EENS 3050	Natural Disasters
Tulane University	Prof. Stephen A. Nelson
Earthquake Prediction, Control and Mitigation	

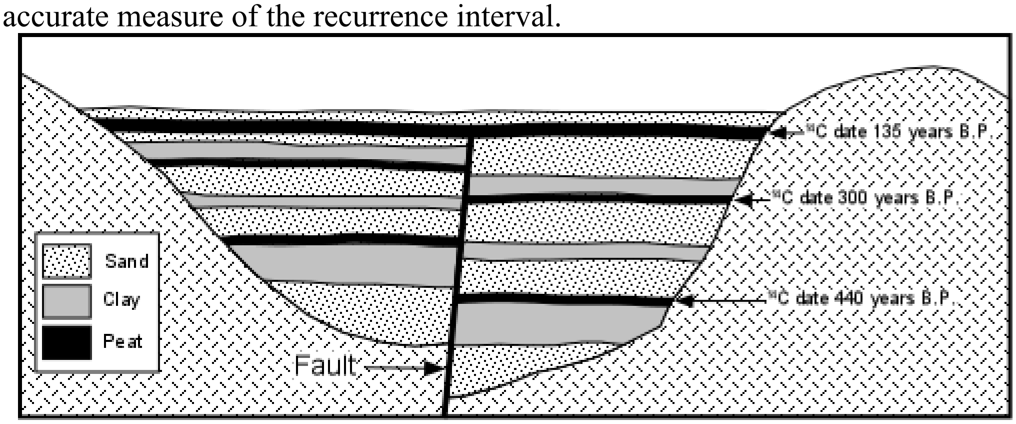
This page last updated on 16-Sep-2016

Earthquake Prediction

Long-Term Forecasting

Long-term forecasting is based mainly on the knowledge of when and where earthquakes have occurred in the past. Thus, knowledge of present tectonic setting, historical records, and geological records are studied to determine locations and recurrence intervals of earthquakes. Two methods of earthquake forecasting are being employed - paleoseismology and seismic gaps.

- Paleoseismology - the study of prehistoric earthquakes. Through study of the offsets in sedimentary layers near fault zones, it is often possible to determine recurrence intervals of major earthquakes prior to historical records. If it is determined that earthquakes have recurrence intervals of say 1 every 100 years, and there are no records of earthquakes in the last 100 years, then a long-term forecast can be made and efforts can be undertaken to reduce seismic risk.
    - Example: The diagram below shows a hypothetical cross-section of a valley along a fault zone. The valley has been filled over the years with clays, sands, and peat (decaying organic matter). The upper peat layer is not yet cut by the fault. Peat is a useful material to geologists, since it contains high amounts of Carbon that can be dated using the ^{14}C method. The ages for each of the peat layers are shown. The dates suggest that a major faulting event cut the lower peat layer sometime after it was deposited 440 years ago. The dates also show the middle peat layer was cut by a faulting event after it was deposited 300 years ago. If these faulting events were associated with earthquakes, this suggests a recurrence interval of about 140 years. Since the upper peat layer has not yet been cut by the fault and is 135 years old, we can speculate that within the next 10 years or so there may be another earthquake. This assumes, of course, that the two previous events are an accurate measure of the recurrence interval.

