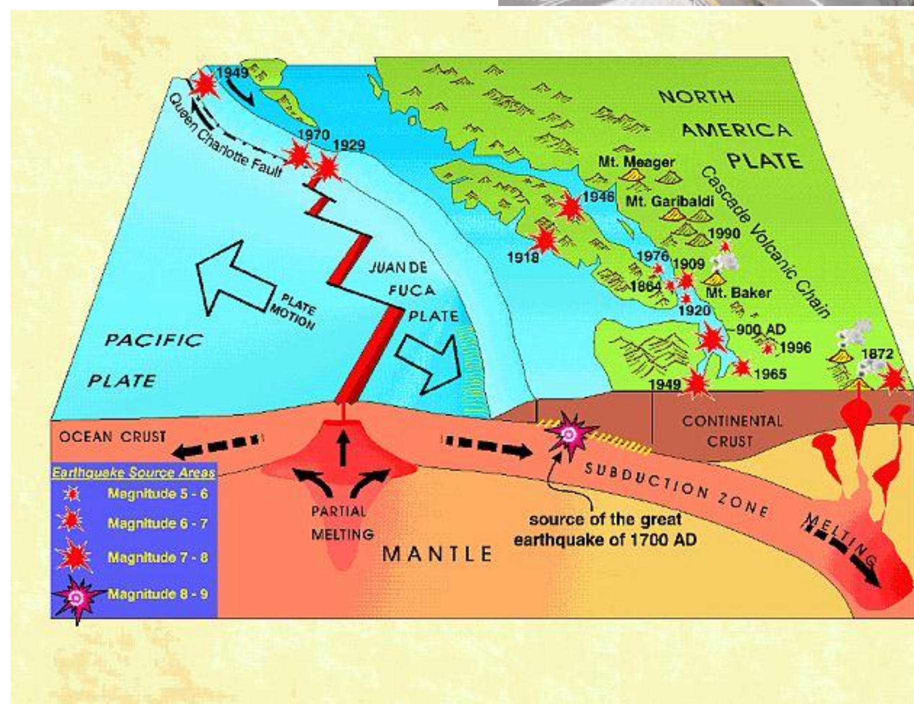
EARTHQUAKES-Causes and Effects

- Earthquakes may result from a number of natural and human induced phenomena, including meteoric impact, volcanic activity , underground nuclear explosion, and stress changes introduced by the filling of large human-made reservoirs.
- However, the vast majority of damaging earthquakes originate at, or adjacent to, the boundaries of crustal tectonic plates, due to relative deformation at the boundaries.



EARTHQUAKES-Causes and Effects

- Because of the nature of the rough interface between adjacent plates, at stick –slip phenomenon generally occur, rather than smooth continuous relatives deformation, or creep.
- The relative deformation at adjacent plates is resisted at the rough interface by the friction, inducing shear stress in the plates adjacent to the boundary.

EARTHQUAKES-Causes and Effects

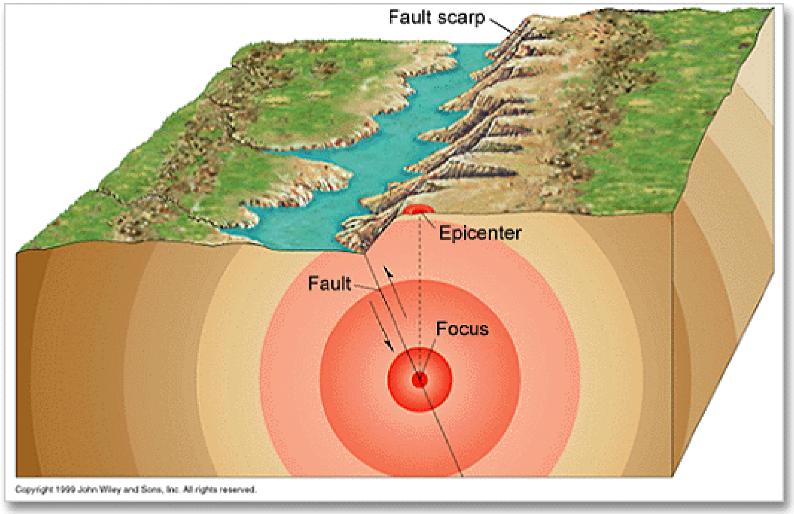
- Recent Earthquakes movies

- Nepal Earthquake movie-1

- Why do Buildings fall in Earthquakes.

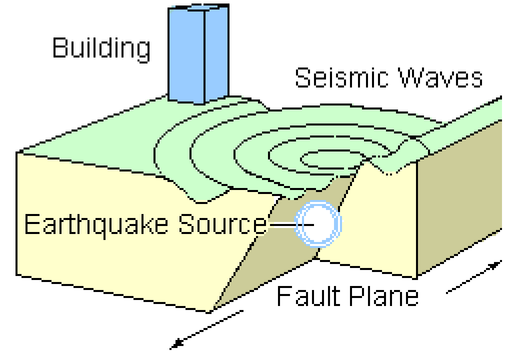
EARTHQUAKES-Causes and Effects

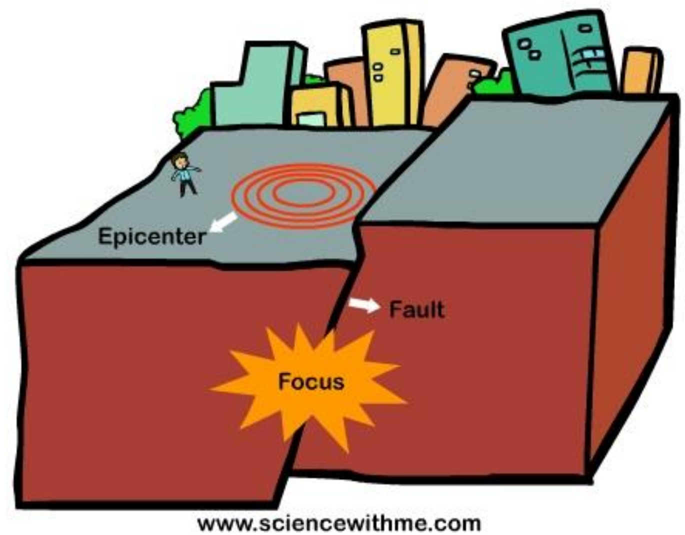
- When the induced stress exceed the frictional capacity of the interface, or the inherent material strength, slip occurs, releasing the elastic energy stored in the rock primarily in the from of shock waves propagating through the medium at the ground-wave velocity.
- Relative deformations in the vicinity of the plate boundaries may reach several meters before faulting occurs, resulting in substantial physical expressions of the earthquake activity at the ground surface in the form of fault traces with considerable horizontal or vertical offsets.



EARTHQUAKES-Causes and Effects

- Clearly , structures built on built on a foundation within which faulting occurs can be subjected to extreme physical distress.
- However, it has been noted that buildings constructed on strong integral foundations structures, such as rafts and footings interconnected by basement walls, cause the fault trace to deviate around the boundaries rather than through a strong foundation.



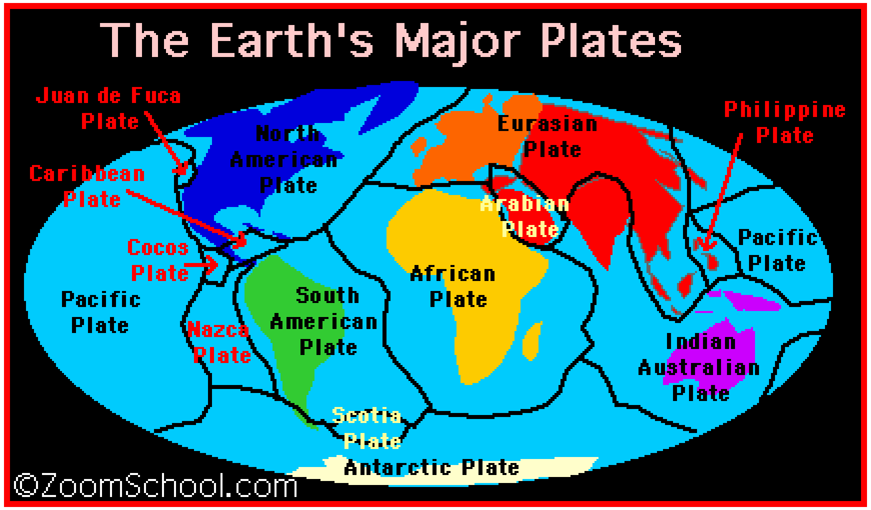


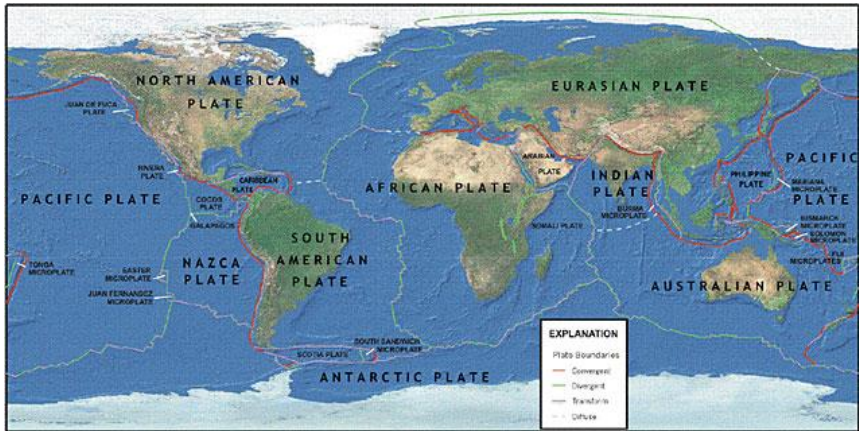
EARTHQUAKES-Causes and Effects

- The structural dislocation caused by relative ground movement at a fault trace is potentially more serious for bridges or for low-rise buildings of considerable length where the footing of adjacent support may be unconnected.
- Although physical ground dislocation is the most immediately apparent structural threat, it affects only a very restricted surface area and hence does not generally constitute significant seismic risk.

EARTHQUAKES-Causes and Effects

- of much greater significance is the inertial response of structures to the grounds accelerations resulting from the energy released during fault slips, and it is this aspect that is of primary interest to the structural designer.
- Typically, the boundaries between plates do not consist of single fault surfaces. Frequently, the relative movement is spread between a number of essentially parallel faults transverse to the plate boundaries.





