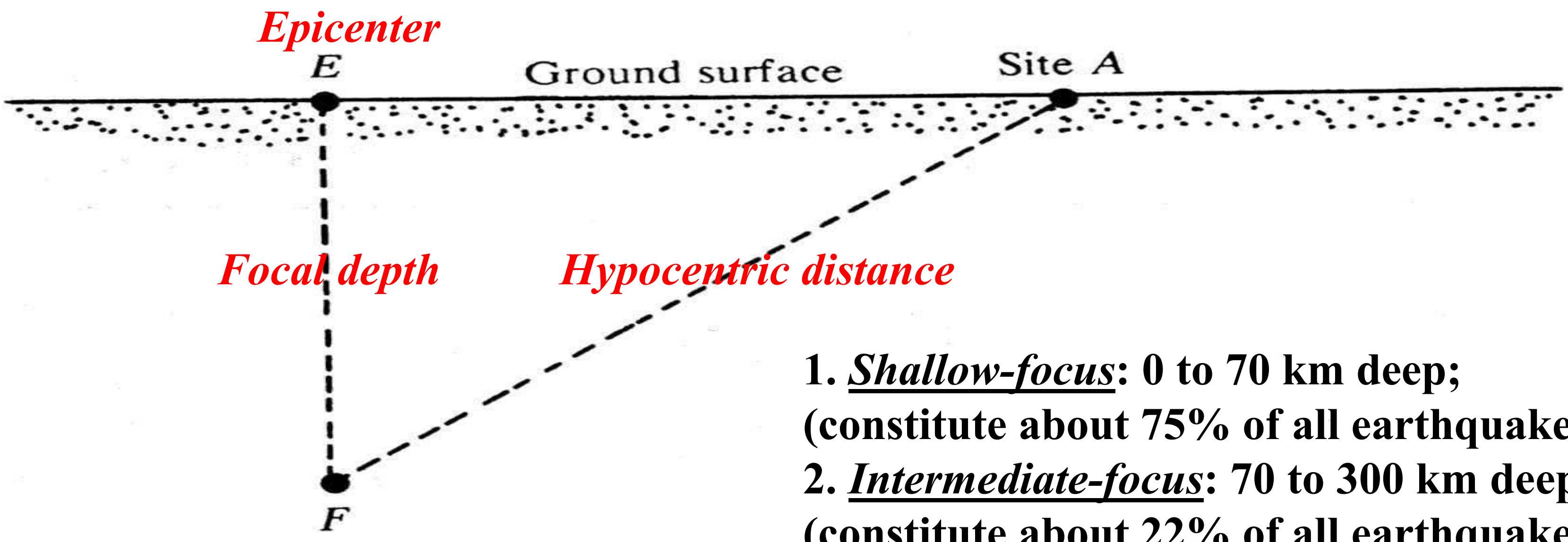
Soil Dynamics

Lecture 08

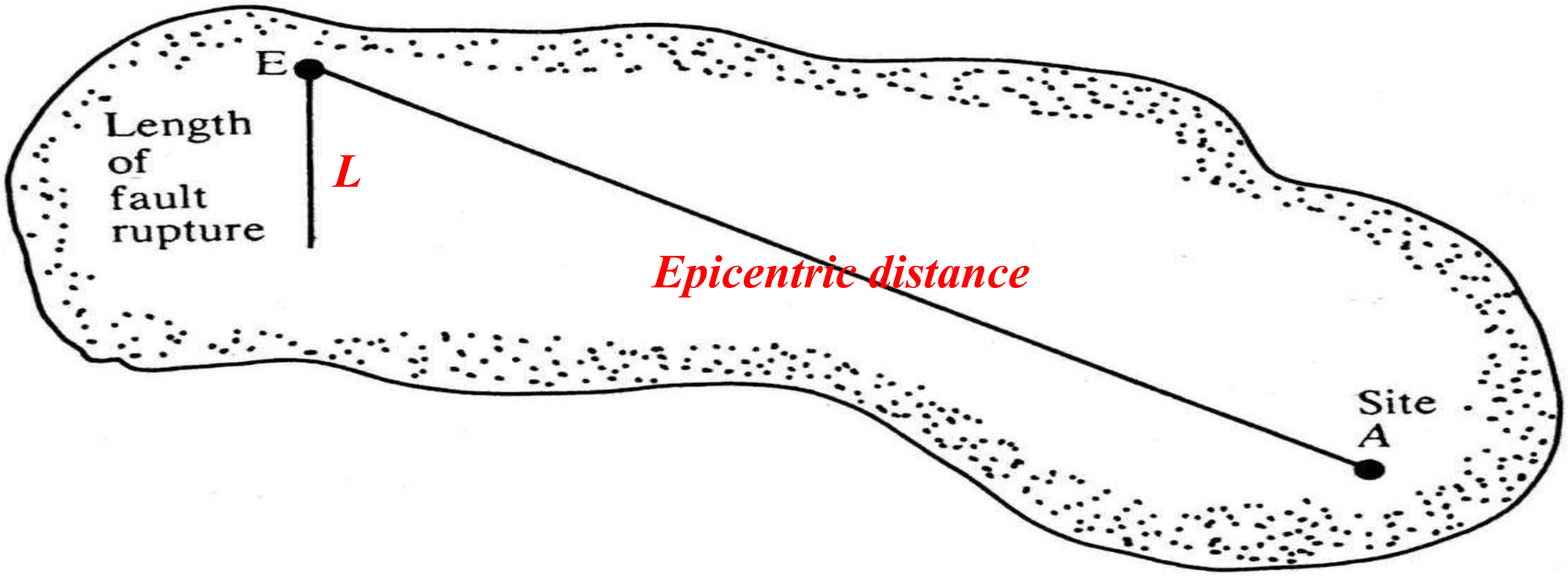
Earthquakes

Definitions.