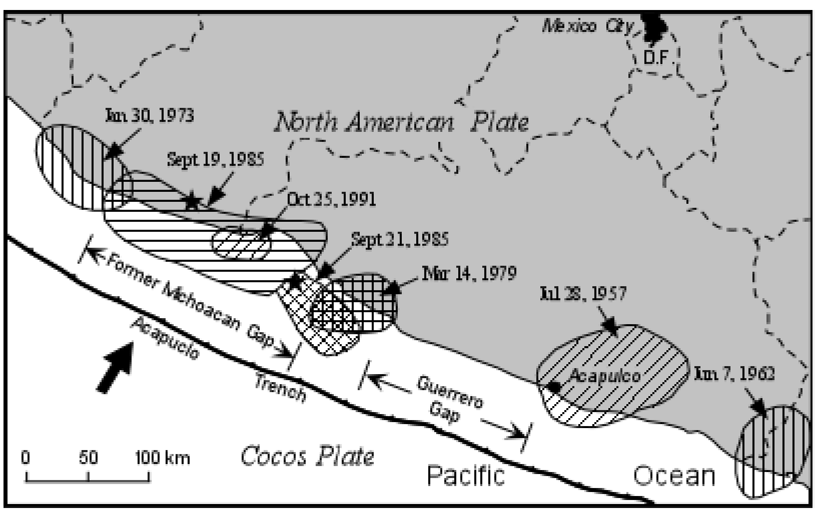


Modified after P.L. Abbott, 1996

- Seismic gaps - A seismic gap is a zone along a tectonically active area where no earthquakes have occurred recently, but it is known that elastic strain is building in the rocks. If a seismic gap can be identified, then it might be an area expected to have a large earthquake in the near future.

  - Example - The Mexico Earthquake of 1985

    The map below shows the southern coast of Mexico. Here the Cocos plate is subducting beneath the North American Plate along the Acapulco Trench. Prior to September of 1985 it was recognized that within recent time there had been major and minor earthquakes on the subduction zone in a cluster pattern. For example, there were clusters of earthquakes around a zone that included a major earthquake on Jan 30, 1973, another cluster around an earthquake of March 14, 1979, and two more cluster around earthquakes of July 1957 and January, 1962. Between these clusters were large areas that had produced no recent earthquake activity. The zones with low seismically are called seismic gaps. Because the faulting had occurred at other places along the subduction zone it could be assumed that strain was building in the seismic gaps, and earthquake would be likely in such a gap within the near future. Following a magnitude 8.1 earthquake on September 19, 1985, a magnitude 7.5 aftershock on Sept. 21, and a magnitude 7.3 aftershock on Oct. 25, along with thousands of other smaller aftershocks, the Michoacan Seismic gap was mostly filled in. Note that there still exists a gap shown as the Guerrero Gap and another farther to the southeast. Over the next 5 to ten years we may expect to see earthquakes in these gaps.