EARTHQUAKES-Causes and Effects

TECTONIC PLATES MOVEMENT HISTORY

225 million years ago

150 million years ago

100 million years ago

Earth today

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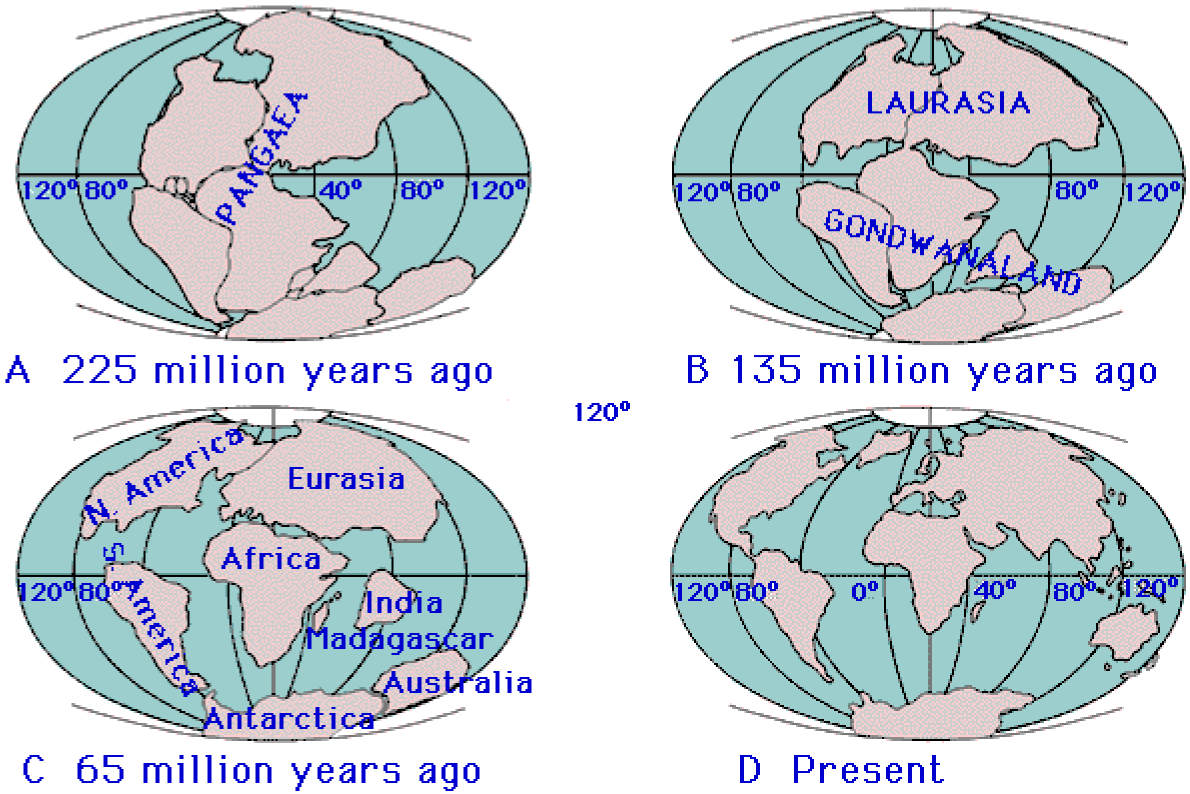
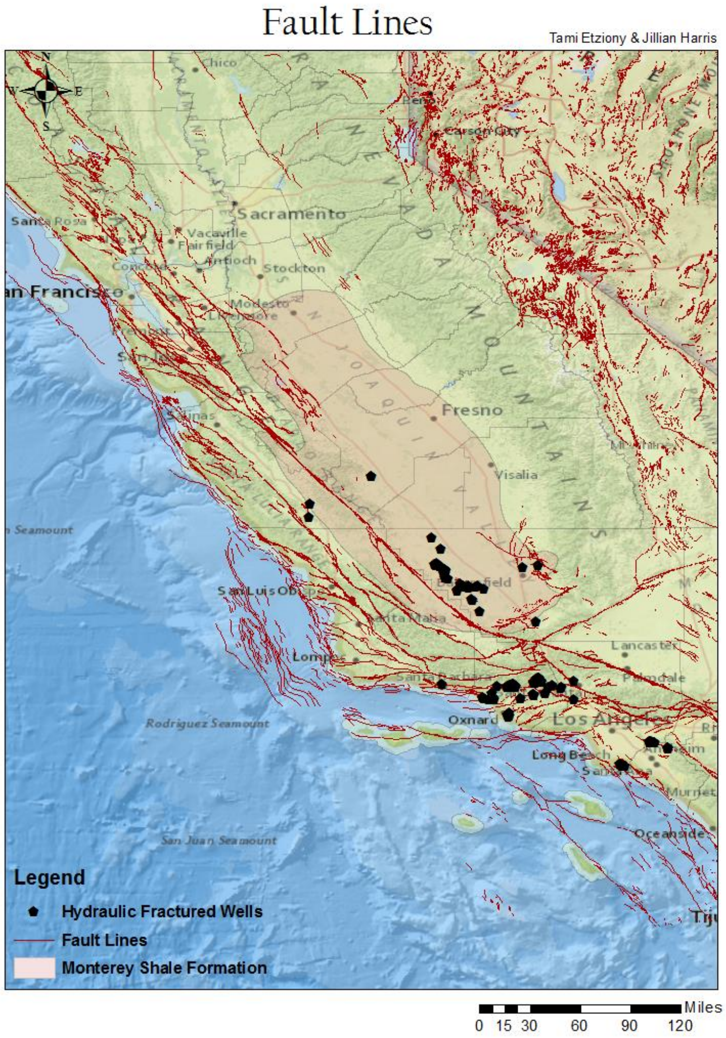
EARTHQUAKES-Causes and Effects

TECTONIC PLATES MOVEMENT HISTORY



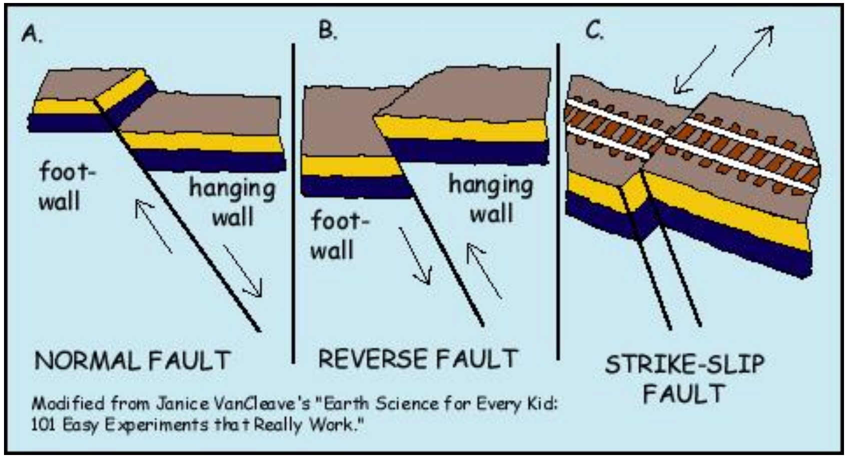
EARTHQUAKES-Causes and Effects

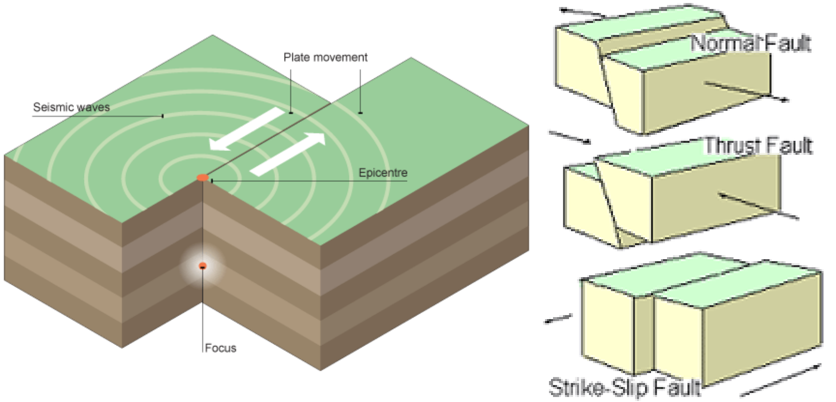
- Figure shows a distribution of the known faults lines capable of generating significant earthquakes in southern California.



EARTHQUAKES-Causes and Effects

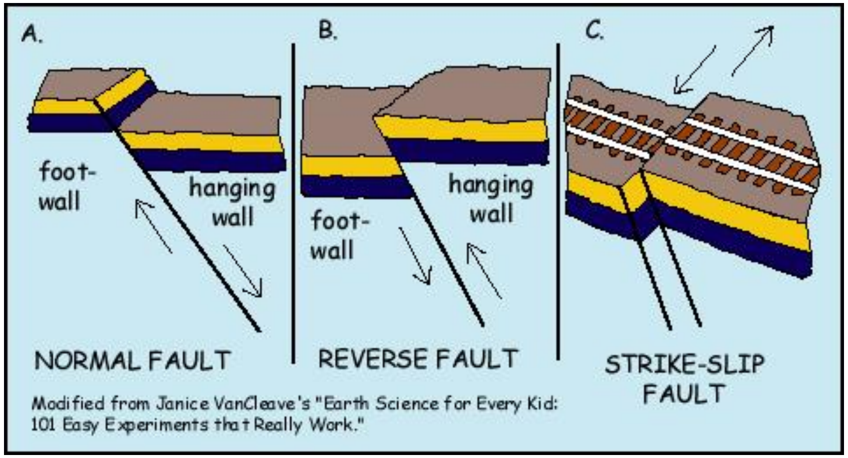
- Figure describes the basic categories of fault movement.
- Strike slip faults fig 2.2 (a) display primarily lateral movement, with the direction of movement identified as left-slip or right slip, depending on the direction of the movement of one side of the fault as viewed from the other side.
- Note that direction of movement is independent of which side is chosen as the reference.

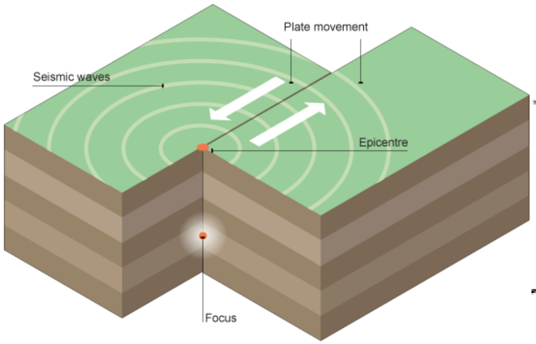


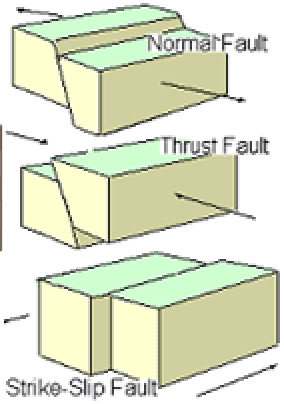


EARTHQUAKES-Causes and Effects

- Normal slip fault display movement normal to fault, but no lateral displacement.
- The movement is associated with extension of distance between of opposite sides of the fault, and the term tension fault is sometimes used to characterize this type of movement.
- Reserve-slip faults also involve normal movement, but compression between points on opposite sides of the faults.
- These are sometimes termed thrust or subduction faults.

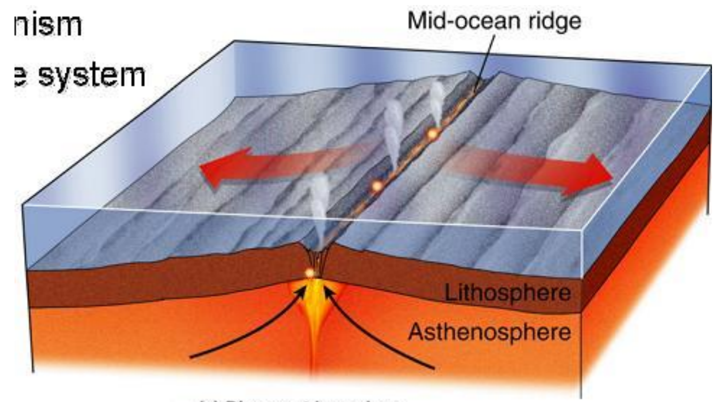






EARTHQUAKES-Causes and Effects

- Generally, movement is a combination of strike and normal components, involving oblique movement , resulting in compound names.
- Rates of average displacement along faults can vary from a few millimeters a year to a maximum of about 100mm / year (4 in / year).
- The magnitude of dislocation caused by an earthquake may be from less than 100mm (4in). Up to the several meters, with 10m (33ft) being an approximate upper bound.



(a) Divergent boundary
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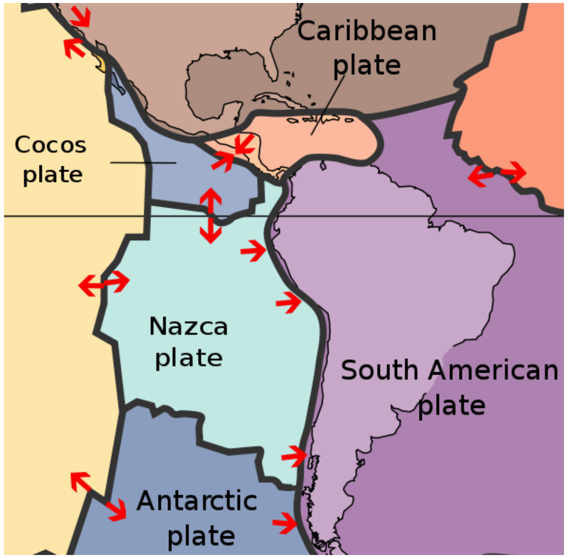
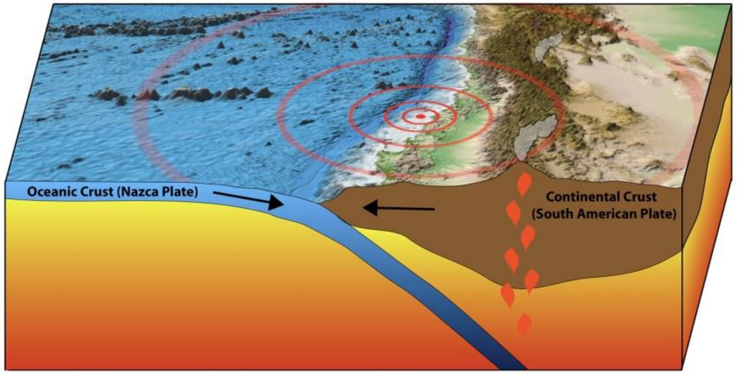
EARTHQUAKES-Causes and Effects

- In some region of plate boundaries, subduction, occurs , generally at an angel acute, to the ground surface, as in the case with the Chilean earthquakes, where the Nazea plate is sub ducting under the South American Plate, as shown in Fig. 2.3.
- Sub ducting plate boundaries are thought to be capable of generating larger earthquakes than plate boundaries with essentially lateral deformation, and appear to subject larger surface areas to strong ground motion.