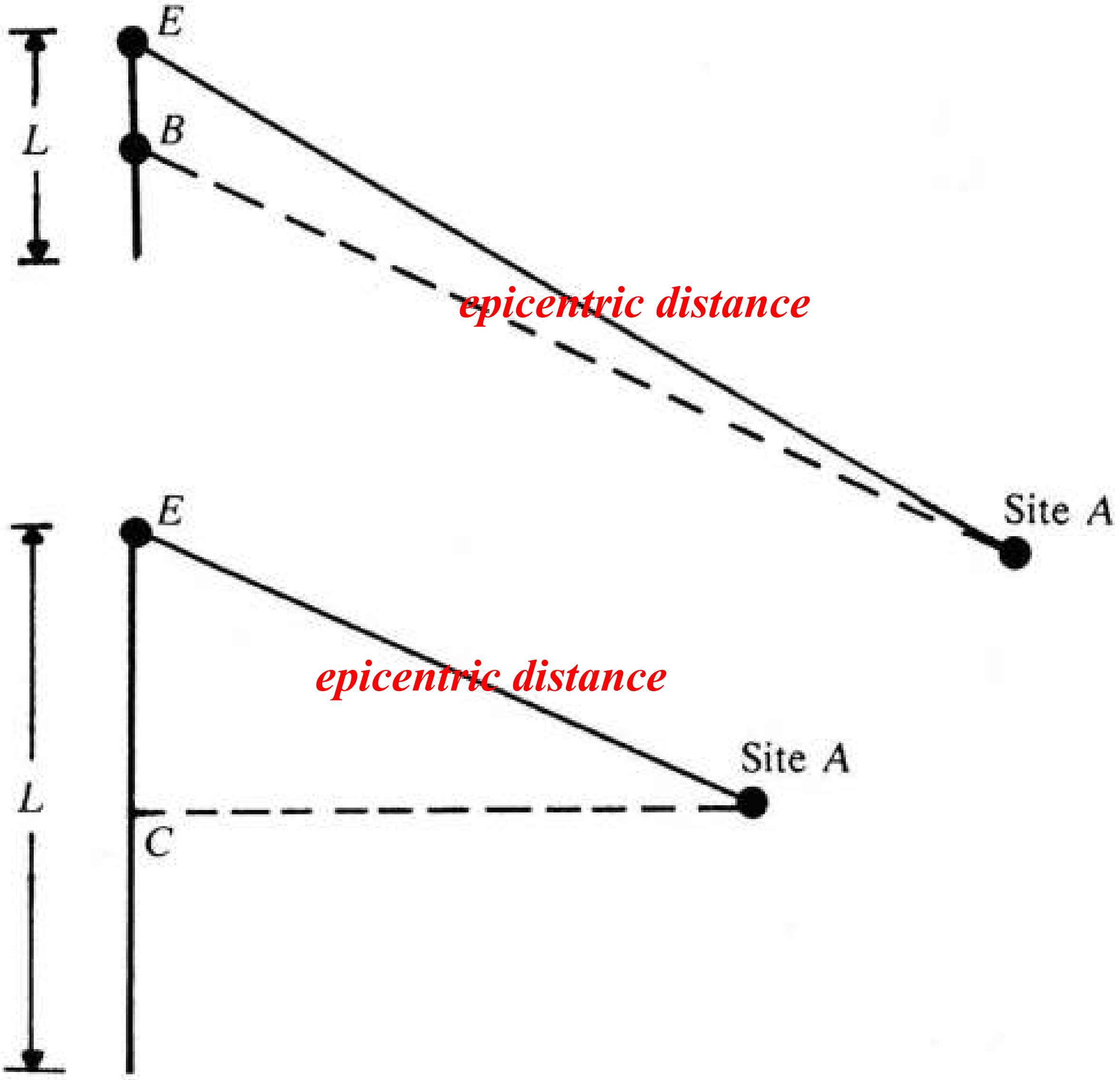
Focus *– point of rupture of a fault*

1. ***Shallow-focus*****: 0 to 70 km deep;** **(constitute about 75% of all earthquakes);**
2. ***Intermediate-focus*****: 70 to 300 km deep;** **(constitute about 22% of all earthquakes);**
3. ***Deep-focus*****: 300 to 700 km deep;** **(constitute about 3% of all earthquakes).**



The effective distance to the causative fault.