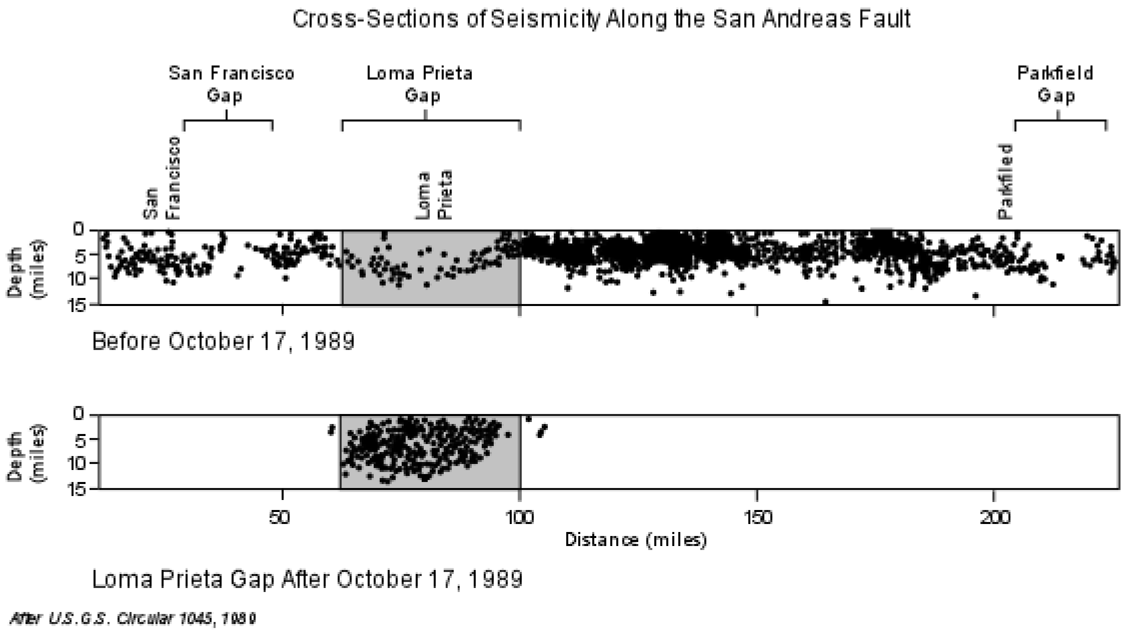


After J.G. Anderson et al, 1986 - Science, v. 233

  - Example - The San Francisco, Loma Prieta, and Parkfield Seismic Gaps

    Shown below are two cross-sections along the San Andreas Fault in northern California. The upper cross section shows earthquakes that occurred along the fault prior to October 17, 1989. Three seismic gaps are seen, where the density of earthquakes appears to be lower than along sections of the fault outside the gaps. To the southeast of San Francisco is the San Francisco Gap, followed by the Loma Prieta Gap, and the Parkfield Gap. Because of the low density of density of earthquakes in these gaps, the fault is often said to be locked along these areas, and thus strain must be building. This led scientist to issue a prediction for the

Parkfield gap that sometime between 1986 and 1993 there would be an earthquake of magnitude 6 or greater south of Parkfield. No such earthquake has yet occurred. However a magnitude 7.1 earthquake occurred in the Loma Prieta gap on Oct. 17, 1989, followed by numerous aftershocks. Note how in the lower cross-section, this earthquake and its aftershocks have filled in the Loma Prieta Gap. This still leaves the San Francisco and Parkfield gaps as areas where we might predict a future large event.



Short-Term Prediction

- Short-term predication involves monitoring of processes that occur in the vicinity of earthquake prone faults for activity that signify a coming earthquake.
- Anomalous events or processes that may precede an earthquake are called ***precursor events*** and might signal a coming earthquake.
- Despite the array of possible precursor events that are possible to monitor, successful short-term earthquake prediction has so far been difficult to obtain. This is likely because:
  - the processes that cause earthquakes occur deep beneath the surface and are difficult to monitor.
  - earthquakes in different regions or along different faults all behave differently, thus no consistent patterns have so far been recognized

Among the precursor events that may be important are the following:

- Ground Uplift and Tilting - Measurements taken in the vicinity of active faults sometimes show that prior to an earthquake the ground is uplifted or tilts due to the swelling of rocks caused by strain building on the fault. This may lead to the formation of numerous small cracks (called microcracks). This cracking in the rocks may lead to small earthquakes called foreshocks.

- Foreshocks - Prior to a 1975 earthquake in China, the observation of numerous foreshocks led to successful prediction of an earthquake and evacuation of the city of the Haicheng. The magnitude 7.3 earthquake that occurred, destroyed half of the city of about 100 million inhabitants, but resulted in only a few hundred deaths because of the successful evacuation.

- Water Level in Wells - As rocks become strained in the vicinity of a fault, changes in pressure of the groundwater (water existing in the pore spaces and fractures in rocks) occur. This may force the groundwater to move to higher or lower elevations, causing changes in the water levels in wells.

- Emission of Radon Gas - Radon is an inert gas that is produced by the radioactive decay of uranium and other elements in rocks. Because Radon is inert, it does not combine with other elements to form compounds, and thus remains in a crystal structure until some event forces it out. Deformation resulting from strain may force the Radon out and lead to emissions of Radon that show up in well water. The newly formed microcracks discussed above could serve as pathways for the Radon to escape into groundwater. Increases in the amount of radon emissions have been reported prior to some earthquakes.

- Changes in the Electrical Resistivity of Rocks - Electrical resistivity is the resistance to the flow of electric current . In general rocks are poor conductors of electricity, but water is more efficient a conducting electricity. If microcracks develop and groundwater is forced into the cracks, this may cause the electrical resistivity to decrease (causing the electrical conductivity to increase). In some cases a 5-10% drop in electrical resistivity has been observed prior to an earthquake.