EARTHQUAKES-Causes and Effects

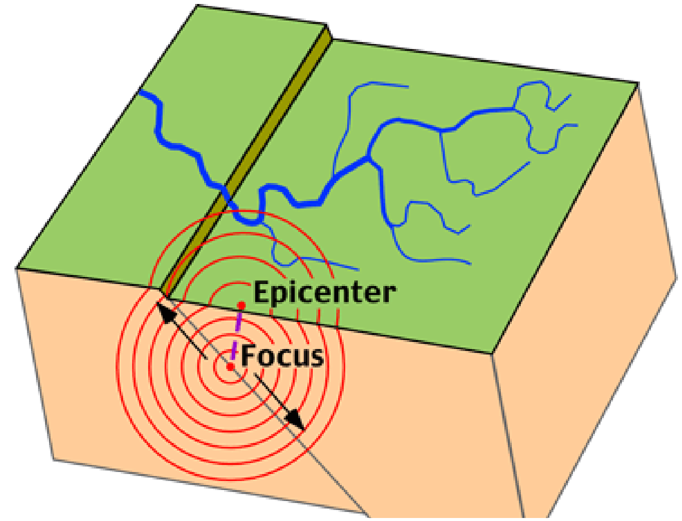
- Conversely, normal slip, movement are thought to generate less intense shaking because the tensile force components across the fault implies lower stress drop associated wit fracture.
- Despite the clear preponderance of earthquakes associated with the plate boundaries, earthquakes, can occur, within plates, at considerable distance from boundaries with devastating effect.
- The largest earthquake in the contiguous 48 meters of the United State in recorded history did not occur in California but in new Mardid, Illinois, in 1811.

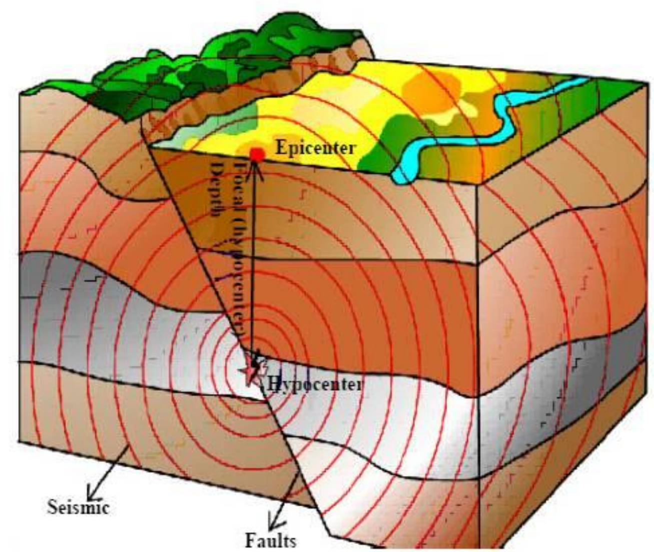
EARTHQUAKES-Causes and Effects

- Frequently the lack of recent earthquakes activity in an area results in a false sense of security and a tendency to ignore seismic effects in building design.
- Although the annual risk of significant earthquake activity may be low in intra-plate regions, the consequences can be disastrous, and should be assessed, particularly for important or hazardous structures.

EARTHQUAKES-Seismic Waves

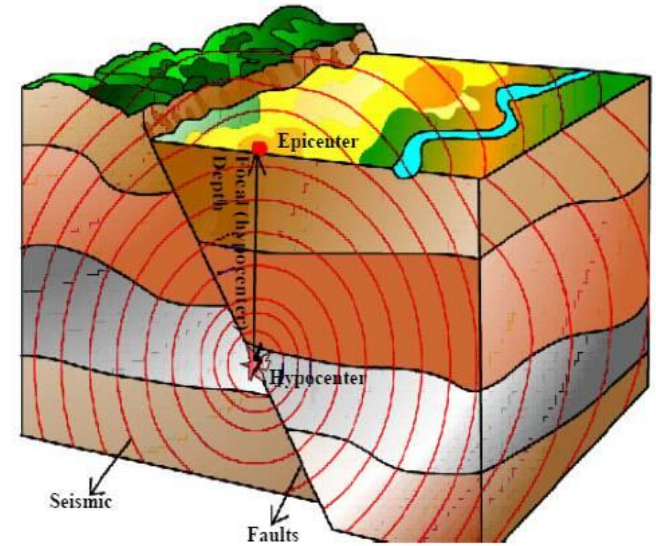
- The rupture point within the earth's crust represents the source of emission of energy. It is known as the hypocenter, focus, or source.
- For a small earthquake, it is reasonable to consider the hypocenter as a point source, but for very large earthquakes, where rupture may occur over hundreds or even thousands of square kilometers of fault surface, a point surface does not adequately represent the rupture zone.





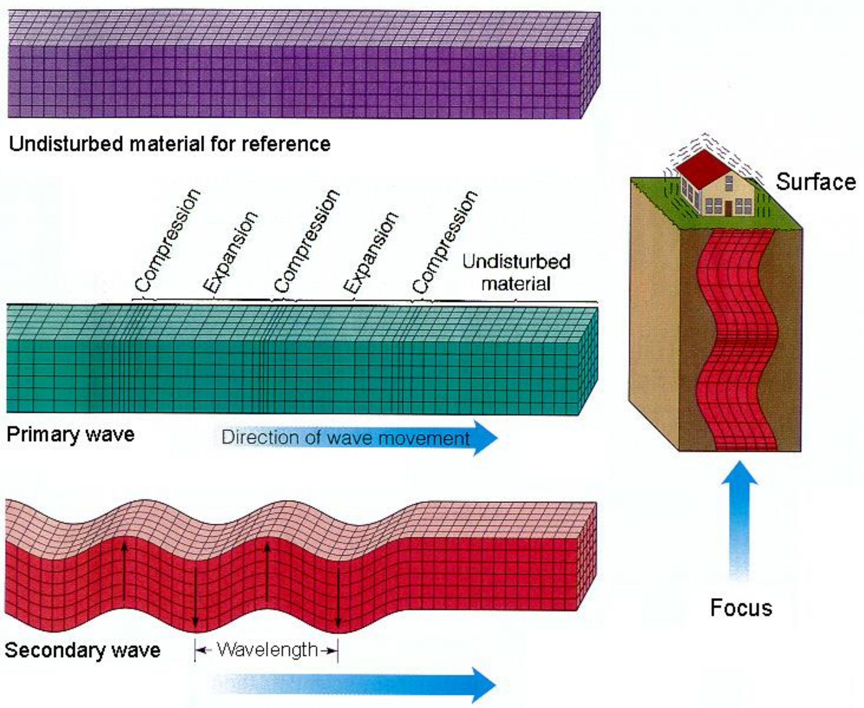
EARTHQUAKES-Seismic Waves

- In such cases the hypocenter is generally taken as that point where rupture first initiated, since the rupture requires a finite time to spread over the entire fracture surface.
- The epicenter is the point on the earth's surface immediately above the hypocenter, and the focal depth is the depth of the hypocenter below the epicenter. Focal distance is the distance from the hypocenter to a given reference point.



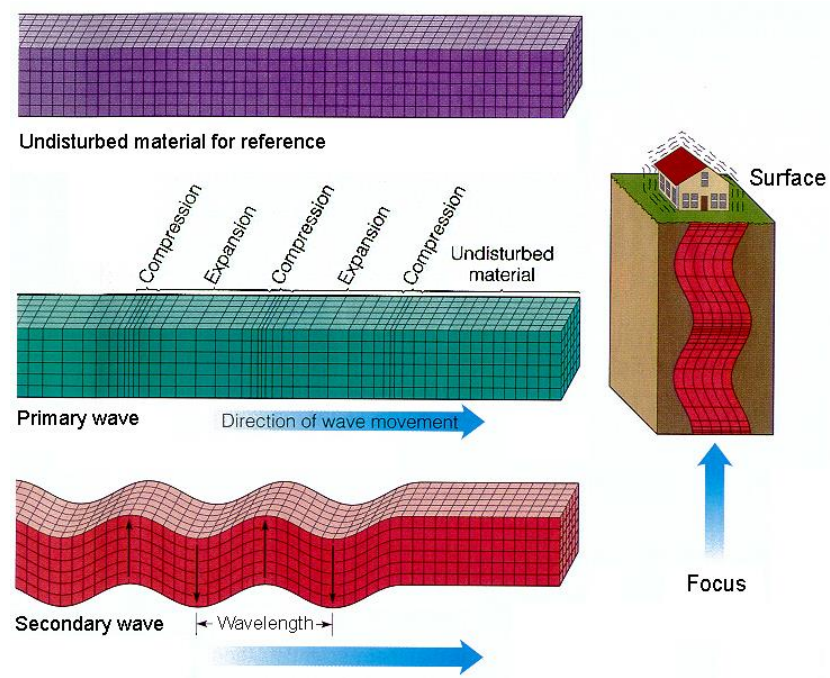
EARTHQUAKES-Seismic Waves

- The energy released by earthquakes is propagated by different types of waves.
- Body waves, originating at the rupture zone, include P waves (primary or dilatation waves), which involve particle movement parallel to the direction of propagation of the wave.



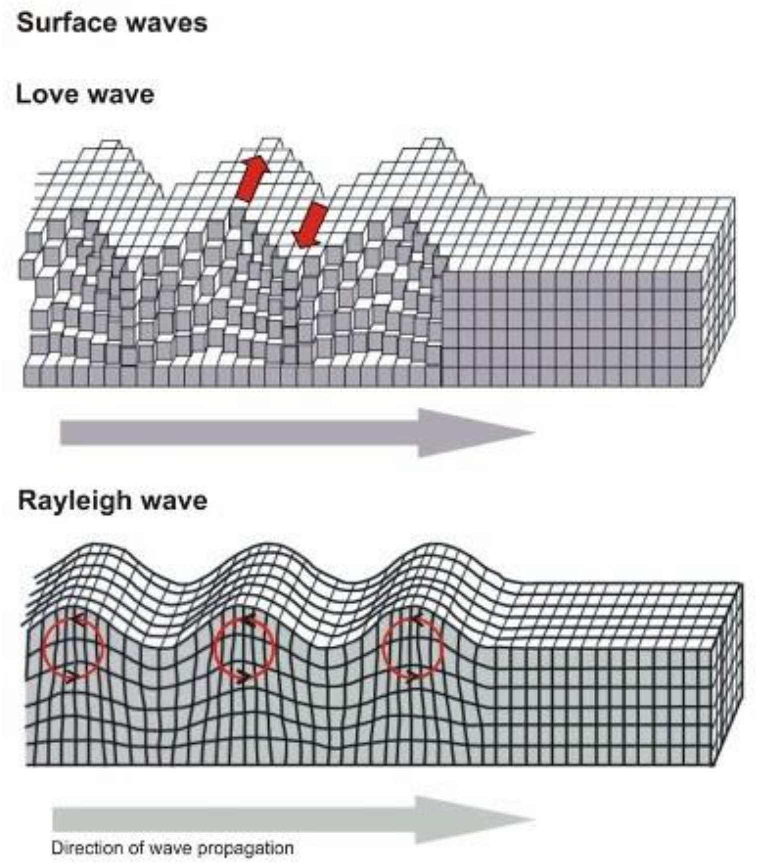
EARTHQUAKES-Seismic Waves

- S waves (secondary or shear waves), which involve particle movement perpendicular to the direction of propagation.
- When body waves reach the ground surface they are reflected but also generate surface waves which include Rayleigh and Love waves (R and L waves).



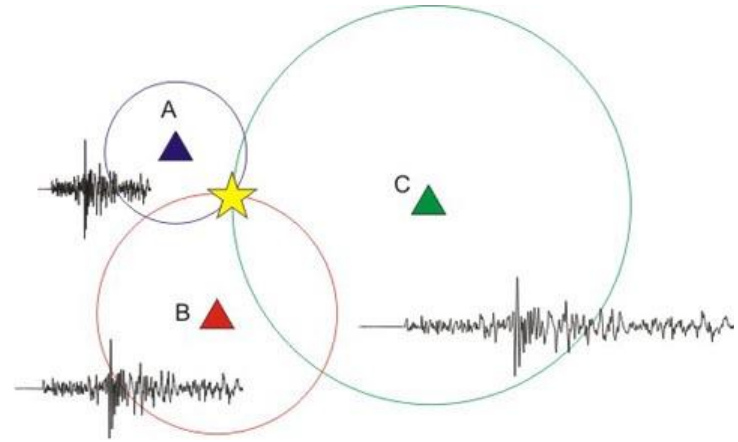
EARTHQUAKES-Seismic Waves

- Love waves produce horizontal motion transverse to the direction of propagation.
- Rayleigh waves produce a circular motion analogous to the motion of ocean waves. In both cases the amplitude of these waves reduces with depth from the surface.
- P and S waves have different characteristic velocities vp, and vs. For an elastic medium these velocities are frequency independent and in the ratio of vp/vs= $\sqrt{3}$.