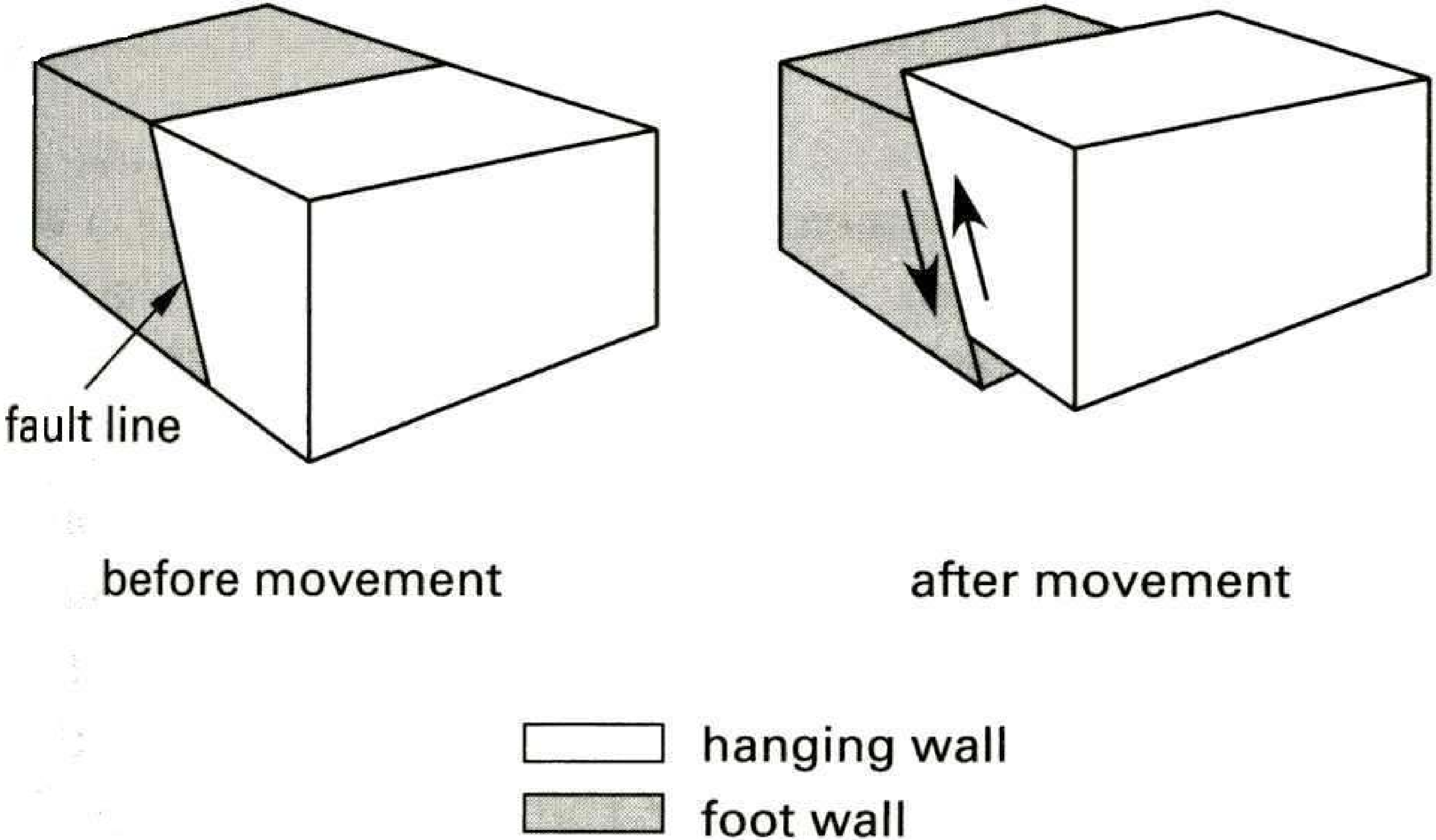
This distance is the epicentric distance should be to the midpoint of the fault length.



Length *L* of the fault rupture.

Length *L* of the fault rupture.

In the figure below, the hanging wall is thrust upward and over the footwall. This is called a *reverse thrust fault*. Other types of faults between these two blocks can be *normal*, *oblique* and *strike-slip* faults.



before movement

after movement

A sudden displacement of the crust is called a *slip*. Slips are described according to their movement. For example, when a person stands on either side of the San Andreas fault in mid-California, and looks across the fault, that fault's movement will towards that person's right. Therefore, the San Andreas fault is a *right-lateral movement*. The other three types of movements are *left-lateral*, *normal* and *reverse*.

The process where an oceanic plate slides beneath a continental plate is known as a *subduction*. This is the case for the Pacific plate that is sliding beneath the North America continental plate. The seismic activity common to the states of California, Oregon and Washington ensues from this subduction.

The seismic waves radiate out of from the focus. The *compression waves* (primary or P-waves) travel through the earth's interior to reach the surface first. These compression waves displace materials directly behind or ahead of their path of travel.

The *shear waves* (secondary or S-waves) displace material at right angles to their line of travel and reach the surface later. These shear waves have horizontal and vertical components since their propagation path may be in any direction from the source.

The S-waves travel more slowly than the P-wave, but they transmit more energy. Thus, S-waves cause the bulk of the damage to surface structures.