- Unusual Radio Waves - Just prior to the Loma Prieta Earthquake of 1989, some researchers reported observing unusual radio waves. Where these were generated and why, is not yet known, but research is continuing.

- Strange Animal Behavior - Prior to a magnitude 7.4 earthquake in Tanjin, China, zookeepers reported unusual animal behavior. Snakes refusing to go into their holes, swans refusing to go near water, pandas screaming, etc. This was the first systematic study of this phenomenon prior to an earthquake. Although other attempts have been made to repeat a prediction based on animal behavior, there have been no other successful predictions.

P-wave Warning Systems

Because P-waves are generally less destructive than S-waves and Surface waves, and because P-waves always travel faster than S and Surface waves, recent efforts are being used to exploit these factors to develop a P-wave warning system. Such a warning system would not be very effective near the epicenter of an earthquake because the time delay between the arrival of the first P-wave and the first S-wave would be too short. But, at greater distance from the epicenter, the delay becomes larger and might at least give people time to protect themselves.

Also, devices that shut down gas and electrical lines could do so on detection of the arrival of P-waves to that potential damage from gas and electricity could be avoided when the S- and Surface- waves arrive. Systems that rely on this principle are currently being tested.

Controlling Earthquakes

Although no attempts have yet been made to control earthquakes, earthquakes have been known to be induced by human interaction with the Earth. This suggests that in the future earthquake control may be possible.

Examples of human induced earthquakes

- For ten years after construction of the Hoover Dam in Nevada blocking the Colorado River to produce Lake Mead, over 600 earthquakes occurred, one with magnitude of 5 and 2 with magnitudes of 4.
- In the late 1960s toxic waste injected into hazardous waste disposal wells at Rocky Flats, near Denver apparently caused earthquakes to occur in a previously earthquake quiet area. The focal depths of the quakes ranged between 4 and 8 km, just below the 3.8 km-deep wells.
- Nuclear testing in Nevada set off thousands of aftershocks after the explosion of a 6.3 magnitude equivalent underground nuclear test. The largest aftershocks were about magnitude

In the first two examples the increased seismicity was apparently due to increasing fluid pressure in the rocks which resulted in re-activating older faults by increasing strain.

The problem, however, is that of the energy involved. Remember that for every increase in earthquake magnitude there is about a 30 fold increase in the amount of energy released. Thus, in order to release the same amount of energy as a magnitude 8 earthquake, 30 magnitude 7 earthquakes would be required. Since magnitude 7 earthquakes are still very destructive, we might consider generating smaller earthquakes. If we say that a magnitude 4 earthquake might be acceptable, how many magnitude 4 earthquakes are required to release the same amount of energy as a magnitude 8 earthquake? Answer 30 x 30 x 30 x 30 =810,000! Still, in the future it may be possible to control earthquakes either with explosions to gradually reduce the stress or by pumping fluids into the ground.

Mitigation Against Earthquake Damage

As we discussed previously "earthquakes don't kill people, buildings do". Thus, if we can construct buildings and other structures in such a way that they do not collapse of fail during an earthquake, we can reduce the casualties and damage from earthquakes. This has proven evident from comparison of earthquakes in areas with and without earthquake resistant building codes.

Again, there are many examples to show this, including - the January 12, 2010 earthquake of Moment Magnitude 7.0 occurred in Haiti, where most of the construction was poorly reinforced concrete. The destruction was massive with an estimated 250,000 deaths. This is in contrast to the February 27, 2010 Moment Magnitude 8.8 earthquake in Chile, a country where earthquake resistant building codes were enforced. The death toll from this larger earthquake was about 520, again, proving the effectiveness of building codes.

In order to withstand an earthquake, buildings must be designed and built with the following characteristics of earthquakes in mind:

- Ground acceleration - Can be up to 1.8 g
- Duration of shaking - Can last up to several minutes
- Frequency of seismic waves and resonance with building, including factors related to the geologic materials underlying the structure.
- Horizontal shaking - Causes different parts of building to move in different directions
- Strength of materials - Ductile Materials like wood and steel or brittle materials like concrete.