EARTHQUAKES-Seismic Waves

- Recordings of the P-S time interval at three or more non-collinear sites thus enables the epi-central position to be estimated. Generally, sites at substantial distance are chosen so the epi-central and hypo-central distances are essentially identical.
- As distance from the epicenter increases, the duration of shaking at a given site increases and becomes more complex. This is because of the increase in time between the arrival of P and S waves, and also due to scattering effects resulting from reflection of P and S waves from the surface.

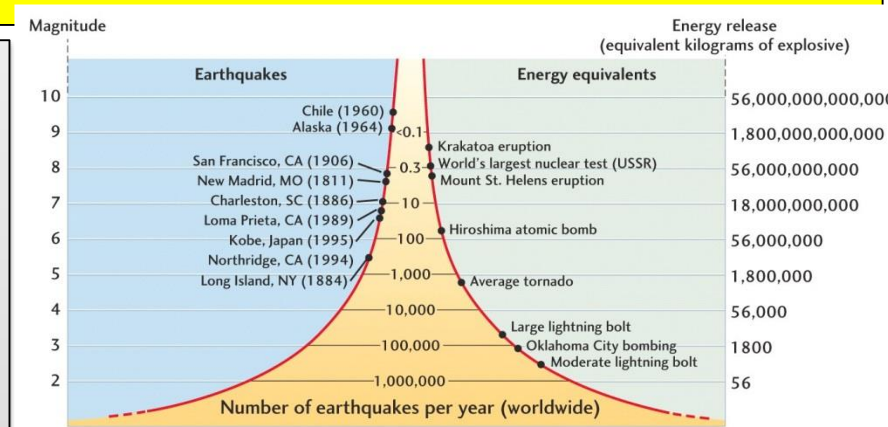


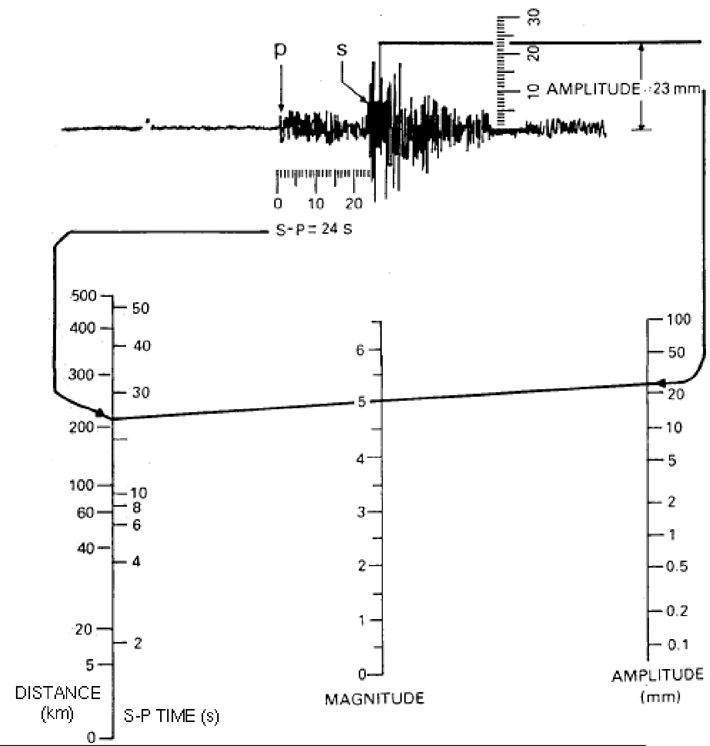
EARTHQUAKES-Magnitue and Intensity

- Earthquake magnitude is a measure of the energy released during the earthquake and hence defines the size of the seismic event.

- Intensity is a subject assessment of the effect of the earthquake at a given location and is not directly related to magnitude.

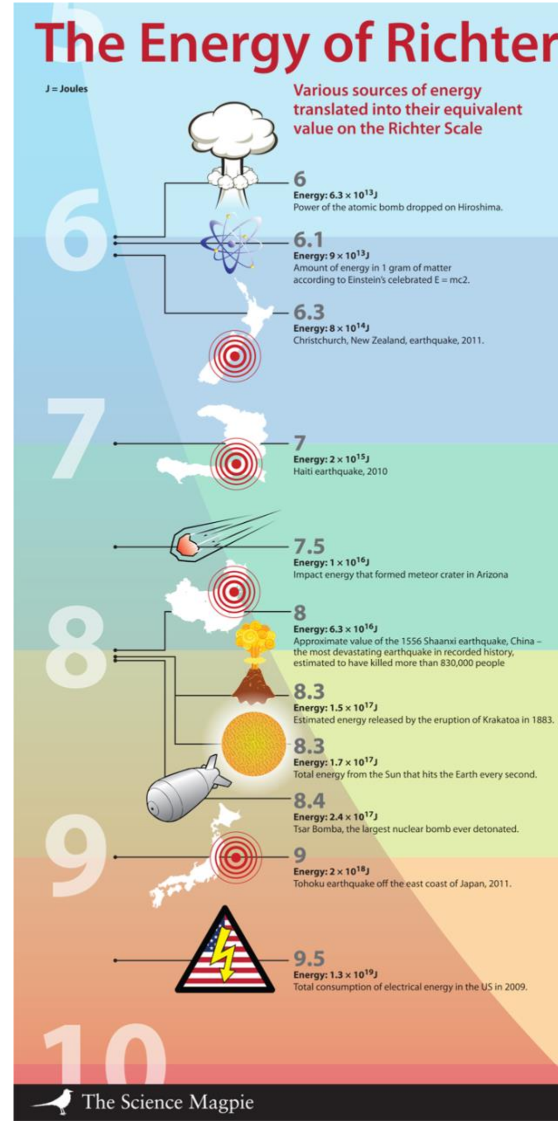
- The accepted measure of magnitude is the Richter scale. The magnitude is related to the maximum trace deformation of the surface-wave portion of seismograms recorded by a standard Wood- Anderson seismograph at a distance of 100 km from the epicenter.



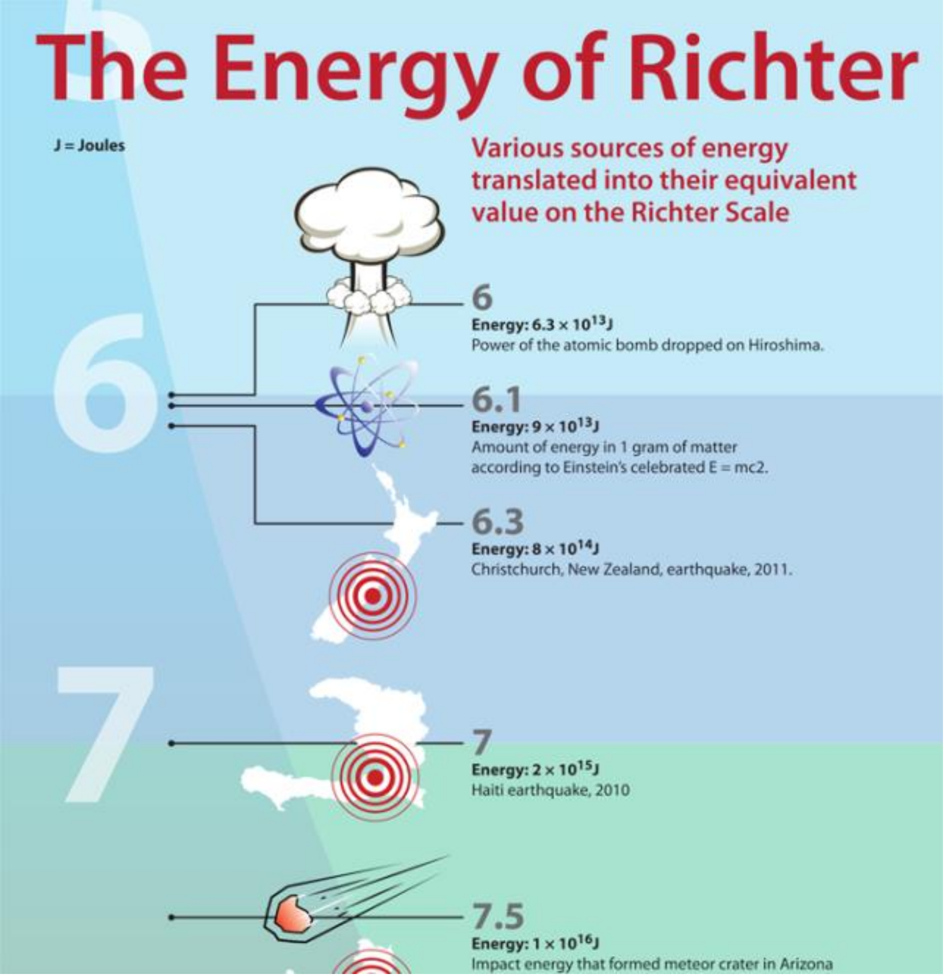


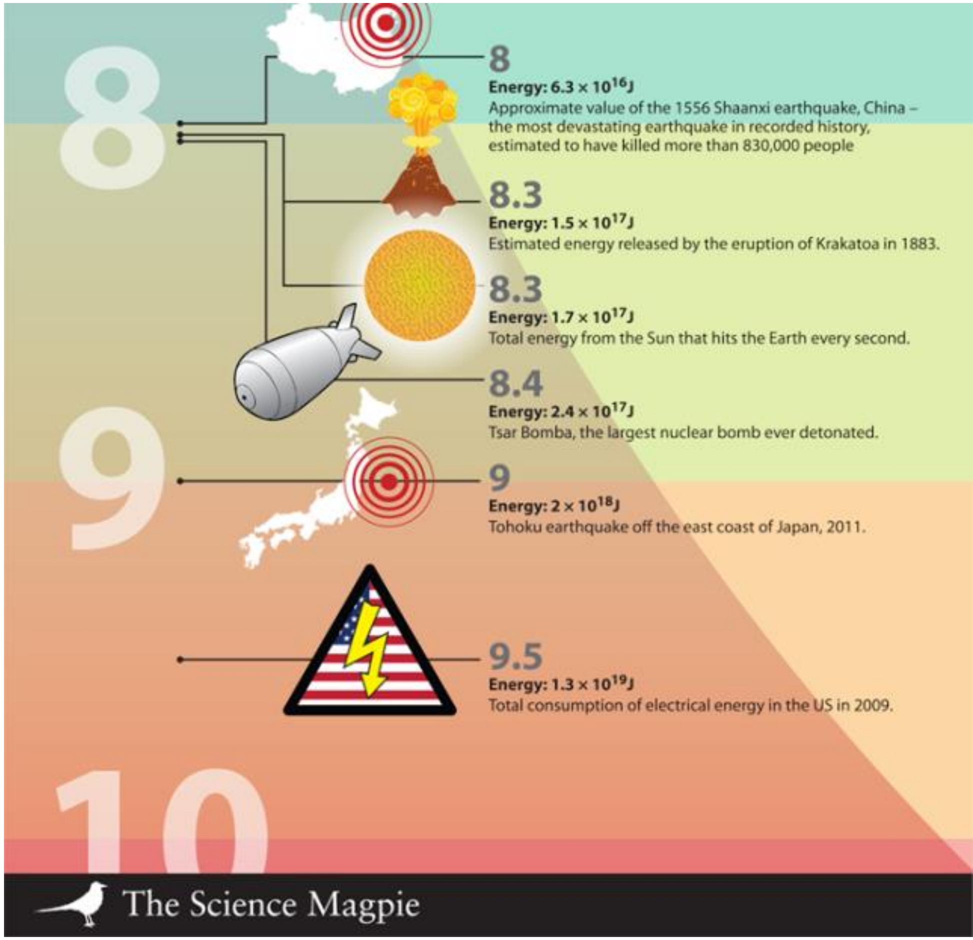
EARTHQUAKES-Magnitue and Intensity

- As such, it can be sensitive to the focal depth of the earthquake, and magnitudes computed from the body wave portions of seismograms are often used to refine estimates of the magnitude. However, the result is generally converted back to equivalent Richter magnitude for reporting purposes.
- The accepted relationship between energy released, E, and Richter magnitude, M, is
- $\log E = 11.4 + 1.5M$
- where E is in ergs.