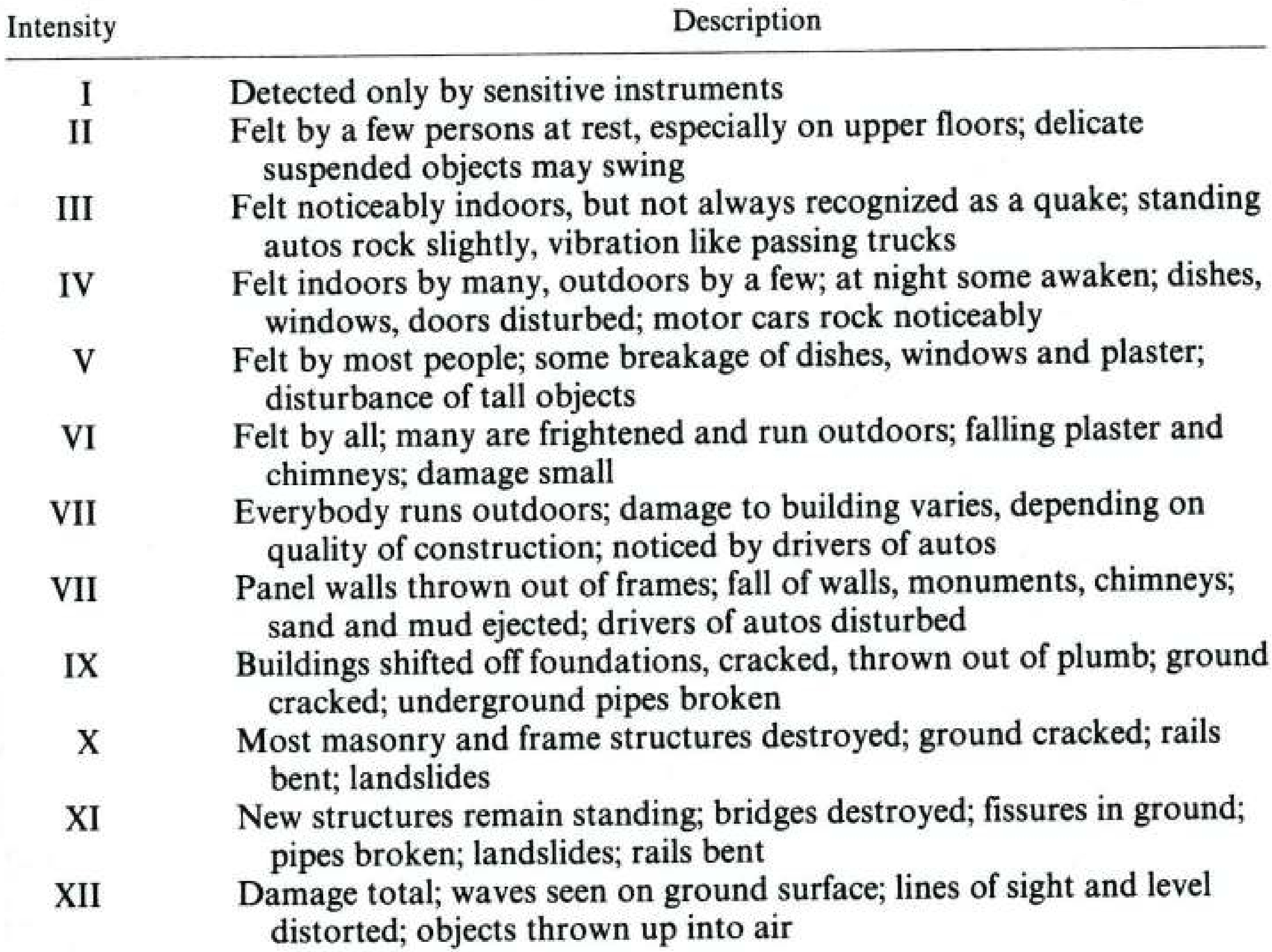
The primary cause of seismic waves (vibrations) are, (1) the sudden dislocations and changes within the earth's crust plates due to their movements against each other, (2) volcanic eruptions, and (3) deep artificially induced explosions.

During an earthquake, the sudden changes in the sea floor at depth (large rising and dropping) set a massive wave in the water in motion. As the wave approaches a land mass, the deep sea floor transitions gradually to a shallower floor. Since the wave has a constant mass, this change causes the wave height to increase. Also, its velocity decreases due to the increased friction with the shallower floor.

Sea waves are called *tsunami* (which means "sea wave" in Japanese). Other synonymous terms are *tidal wave* and *surface-water wave*.

Seismic waves are measured with a *seismometer*. The seismometer measures the actual displacement of the ground with respect to a fixed reference point. The magnitude M of the earthquake can be calculated from the logarithm of the amplitude of the displacement.