To elaborate on some these points:

Duration of Shaking

The duration of shaking largely depends on the size of the earthquake.

Richter Magnitude	Duration of Shaking (seconds)
8 - 8.9	30 - 180
7 - 7.9	20 - 130
6 - 6.9	10 - 30
5 - 5.9	2 - 15
4 - 4.9	0 - 5

In the 2011 Moment Magnitude 9.0 earthquake in Japan, severe shaking continued for 3 to 5 minutes. (See http://www.scientificamerican.com/article.cfm?id=fast-facts-japan)

Building Resonance

Consider that Seismic waves cause the ground to vibrate at frequencies between 20 and 0.002 cycles per second which translates to periods (time to complete one cycle) of between 0.05 seconds and several minutes. All structures have natural frequencies or periods of vibration. If a structure has a period of vibration similar to a seismic wave it will resonate, and the longer it resonates, the more likely it will fail.

Resonance can be eliminated by:

- Changing the height of building
- Moving weight to lower floors
- Changing the shape of building
- Changing the building materials
- Changing how the building attaches to foundation.
- Hard foundation (high-frequency vibrations) - build tall, flexible building
- Soft foundation (low-frequency vibrations) - build short, stiff building

Horizontal Shaking

P-waves, as they arrive at the surface, generally cause the ground to move up and down. But S-waves and Surface Waves cause the ground to move from side to side as well as up and down. The horizontal movement, causes different parts of building to move in different directions. Problems with buildings can be eliminated by using shear walls – designed to receive horizontal forces from floors, roofs and trusses and transmit them to the ground.

Building a house of cards illustrates this point well. A house of cards will stand on its own, but will fall apart of you shake the foundation. If the cards are taped together, so that the vertical components and horizontal components are connected together, the house of cards will not fall over if you shake the foundation.

The structure and also be isolated from the underlying ground by base isolation, wherein devices on the ground or within structure are placed to absorb part of earthquake energy. This can be done by installing wheels, ball bearings, shock absorbers, 'rubber doughnuts', etc. to isolate building from worst shaking.

Concrete and Steel Construction Materials

Large buildings are often constructed with concrete reinforced by steel rebar.
Concrete is strong under compression, but weak under extension or shearing. Steel reinforcement of concrete can help prevent failure, but must be done in such a way to prevent motion both horizontally and vertically. For example, bridges supported by vertically embedded rebar in the support structures can easily fail when subjected to horizontal vibrations, as illustrated by the freeway collapse in the 1989 Loma Prieta earthquake near San Francisco. But, if the vertical rebar is surrounding by rebar spiraling around the vertical rebar, the structure will have more resistance to horizontal movement.

Bridges

Cantilever type bridges, like a portion of the Bay Bridge from Oakland to San Francisco or the Crescent City Connection in New Orleans where towers support the bridge are more susceptible to damage than suspension bridges, like the Golden Gate Bridge in San Francisco, where more flexible steel cables support the bridge deck. In cantilever type bridges, since the towers are fixed, they can move apart during an earthquake, causing the bridge deck to collapse. The more flexible steel cables of a suspension bridge allow the deck to sway with the vibrations and therefore resist failure.

Utilities

Water supplies are often cut off as water pipes break during and earthquake. Failure of the water supply prevents control of secondary fires and slows recovery. Constructing the water supply system wi ht flexible joints can prevent breakage of pipes. Gas mains and electrical meters can be fitted with devices that shut off natural gas automatically at the first sign of shaking. This will also aid in the prevention of secondary fires.

Houses

Modern 1 and 2-story wood-frame houses generally perform well in earthquakes, but they can perform better if additional support is provided by building shear walls, bracing, and tying walls, foundations and roof together.

Even if the house does not fall down during an earthquake, interior furnishings can cause considerable damage and injury as interior items are thrown about during the shaking. Thus, it is essential to bolt down water heaters, air conditioning/heating unites, ceiling fans, cabinets, bookshelves, and electronics, basically anything that can fall or collapse and cause injury.