EARTHQUAKES-Magnitue and Intensity





EARTHQUAKES-Magnitue and Intensity

- Earthquakes of Richter magnitude less than 5 rarely cause significant structural damage, particularly when deep seated.
- Earthquakes in the M5 to M6 range can cause damage close to the epicenter. A recent example is the 1986, magnitude M5.4, San Salvador earthquake, which was located at a depth of 7 km below the city and caused damage estimated at U.S. $1.5 billion. The surface area subjected to strong ground shaking was approximately 100 km and corresponded closely to the city limits.
- In the M6 to M7 range, the area of potential damage is considerably larger. The 1971 San Fernando earthquake (M 6.4) caused structural damage over an area of approximately 2000 kms.

EARTHQUAKES-Magnitue and Intensity

- In the large M7 to M8 range, structural damage may occur over an area up to 10,000 kms. Recent examples are the Tangshan earthquake (China, 1976, M 7+), which destroyed the city and left more than 250,000 people dead, and the Chilean earthquake of 1985 (M7.8).
- Earthquakes of magnitude M 8 or greater, often termed great earthquakes, are capable of causing widespread structural damage over areas greater than 100,000 kms. The Alaskan earthquake of 1964 (M 8 +) and the Chilean earthquake of 1960 (M 8), each of which caused widespread damage to engineered structures, are in this category.
- The logarithmic scale of implies that for each unit increase in the Richter magnitude, the energy released increases by 101.5.

EARTHQUAKES-Magnitue and Intensity

- Thus a magnitude **M8** earthquake releases **1000 times** the energy of an **M6** earthquake. Primarily, the increased energy of larger earthquakes comes from an increase in the fault surface area over which slip occurs.
- A magnitude **5 +** earthquake may result from fault movement over a length of a few kilometers, while a **magnitude 8** event will have fault movement over a length as much as **400 km (250 miles)**, with corresponding increase in the fault surface area.
- Other factors influencing the amount of energy released include the **stress drop in the rock adjacent to fault slip**.

EARTHQUAKES-Magnitue and Intensity

- A secondary but important effect of the increased **size of the fault surface** of large earthquakes is the **duration of strong ground shaking.**
- In a **moderate earthquake** the source may reasonably be considered as **a point source**, and the duration may be only a few seconds.
- In a **large earthquake**, shock waves reach a given site from parts of the fault surface which may be hundreds of kilometers apart. The arrival times of the shock waves will clearly differ, extending the duration of shaking.

EARTHQUAKES-Magnitue and **Intensity**

- **Earthquake intensity** is a subjective estimate of the perceived local effects of an earthquake and is dependent on peak acceleration, velocity, and duration.
- The most widely used scale is the **modified Mercalli scale**, MM, which was originally developed **by Mercalli in 1902**, modified by Wood and Neumann in 1931, and refined by Richter in 1958.

EARTHQUAKES-Magnitue and **Intensity**

- The effective range is from **MM 2**, which is felt by persons at rest on upper floors of buildings, to **MM 12**, where damage is nearly total.

EARTHQUAKES-Modified Mercalli

- The Mercalli (1902) scale, is based on subjective observations and is primarily applicable to masonry construction, to avoid ambiguity in language and perceived quality of construction, the following lettering is used:
- **Masonry A**: good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, and so on; designed to resist lateral forces.
- **Masonry B**: good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
- **Masonry C**: ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
- **Masonry D**: weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

EARTHQUAKES-Modified Mercalli

- **I.** Not felt. Marginal and long period of large earthquakes.
- **II.** Felt by persons at rest, on upper floors, or favorably placed.
- **III.** Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earth- quake.
- **IV.** Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range, wooden walls and frames crack.
- **V.** Felt outdoors; direction estimated. Sleepers wakened. Liquids dis- turbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

EARTHQUAKES-Modified Mercalli

- **VI.** Felt by all. Many frightened and run outdoors. Persons walk un- steadily. Windows, dishes, glassware broken. Knickknacks, books, and so on, off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.

- **VII.** Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, unbraced parapets, and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

EARTHQUAKES-Modified Mercalli

- **VIII.** Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in How or temperature of springs and walls. Cracks in wet ground and on steep slopes.
- **IX** General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

EARTHQUAKES-Modified Mercalli

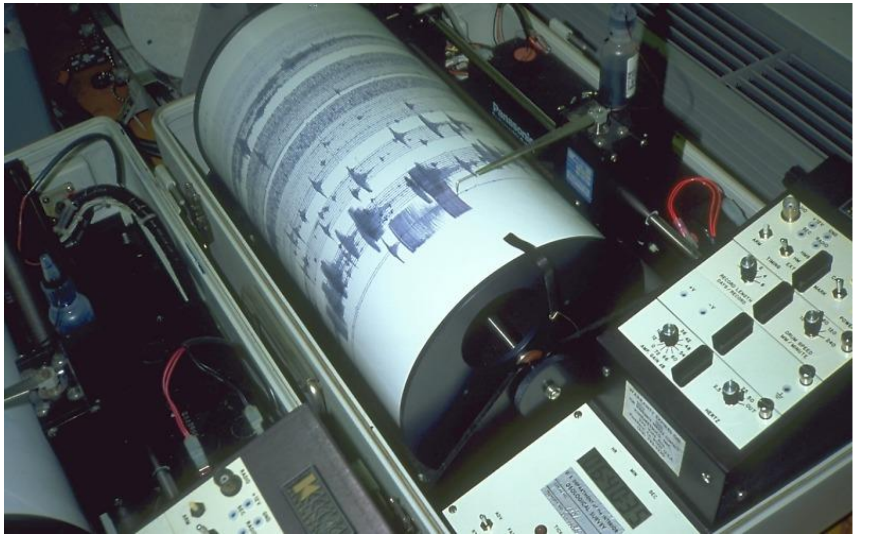
- **X.** Most masonry and frame structures destroyed with their founda- tions. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large mudslides. Water thrown on banks of canals, rivers, lakes, and so on. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly
- **XI.** Rails bent greatly. Underground pipelines completely out of service.
- **XII.** Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

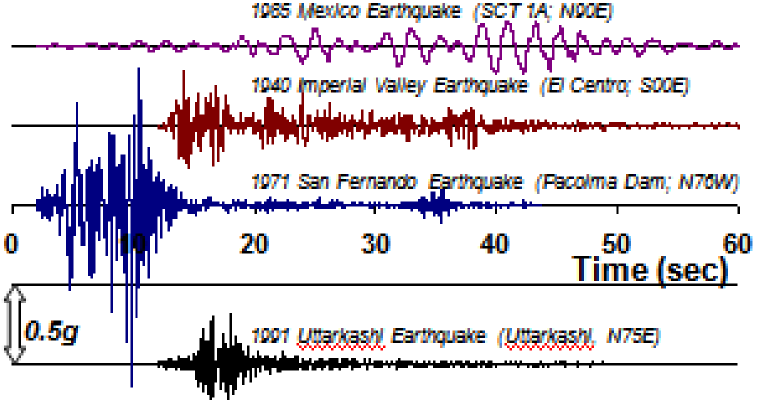
EARTHQUAKES-Magnitue and **Intensity**

- As a measure of structural damage potential the value of this scale has **diminished** over the years, as it is strongly related to the performance of **unreinforced masonry structures**.
- The expected performance of **well-designed modem buildings**, of masonry or other materials, cannot be directly related to modified Mercalli intensity.
- However, it is still of value as a means for recording seismic effects in regions where instrumental values for ground shaking are sparse or nonexistent.
- It is important to realize that the relationship between maximum intensity and size or magnitude is probably nonexistent.
- A shallow seated magnitude 5 + earth- quake may induce local peak ground accelerations almost as high as those occurring during a magnitude 8 + earthquake, despite the difference in energy release.

EARTHQUAKES-Accelorgram

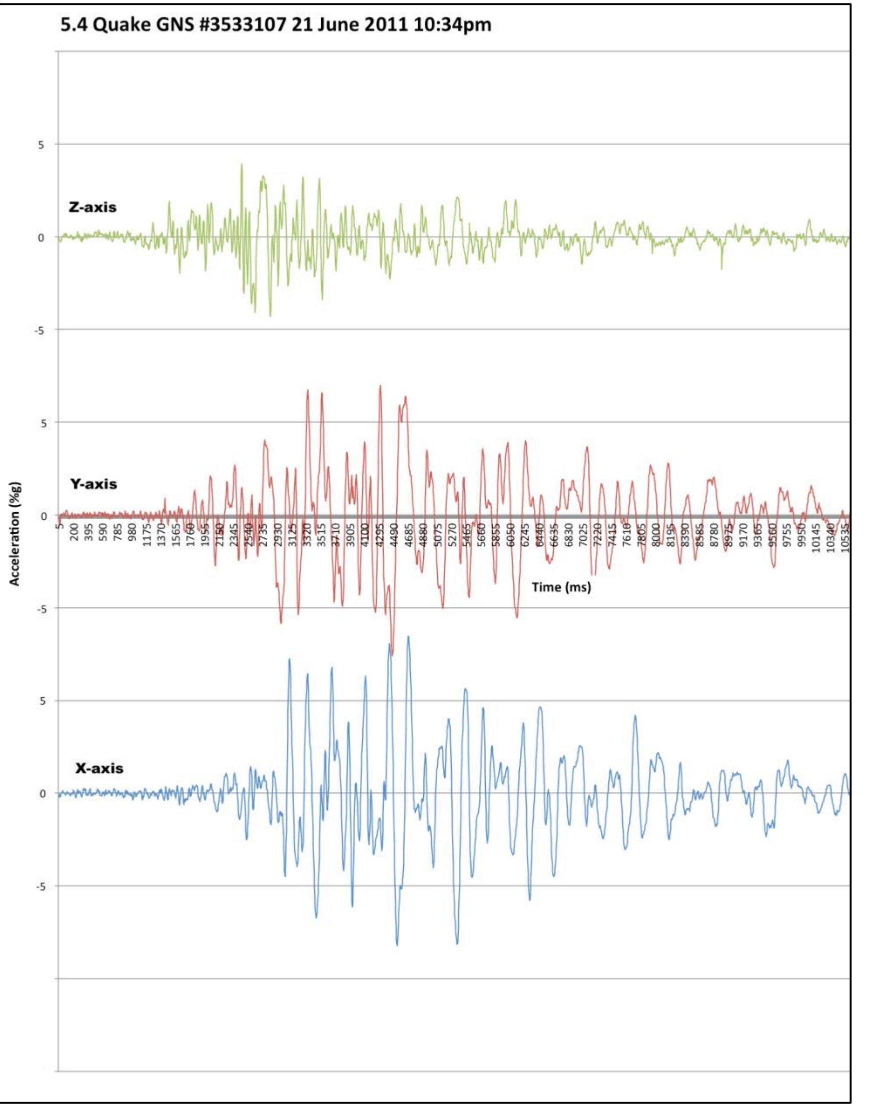
- Earthquake accelerograms recorded by strong-motion Accelerograms.
- These accelerographs record ground acceleration in optical or digital form as a time-history record.
- When mounted in upper floors of buildings, they record the structural response to the earthquake and provide means for assessing the accuracy of analytical models in predicting seismic response.
- Integration of the records enables velocities and displacements to be estimated.





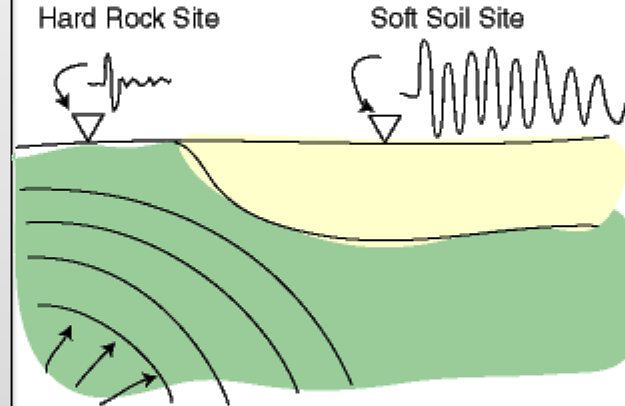
EARTHQUAKES-Vertical acceleration

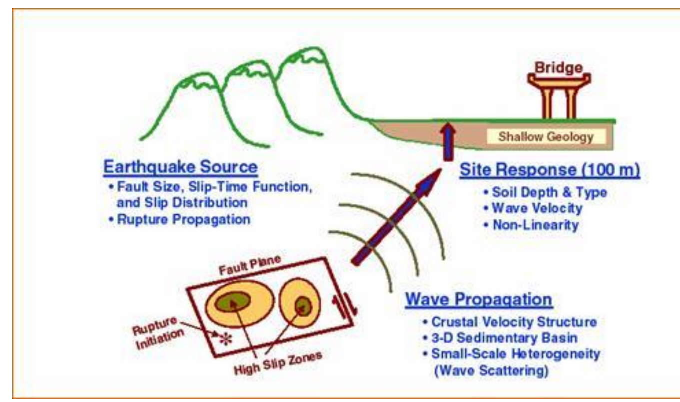
- Vertical accelerations recorded by accelerographs are generally lower than corresponding horizontal components and frequently are richer in low-period components. It is often assumed that peak vertical accelerations are approximately two-thirds of peak horizontal values.
- In general, the vertical components of earthquakes, is not of great significance to structural design.