Intensity. **The *Modified Mercalli Scale* divides the intensity into an arbitrary scale of 12 levels of intensity. It is commonly used in the United States.**



Intensity	Description
I	Detected only by sensitive instruments
II	Felt by a few persons at rest, especially on upper floors; delicate suspended objects may swing
III	Felt noticeably indoors, but not always recognized as a quake; standing autos rock slightly, vibration like passing trucks
IV	Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably
V	Felt by most people; some breakage of dishes, windows and plaster; disturbance of tall objects
VI	Felt by all; many are frightened and run outdoors; falling plaster and chimneys; damage small
VII	Everybody runs outdoors; damage to building varies, depending on quality of construction; noticed by drivers of autos
VII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken
X	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides
XI	New structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent
XII	Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air

The earthquake's magnitude M.

The magnitude *M* is a measure of the *amplitude* of the elastic waves generated by an earthquake.

In 1958, C.F. Richter proposed measuring the earthquake's strength via its magnitude *M*, which is related to the length of the fault slip *L*. His formula was,

$$\log_{10} E = 11.4 + 1.5\, M$$

where *E* is the energy released by the earthquake in *ergs*.

This equation was modified by Båth in 1966 to,

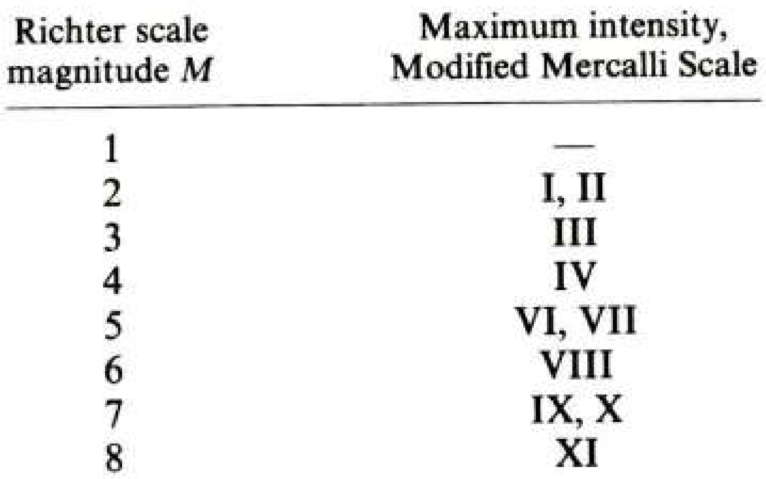
$$\log_{10} E = 12.24 + 1.44\, M$$

and again modified by Tocher (1958), Bonilla (1967) and Houser (1969) as,

$$\log L = 1.02\, M - 5.77$$

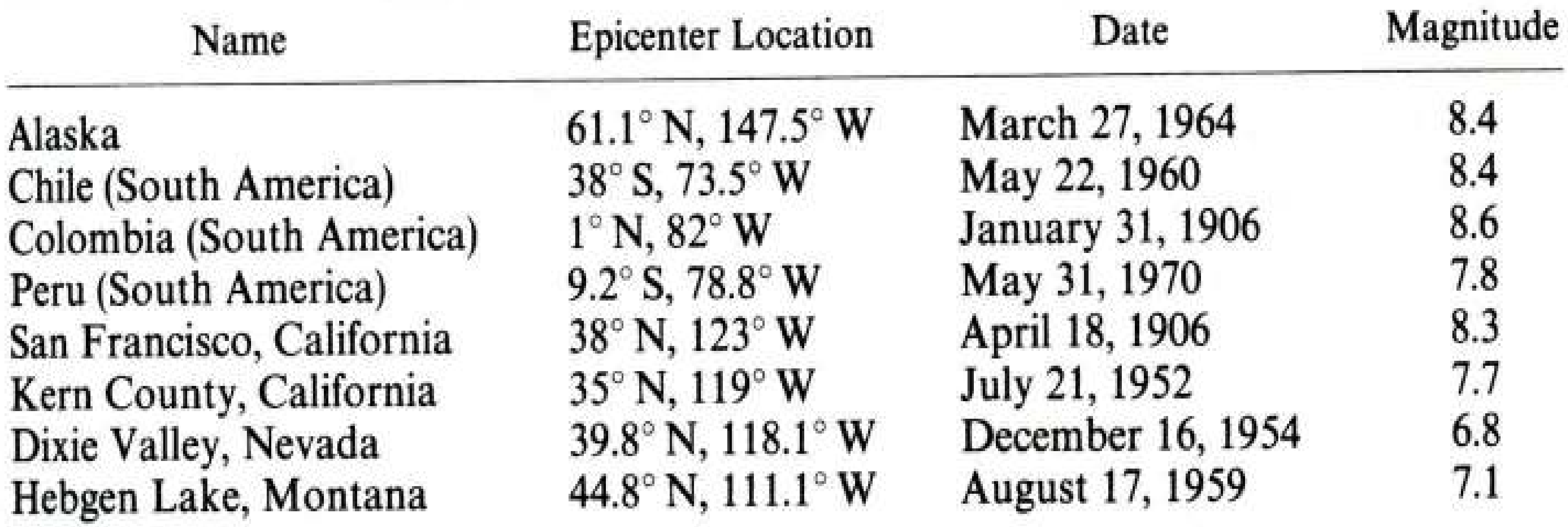
where *L* is the length of the fault's rupture in kilometers.

