية) م.ب.ع 303

- **ملاحظة: مدونة المباني المقاومة للزلازل(مدونة بناء عراقية م.ب.ع. 303) وفي رقم الايداع في دار الكتب والوثائق ببغداد (2331) لسنة 2019، وان هذه المدونة معتمدة رسمياً وملزمة بموجب قانون الجهاز المركزي للتقييس والسيطرة النوعية ومنشورة في جريدة الوقائع العراقية في اصدارها ذي العدد 4431 في 2017/1/16 وجميع ماتحتوية من اشتراطات ملزمة الاتباع والتطبيق من قبل الجهات الحكومية والقطاع الخاص لجميع المشاريع الانشائية وقطاع التشييد في جمهورية العراق.**

Tutorial Problems-1 ---Due Date 07-02-2022

Q1

1. In the most general sense of the word, what is an earthquake?
2. What is a subduction zone?
3. What is an earthquake fault?
4. What are the different types of earthquake faults?
5. What is the difference between the focus and the epicenter of an earthquake?
6. What is a fault’s rupture surface?
7. What is a fault’s slip?
8. What is the estimated velocity with which a fault ruptures?

Q2

Determine the PGA for average and design values for central cities. of Iraq?