EARTHQUAKES- Influence of soil

- It is generally accepted that soft soils modify the characteristics of strong ground motion transmitted to the surface from the underlying bedrock.
- The extent and characteristics of this modification are, however, still not fully understood. Amplification of long-period components occurs, and generally peak accelerations in the short-period range are reduced, as a result of strength limitations of the soil.
- It also appears that amplification of ground motion is dependent on the intensity of ground shaking.





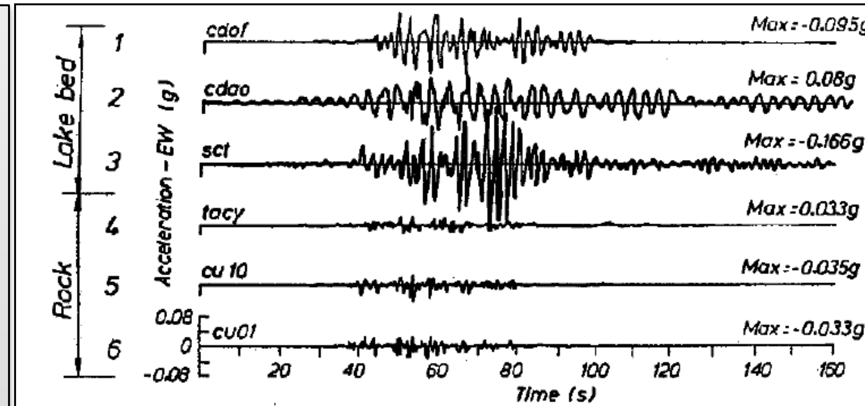
EARTHQUAKES- Influence of soil

- Nevertheless, soil amplification of response is extremely significant in many cases. A classic example is the response of the soft lake bed deposits under Mexico City. These deposits are elastic to high shearing strain, resulting in unusually high amplification of bedrock response.

EARTHQUAKES- Influence of soil

- Figure compares acceleration recorded at adjacent sites on rock and on medium depth lake deposits in the 1985 Mexico earthquake. Mexico City was some 400 km from the epicenter of the earthquake, and peak bedrock accelerations were about 0.05g.

- These were amplified about five times by the elastic characteristics of the old lake bed deposits and generated modified ground motion with energy predominantly in the period range 2 - 3 s.



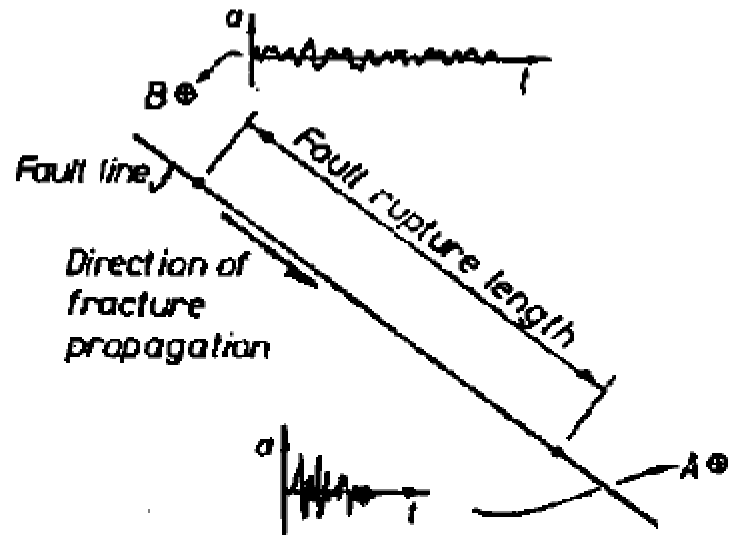
EARTHQUAKES- Influence of soil

- As a consequence, buildings with natural periods in this range were subjected to extremely violent response, with many failures resulting.
- There is still controversy as to the extent of site amplification that can be expected from deep alluvial deposits in very large earthquakes.

EARTHQUAKES- Directionality Effect

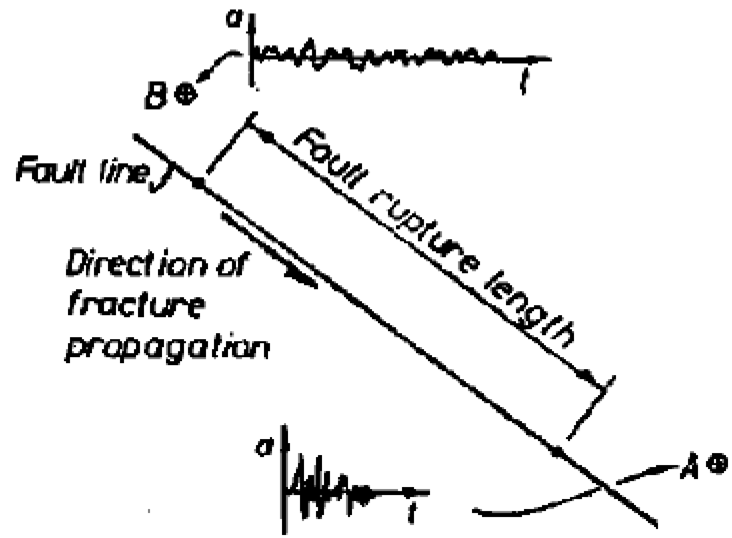
- Energy is not released instantaneously along the fault surface. Rather, fracture initiates at some point and propagates in one or both directions along the fault.

- There is evidence that in many cases, the fracture develops predominantly in one direction. In this case the location of a site with respect to the direction of rupture propagation can influence the local ground motion characteristics, as shown in Figure.



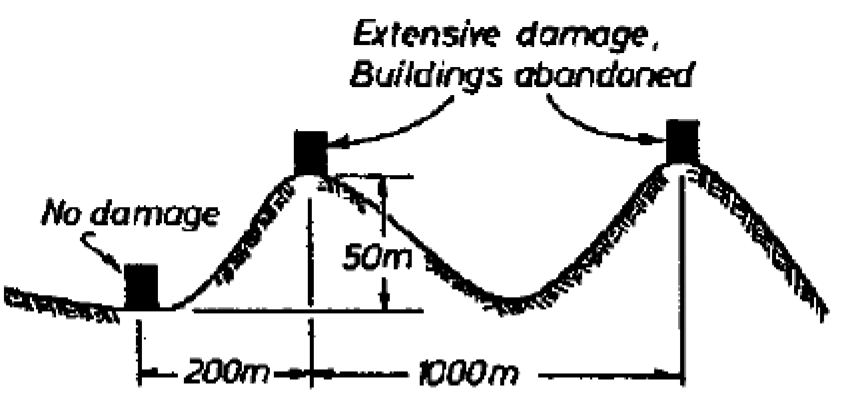
EARTHQUAKES- Directionality Effect

- <u>Station A,</u> "down- stream" of the rupture propagation, is likely to experience enhanced <u>peak accelerations</u> due to reinforcement interaction between the traveling shock waves and new waves released downstream as the fault propagates
- <u>High- frequency components</u> should be enhanced by a kind of Doppler shift, and the duration of shaking <u>should be reduced</u>. Station B, "upstream," should see reduced intensity of ground motion, but with an increased duration. Energy should be shifted toward the long-period range.



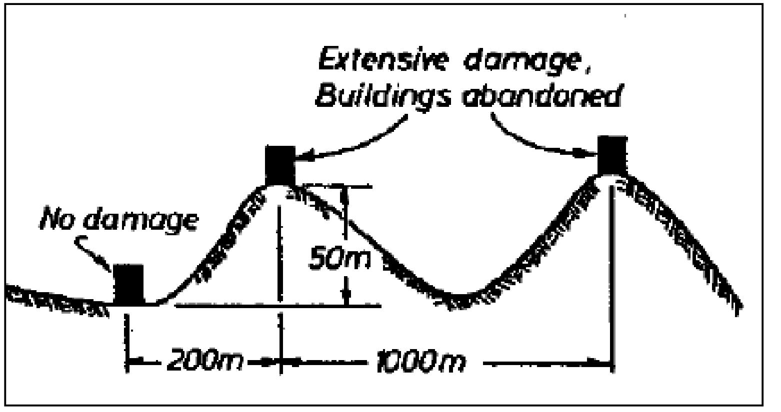
EARTHQUAKES- Geographical amplification

- Geographical features may have a significant influence on local intensity of ground motion.
- In particular, steep ridges may amplify the base rock accelerations by resonance effects in a similar fashion to structural resonance of buildings.
- A structure built on top of a ridge may thus be subjected to intensified shaking. This was graphically illustrated during the 1985 M 7.8 Chilean earthquake.



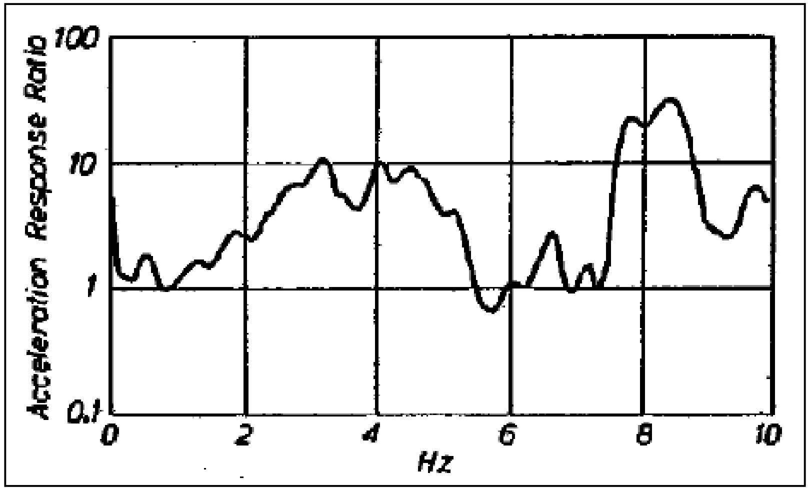
EARTHQUAKES- Geographical amplification

- At the Canal Beagle site, planned housing development resulted in identical four- and five-story reinforced concrete frame apartment buildings with masonry-infill panels being constructed by the same contractor along two ridges and in a valley immediately adjacent to one of the ridges as shown in Figure.
- While the earthquake caused extensive damage to the buildings along both ridges, the buildings in the valley site escaped unscathed.



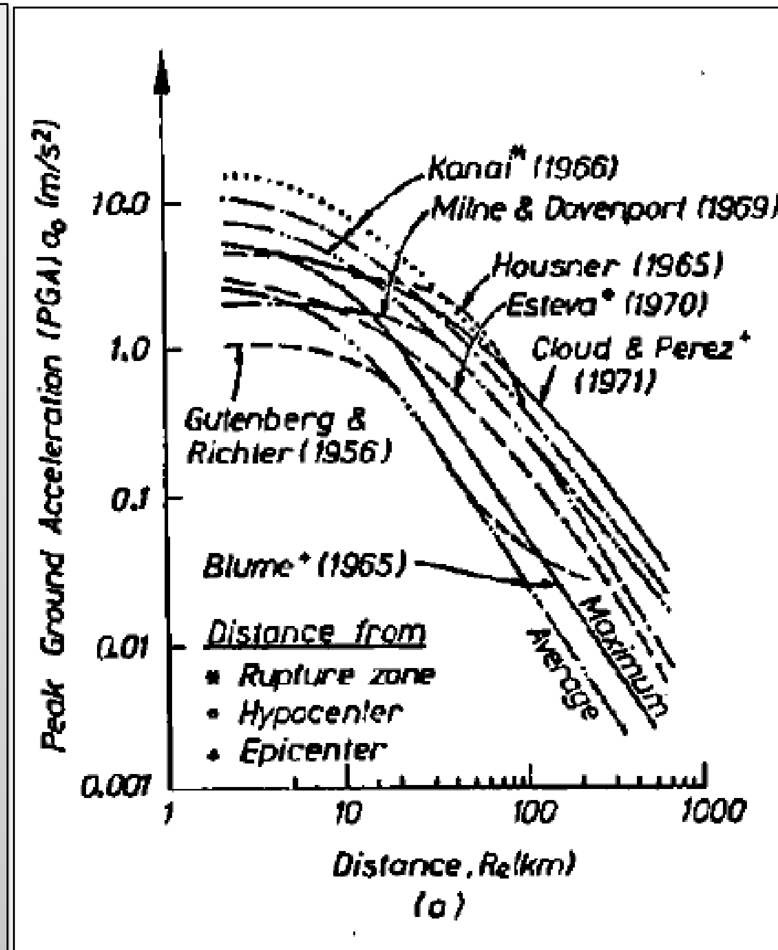
EARTHQUAKES-Attenuation Relationships

- A key element in the prediction of seismic risk at a given site is the attenuation relationship giving the reduction in peak ground acceleration with distance from the epicenter.
- Three major factors contribute to the attenuation.
  - First, the energy released from an earthquake may be considered to be radiated away from the source as a combination of spherical and cylindrical waves.