Summary

While architecture & building codes reduce risk, not all kinds of behavior can be predicted. For example: different earthquakes show different frequencies and durations of ground shaking, & different vertical & horizontal ground accelerations. Old buildings cannot cost-effectively be brought up to code, especially with yearly refinements to code. And, even with construction to earthquake code, buildings fail for other reasons - like poor quality materials, poor workmanship, etc., that are not discovered until after an earthquake.

What To Do Before and During an Earthquake

Every person living in areas susceptible to earthquakes should be educated in steps they can take to minimize risk, before, during and after an earthquake. These steps are discussed in detail on FEMA web pages - see https://www.ready.gov/earthquakes and are briefly summarized here, but you should check the website for important details.

Before an Earthquake

1. Check for Hazards in the Home - look for items that might fall, dangerous substances that might spill, items that might shatter, faulty electrical and gas connections, etc. and secure or repair any deficiencies.
2. Identify Safe Places Indoors and Outdoors - Find places where you can go to protect yourself, such as under a heavy desk or table, away from glass, and away from buildings, structures, poles, etc. that might collapse.
3. Educate Yourself and Family Members - make sure everyone knows what to do in the event of an earthquake.
4. Have Disaster Supplies on Hand - things like flashlights and batteries, first aid kits, emergency food and water, medicines, cash, etc.
5. Develop an Emergency Communication Plan - remember telephone communication (even cell phones) may not work.

During an Earthquake

Be aware that some earthquakes are actually foreshocks and a larger earthquake might occur. Minimize your movements to a few steps to a nearby safe place and if you are indoors, stay there until the shaking has stopped and you are sure exiting is safe.
If indoors - drop and cover - get under a sturdy table, hold on until the shaking stops, crouch in an inside corner if no other protection is available, stay away from glass and anything else that might shatter or fall. **DO NOT** use elevators.

If outdoors - Stay there. Move away from buildings, streetlights, and utility wires or anything else that may fall on you.

If in a moving vehicle - Stop as quickly as safety permits and stay in the vehicle. Avoid stopping near or under buildings, trees, overpasses, and utility wires. Proceed cautiously once the earthquake has stopped. Avoid roads, bridges, or ramps that might have been damaged by the earthquake.

If trapped under debris - Do not light a match. Do not move about or kick up dust. Cover your mouth with a handkerchief or clothing. Tap on a pipe or wall so rescuers can locate you. Use a whistle if one is available. Shout only as a last resort. Shouting can cause you to inhale dangerous amounts of dust.

After an Earthquake

1. Expect aftershocks which can cause more damage and injury.
2. Listen to a battery-operated radio or television for the latest emergency information.
3. use the telephone only for emergency calls.
4. Open cabinets cautiously.
5. Stay away from damaged areas.
6. Return home only when authorities say it is safe.
7. Be aware of possible tsunami if you live in coastal areas.
8. Help injured or trapped persons
9. Do not move seriously injured persons unless they are in immediate danger of further injury. Call for help.
10. Clean up spilled medicines, bleaches, gasoline or other flammable liquids immediately. Leave the area if you smell gas or fumes from other chemicals.
11. Inspect utilities, Check for gas leaks, look for electrical system damage, check for sewer and water supply damage.

Awareness of this information is essential to saving your life! Note that most of this information is applicable to only to earthquakes but other natural disasters as well.

Examples of questions on this material that could be asked on an exam

1. Compare the two methods of long-term earthquake forecasting: paleoseismology and seismic gaps.

2. What are precursor events and how might they be used for short-term prediction of earthquakes? List some examples.

3. Why has short-term earthquake prediction so far been unsuccessful?

4. Discuss the possibility of humans being able to control earthquakes.

5. Discuss the best possible steps to mitigate against earthquake damage and death.

6. Explain the steps you should take before, during, and after an earthquake to minimize the possibility of injury to you and your family.

References

Return to EENS 3050 Homepage