The comparison between the Richter magnitude scale and the Modified Mercalli intensity scale is approximately as follows,



Richter scale magnitude M	Maximum intensity, Modified Mercalli Scale
1	—
2	I, II
3	III
4	IV
5	VI, VII
6	VIII
7	IX, X
8	XI

A table of some major earthquakes is shown below,



Name	Epicenter Location	Date	Magnitude
Alaska	61.1° N, 147.5° W	March 27, 1964	8.4
Chile (South America)	38° S, 73.5° W	May 22, 1960	8.4
Colombia (South America)	1° N, 82° W	January 31, 1906	8.6
Peru (South America)	9.2° S, 78.8° W	May 31, 1970	7.8
San Francisco, California	38° N, 123° W	April 18, 1906	8.3
Kern County, California	35° N, 119° W	July 21, 1952	7.7
Dixie Valley, Nevada	39.8° N, 118.1° W	December 16, 1954	6.8
Hebgen Lake, Montana	44.8° N, 111.1° W	August 17, 1959	7.1

Example 1.

Using the Tocher equation, calculate the length of the fault rupture for an earthquake of magnitudes 6, 7 and 8.

$$\textbf{\textit{For a magnitude}}\ M = 6,$$

$$log_{10} L = 1.02M - 5.77 = 1.02(6) - 5.77 = 0.35$$

$$\therefore \quad \underline{L = 2.24\ \textit{kilometers}}$$

$$\textbf{\textit{For a magnitude}}\ M = 7,$$

$$log_{10} L = 1.02M - 5.77 = 1.02(7) - 5.77 = 1.37$$

$$\therefore \quad \underline{L = 23.4\ \textit{kilometers}}$$

$$\textbf{\textit{For a magnitude}}\ M = 8,$$

$$log_{10} L = 1.02M - 5.77 = 1.02(8) - 5.77 = 2.39$$

$$\therefore \quad \underline{L = 245\ \textit{kilometers}}$$

Note that each unit increase in magnitude corresponds to an increase of one order of magnitude.

The amount of energy in a seismic wave decreases when it propagates through rock, and this decrease is called *attenuation*.

Since attenuation is a decrease in the seismic energy, the factors that influence it are,

(1) the path line,
(2) the path length,
(3) the nature of the intervening geologic formations,
(4) the focal depth, and
(5) the location of the epicenter.

The magnitude of an earthquake does not decrease the amount of energy.

The motion of rocks during an earthquake.

The effects of an earthquake upon the surface are due primarily to the upward propagation of *shear waves* through the underlying soft rocks. The P-wave produces vertical motion, but the S-wave is the one that produces the large two horizontal components of the surface motions.

The typical shear wave velocity in a hard rock such as granite is about 10,000 to 12,000 ft/s. In contrast, the velocity in a soft rock such as sandstone can be as low as 2,000 ft/s.

The nature of the surface ground motions were studied by Seed, Idriss and Kiefer in 1969 and they proposed that three factors need to be understood:

- **the (a) *duration* of the earthquake,**

- **the (b) *predominant period of the acceleration*, and**

- **the (c) *maximum amplitude* of the motion.**

A. The duration of the earthquake.

The duration is almost identical to the time taken by the fault to rupture. The *rate of propagation* of a fault rupture has been reported by Housner in 1965 to be approximately 3.2 km/s. For a given magnitude, the duration can be found from the Tocher equation that finds *L*.