EARTHQUAKES-Attenuation Relationships

- The increase in surface area of the wave fronts as they move away from the source implies that accelerations will decrease with distance as the sum of a number of terms proportional to $R_e^{-1/2}$, R_e^{-1}, R_e^{-2} , where R, is the distance to the point source or cylindrical axis.
- <u>Second,</u> the total energy transmitted is reduced with distance due to material attenuation or damping of the transmitting medium.
- <u>Third,</u> attenuation may result from wave scattering at interfaces between different layers of material.



EARTHQUAKES-Attenuation Relationships

- It would appear that for small-to-moderate earthquakes, the source could reasonably be considered as a point source, and spherically radiating waves would characterize attenuation.
- For large earthquakes, with fault movement over several hundred kilometers, cylindrical waves might seem more appropriate, although this assumes instantaneous release of energy along the entire fault surface.
- Hence attenuation relationships for small and large earth-quakes might be expected to exhibit different characteristics.
- Most existing attenuation relationships have been developed from analyses of records obtained from small-to-moderate earth-quakes, as a result of the paucity of information on large earthquakes.
- The relationships are then extrapolated for seismic risk purposes to predict the response under larger earthquakes.

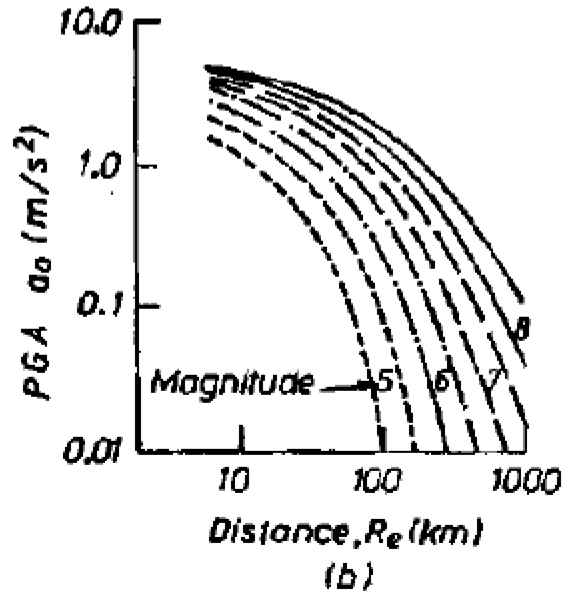
EARTHQUAKES-Attenuation Relationships

- Typical attenuation relationships take the form

$$a_0 = C_1 e^{C_2 M}(R_e + C_3)^{C4}$$

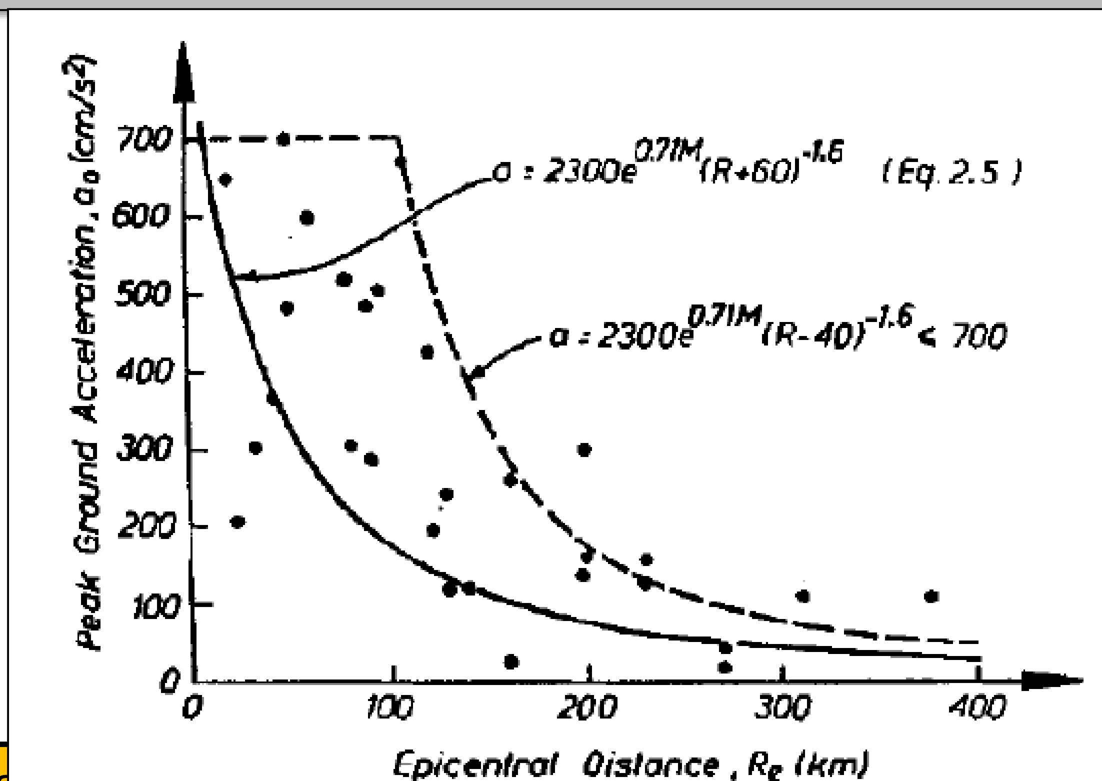
  where a_o is the peak ground acceleration, M the Richter magnitude of the earthquake, R_e the epicentral distance, and C1 to C4 are constants.

- Many relationships of the general form of above equations have been proposed, resulting in a rather wide scatter of predicted values.



EARTHQUAKES-Attenuation Relationships

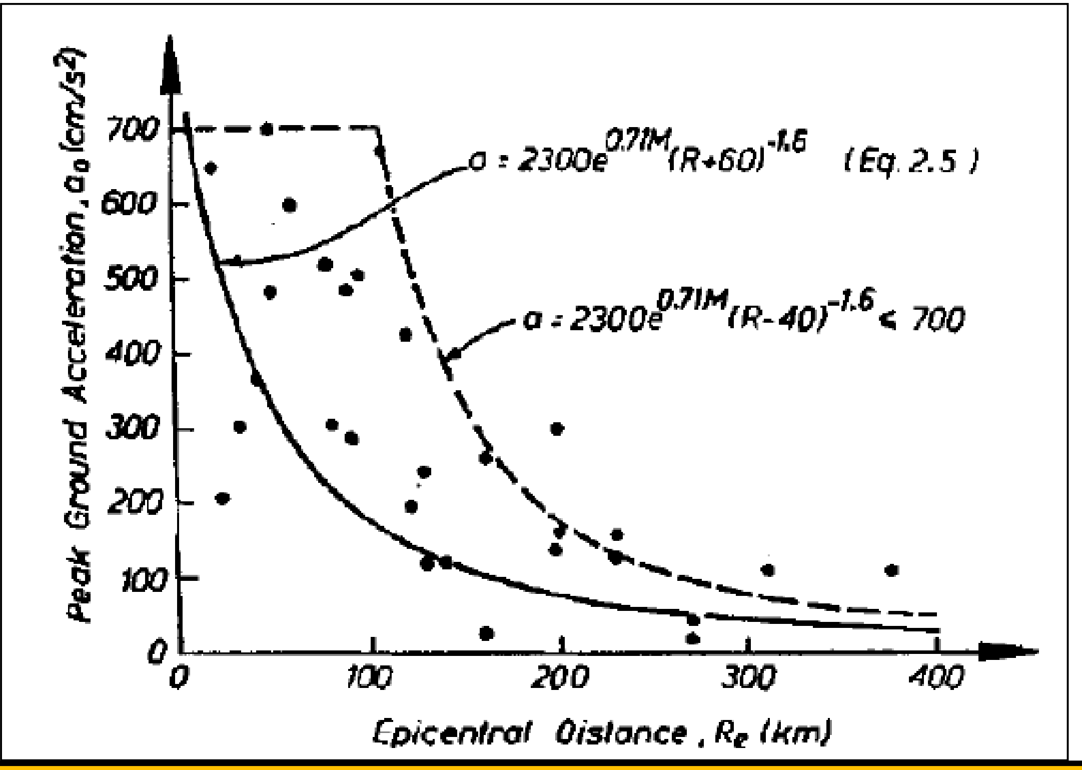
- Esteva and Villaverde recommend the following form of last equation
- $a_0 = 5829 e^{0.8M} (R_e + 40)^{-2}$.........(a)
- where the peak ground acceleration ao is in cm/sec^2 and Re is in kilometers.



EARTHQUAKES-Attenuation Relationships

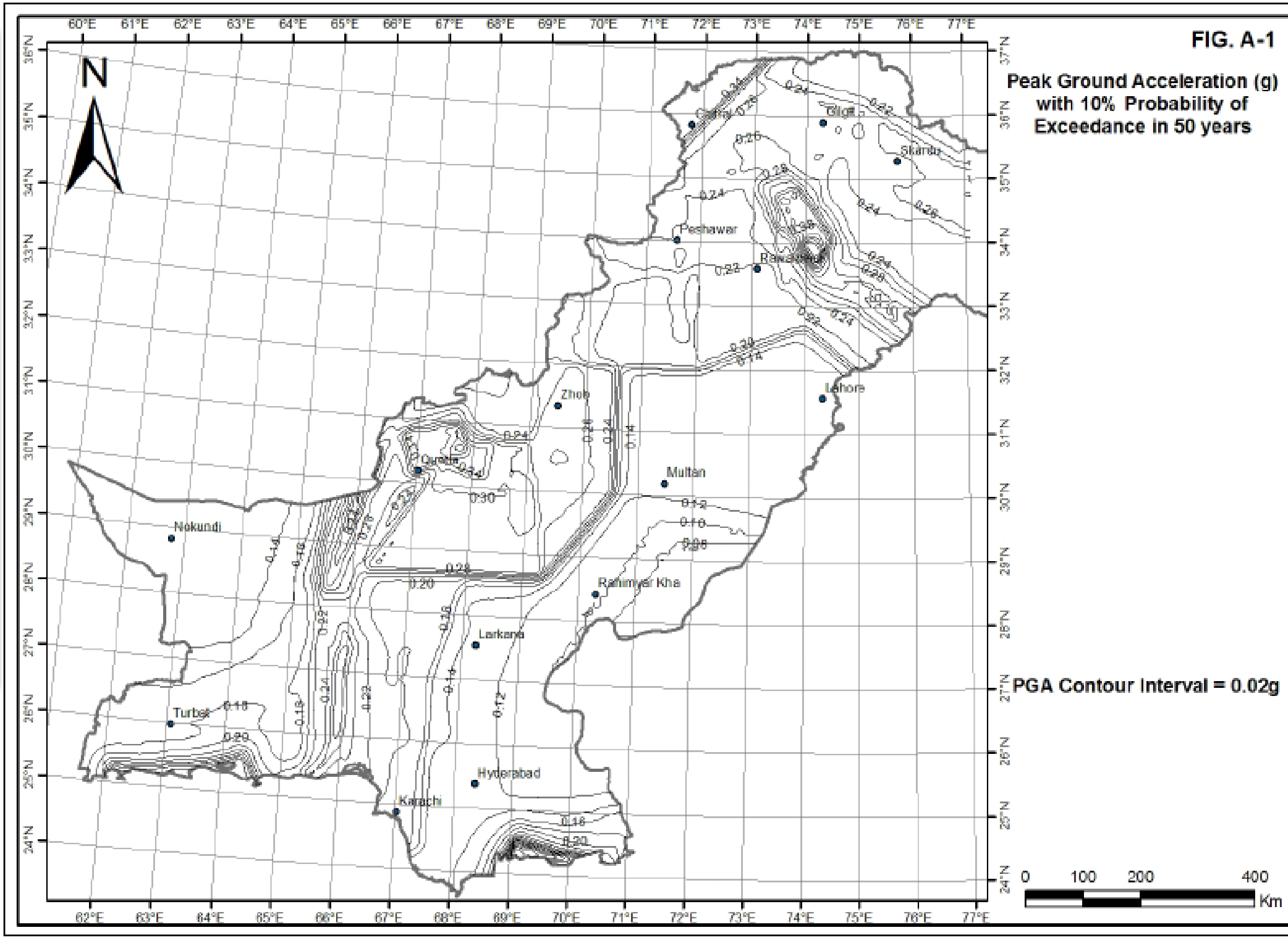
- On the basis of records obtained from three earthquakes, ranging in magnitude from 5.5 to 6.5 prior to 1982,
- Saragoni et al. proposed an attenuation relationship:

$$a_0 = 2300e^{0.71M}(R_e + 60)^{-1.6} \ldots \text{(b)}$$



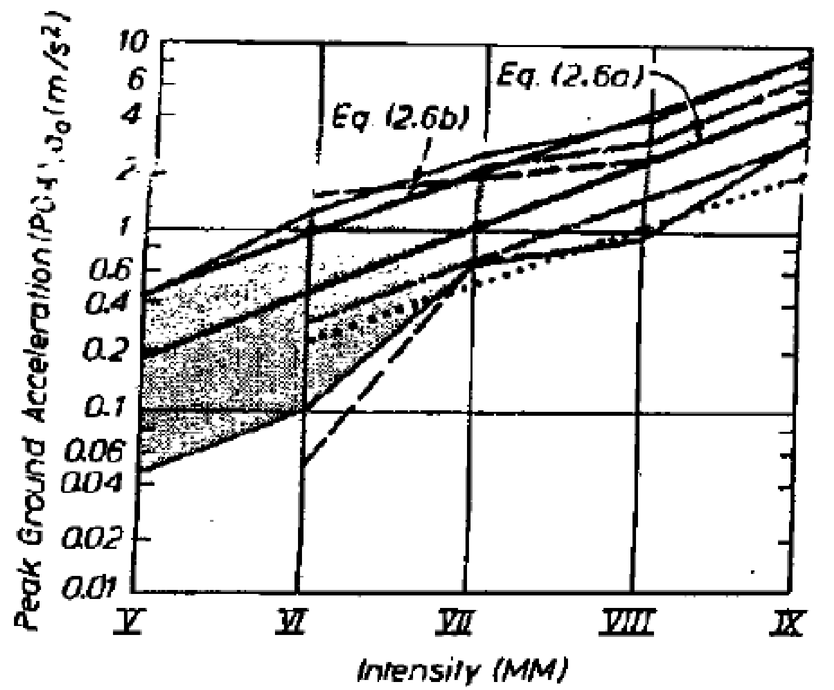
EARTHQUAKES-Attenuation BCP2007.

- BCOP provides the peak ground accelerations also called PGA's for different area.



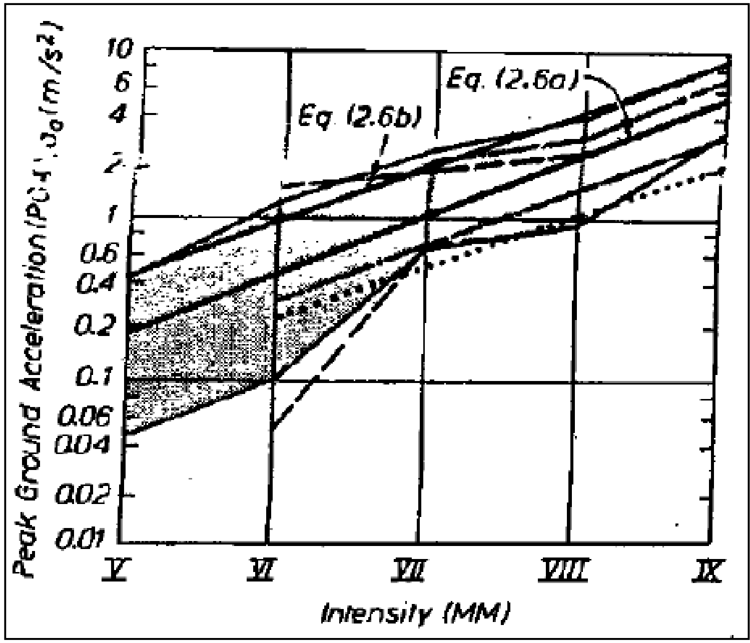
EARTHQUAKES-Choice-Intensity and G.A Relationships

- Structures are designed to withstand a specified intensity of ground shaking.
- In earlier times this was expressed in terms of a design Modified Mercalli (MM) level, and in some parts of the world this approach is still adopted.
- Nowadays intensity is generally expressed as a design peak ground acceleration, since this is more directly usable by a structural engineer in computing inertia forces.



EARTHQUAKES-Choice-Intensity and G.A Relationships

- The relationship between MM intensity and peak ground acceleration (PGA), based on a number of studies is shown in figure.
- Peak ground acceleration is only one factor that affects intensity.
- Other factors include duration and frequency content of the strong motion.
- Different earthquakes with the same PGA can thus have different destructive power and are perceived, correctly, to have different intensities.

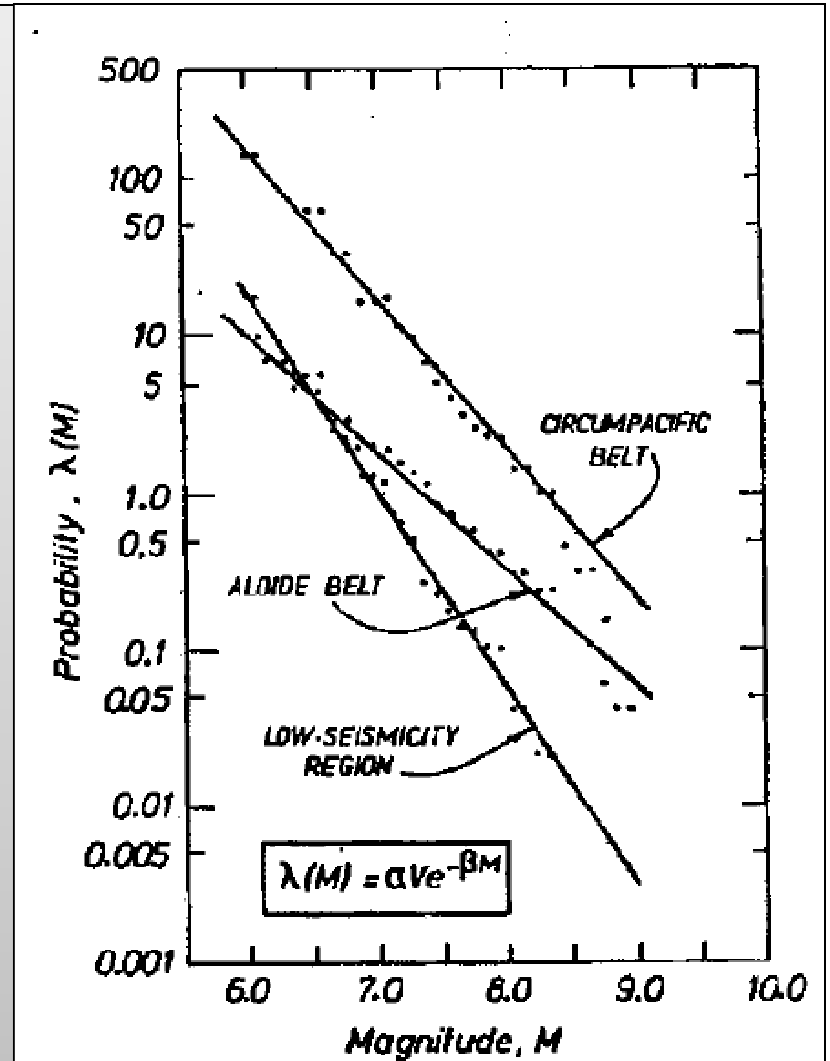


EARTHQUAKES-Choice-Intensity and G.A Relationships

- The damage potential of an earthquake is as much related to peak ground velocity as to acceleration, particularly for more flexible structures.
- For this class of structure, MM intensity or some measure of ground acceleration, both of which are mainly relevant to the response of stiff structures, provides a poor estimate of damage potential.
- There is an approximate linear relationship as follows:
- $PGA_{avg} = 10^{-2.4+0.34I}$
- The design acceleration is
- $PGA_{avg} = 10^{-1.94+0.32I}$

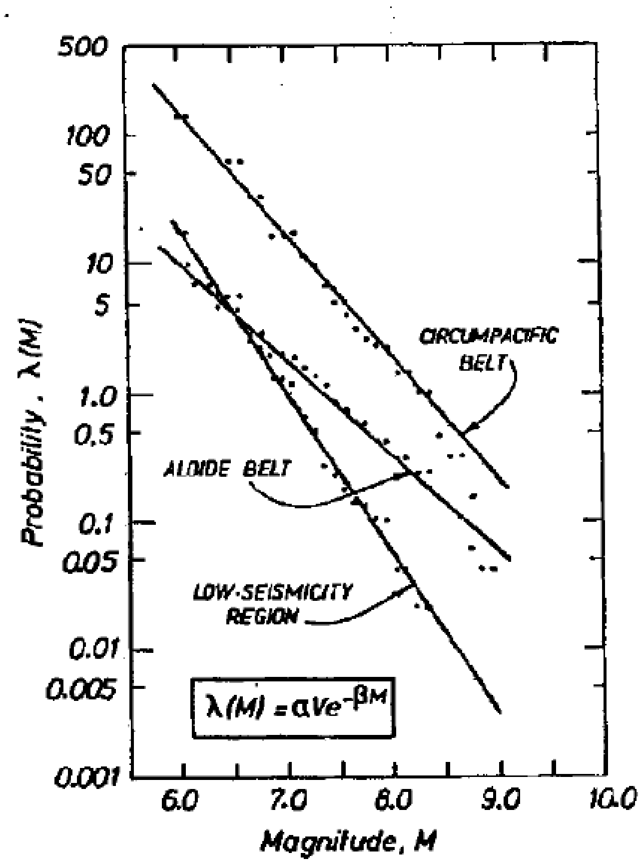
EARTHQUAKES-Return Period

- To assess the seismic risk associated with a given site, it is necessary to know not- only the characteristics of strong ground shaking that are feasible for at given site, but also the frequency with which such events are expected.
- It is common to express this by the return period of an earthquake of given magnitude, which is the average recurrence interval for earthquakes of equal or larger magnitude.
- Large earthquakes occur less frequently than small ones.



EARTHQUAKES-Return Period

- Over much of the range of possible earthquake magnitudes the probability of occurrence (of earthquakes of different magnitude M are well represented by a Gumbel
- $\lambda(M) = \alpha V e^{-\beta M}$
- where $\lambda(M)$ is the probability of an earthquake of magnitude M or greater occurring in a given volume V of the earth's crust per unit time, and α and β are constants related to the location of the given volume.
- Figure shows data for different tectonic zones compared with predictions of above equation calibrated to the data by Esteve.



MACROZONE	αV	β
Circumpacific Belt	6.5×10^7	2.16
Alpide Belt	2.8×10^5	1.71
Low-seismicity Region	3.9×10^8	2.82

EARTHQUAKES-Return Period

- However, it is clear that slip at portions of major tectonic boundaries occurs at comparatively regular intervals and generates earthquakes of comparatively uniform size.
- An example is the region of the San Andreas fault east of Los Angeles.
- Cross-fault trenching and carbon dating of organic deposits have enabled the year and magnitude of successive earthquakes to be estimated. This research indicates that M 7.5 + earthquakes are generated with a return period between 130 and 200 years.

TABLE 2.1 Historical Seismicity of Valparaiso

Year	Interval (yrs)	Magnitude (approx.)
1575		7.0–7.5
	72	
1647		8.0–8.5
	83	
1730		8.7
	92	
1822		8.5
	84	
1906		8.2–8.6
	79	
1985		7.8
	Ave: 82 ± 10	Ave: 8.1 ± 0.6

EARTHQUAKES-Return Period

- Even more regular behavior has been noted on the Nazca/South American plate boundary at Valparaiso in Chile.
- Table lists data and approximate magnitudes of earthquakes in this region since the arrival of the Spanish in the early sixteenth century led to reliable records being kept.
- It will be seen that the average return period of **<u>82 years has a standard deviation of only 7 years</u>**.
- This information can be relevant to design of structures with limited design life.

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