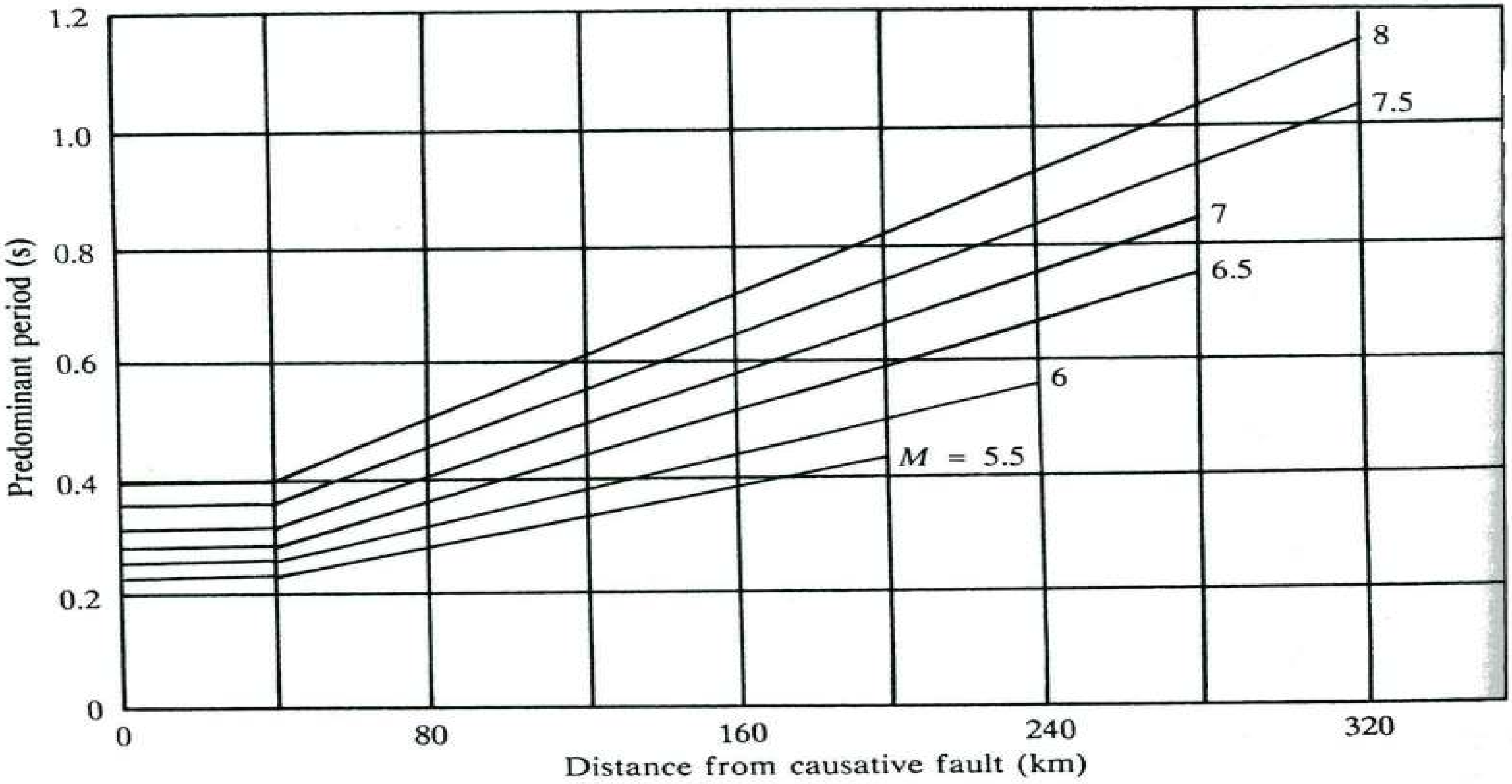
Example 2.

If the epicentric distance from an earthquake of magnitude 7 is 88 km, what is the probable duration of the event?

$$duration = \frac{distance}{rate\ of\ \ propagation\ of\ \ the\ \ fault\ rupture} = \frac{88\ km}{3.2\ km/s} = \underline{27.5\ seconds}$$

B. The predominant period of rock acceleration.

Seed, Idriss and Kiefer prepared in 1969 the graph shown below for the predominant period for maximum rock acceleration. The distance plotted below is approximately the epicentric distance when the fault length is small. When the fault length is large, the perpendicular distance to the fault line must be used.



The period of the earthquake refers to the predominant period of the seismic wave. It is determined by a Fourier analysis of its wave.

Both the site (local geology and surficial soils) and the building have their own fundamental or natural periods. Therefore, these three periods are all different.

The site period is determined from geotechnical data. The building's period is determined from the analysis of the structure.

The structural damage due to an earthquake depends on (1) the ground acceleration, (2) the duration of the motion, (3) the frequency content, (4) local soil conditions, (5) the period of the site, (6) the distance between the focus and the structure, (7) the intervening geological formations, and (8) the natural frequency of the structure and its damping.

Resonance results in an amplification of the response. It occurs when the earthquake, the site and the building's periods coincide with each other. An example of resonance occurred during the 1985 Mexico City earthquake. The focus was 365 km from the city, but although the acceleration amplitude was small, its period matched that of the city's underlying lake beds. In addition, some of the buildings had natural periods similar to the seismic wave and local soils. The consequence was a major magnification of the response, and major collapses of many buildings.

Example 3.

What effect would placing permanent and heavy air-conditioning equipment on the top floor of a building? How does this affect the fundamental period of the building?

Since,

$$T = 2\pi\sqrt{\frac{m}{k}}$$

the stiffness of the building *k* will not be affected by the installation of the heavy air-conditioning equipment. However, the mass *m* does increase, which in turn increases the fundamental period *T* of the building.

Example 4.

For the magnitudes 6, 7 and 8 earthquake discussed in *Examples 1* and *2*, what are their predominant periods for the maximum rock accelerations?

Using the plot on slide #10, and the distance of 88 km from the causative fault,

- **For the magnitude 6 earthquake, the predominant period is 0.35 seconds;**

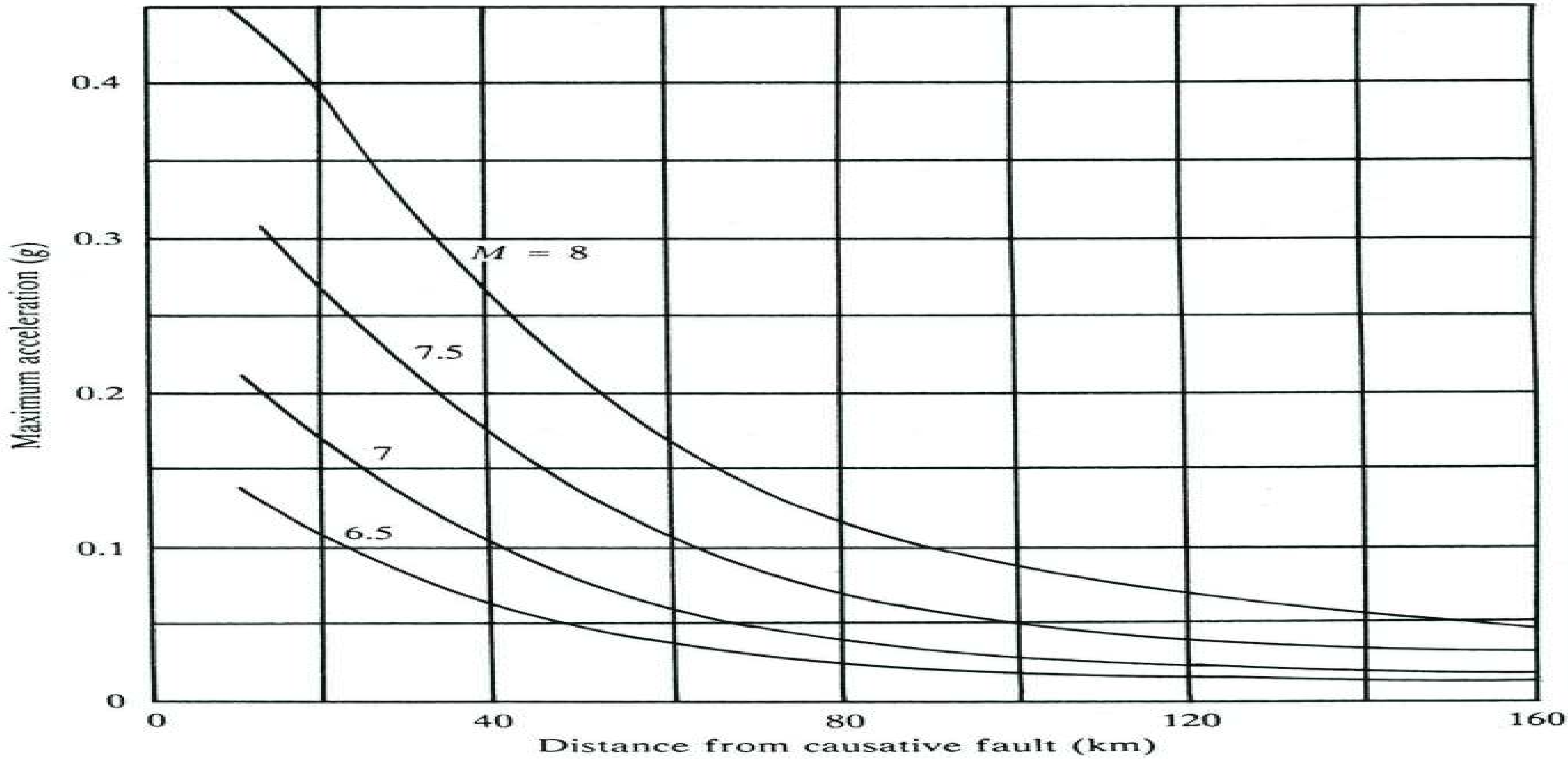
- **For the magnitude 7 earthquake, the predominant period is 0.43 seconds;**

- **For the magnitude 8 earthquake, the predominant period is 0.52 seconds;**

C. The maximum amplitude of the acceleration. **Gutenberg and Richter proposed in 1956 a formula for the maximum amplitude of the acceleration a_0 in the rock in the epicenter region for *shallow* earthquakes, which have focal depths of less than 16 km,**

$$\log a_0 = -2.1 + 0.81\, M - 0.027\, M^2$$

When the earthquake is not shallow, the maximum amplitude decreases rapidly as shown below,



The magnitude *M* of an earthquake has no correlation with either the acceleration or duration.

For example, the 1989 Loma Prieta earthquake in the San Francisco area had a magnitude of 7.1 and registered a peak ground acceleration of 0.65g.

The 1994 Northridge earthquake in the Los Angeles area had a magnitude of 6.7 and a peak ground acceleration of 1.80g.

The 1971 San Fernando earthquake had a magnitude of 6.6 and lasted only 7 sec.

The 1940 El Centro earthquake had a magnitude of 6.4 and lasted 16 seconds.

The frequency of a seismic wave, its duration and the ground acceleration all affect the amount of structural damage.

The effects of an earthquake upon the soil’s structural performance.

Liquefation **is one of the consequences of seismic waves traveling through saturated loose granular surface soils. Liquefaction is the sudden and dramatic reduction of the shear strength of the soil, a large increase in its pore water pressure, a complete loss of the bearing capacity and a decrease in the effective stress of the soil.**

Earthquakes can trigger the rapid consolidation of soft clays. The loss of the grain-to-grain contact and the excess pore water pressure leads to a complete loss of the soil strength.

The soft clay strata tend to increase the amplitude of the earthquake motions, much more than granular sites.

Earthquakes in California with magnitudes between 8.0 to 8.5 are associated with ground accelerations of about 0.50g.

The maximum vibration of a single-degree-of-freedom system is measured in terms of acceleration, velocity or displacement. The maximum velocity of a structure relative to the ground is known as the *spectral velocity*.

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