OH NO! NOT ANOTHER EXAM?

SADLY, YES
THURSDAY, NOVEMBER 9th
In Class, Usual Time

REVIEW SESSION
TUESDAY, NOVEMBER 7th
6:00 pm  Morrill I Auditorium (Room 375)
EARTHQUAKE PREDICTION
Predicting the unpredictable!

To successfully predict an earthquake we would like to know:-

- PLACE
- TIME
- MAGNITUDE

(rather like a weather forecast)
Evidence must be integrated from a variety of sources, including:

- GEOLOGICAL EVIDENCE
- STATISTICAL INFORMATION
- SEISMIC MEASUREMENTS
- PHYSICAL MEASUREMENTS
- Other Information
Geological Evidence

From a knowledge of the geology, and geological processes, in an area, combined with previous earthquake records, we can prepare:-

*earthquake hazard maps.*

Remember, the geological past is a guide to the future.
The information for earthquake hazard maps includes:-

- Geology of the area including, landslides, ground settling, water-logged and poorly consolidated rocks.
- Location of active and inactive faults.
- Types of faults
- Evidence for recent fault movement
- The earthquake history of the area
- Location of previous earthquake epicenters
- Determination of previous earthquake intensities
- Correlation (if possible) of earthquakes with local faults
Statistical Information

There appears to be a rough relationship between the magnitude of an earthquake and the length of fault that ruptures:

<table>
<thead>
<tr>
<th>Magnitude (Richter)</th>
<th>Rupture Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>5 - 10</td>
</tr>
<tr>
<td>6.0</td>
<td>10 – 15</td>
</tr>
<tr>
<td>6.5</td>
<td>15 – 30</td>
</tr>
<tr>
<td>7.0</td>
<td>30 – 60</td>
</tr>
<tr>
<td>7.5</td>
<td>60 – 100</td>
</tr>
<tr>
<td>8.0</td>
<td>100 - 200</td>
</tr>
</tbody>
</table>

In other words if we could predict what part of a fault was likely to rupture, we could estimate the magnitude of the forthcoming earthquake.
Frequency of Earthquakes

Most attempts to predict the **frequency** of earthquakes rely on the **assumption** that the forces creating earthquakes are **constant** and **long-lived**.

[i.e. the slow but inexorable movement of the plates]

<table>
<thead>
<tr>
<th>EXAMPLE:</th>
<th>San Francisco 1906 (Reid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement over 50 years (prior to the earthquake)</td>
<td>= 10 feet</td>
</tr>
<tr>
<td>Therefore, years/foot movement</td>
<td>= 5 years</td>
</tr>
<tr>
<td>Movement during earthquake</td>
<td>= 20 feet</td>
</tr>
<tr>
<td>Predicted Frequency (20 x 5)</td>
<td>= 100 years</td>
</tr>
</tbody>
</table>

**CONCLUSION:** There might be an earthquake on this part of the San Andreas fault every 100 years or so.
Parkfield

Parkfield is located on a 15 mile segment of the San Andreas fault. Small earthquakes (5.5 – 5.6) have occurred here regularly, almost every 22 years.

As a consequence of this regularity it has been under intense scrutiny by the U.S. Geological Survey.

What went wrong in 1988?
In a similar manner, evidence for fossil earthquakes along the southern segment of the San Andreas fault near Los Angeles shows that major earthquakes occur here roughly **every 160 years**.

The largest interval was 300 years, and the smallest interval was 55 years. **Hence a lot of uncertainty!**

The last major earthquake on this segment occurred in 1857. **Does this mean we can expect the next “Big One” this year? (1857 + 160 = 2017)**

(However it could be as far away as 2157!)
Seismic Gap Theory

If earth movements that ultimately lead to earthquakes are steady and constant, then:-

- Active regions that have been seismically quiet or inactive for some time are probably building up excessive elastic strain.
- This could mean that these regions are potential locations for future earthquakes.
- The longer the time interval without seismic activity, the more elastic strain is being built up and therefore the larger the subsequent earthquake.
- This theory has been applied to segments of individual faults and also to the broader regions along subduction zones.
Seismic gaps of coastal Mexico

- The Guerrero seismic gap is thought to be overdue for major earthquakes.
- Note how the former Michoacan gap was filled by earthquakes between 1973 and 1985.
Oaxaca, Mexico 7.4 March 20th, 2012
Depth ~ 20 km. Occurred in seismic gap.
The North Anatolia fault in Turkey is very similar to the San Andreas fault.

Note how fault movement and associated earthquake activity has moved west over time.

The most recent earthquakes (1992 and 1999) occurred at either end of this active region where there had been no recent earthquake activity.
Seismic gaps along the San Andreas system

Notice that there have been no recent earthquakes along either the Hayward Fault or the northern part of the San Andreas Fault. According to the seismic gap theory, we might expect the next large earthquakes to be along these fault segments.
Note progressive southerly movement of earthquakes along the subduction zone marking the plate boundary between the Australian and Burma - Sunda plates.

Sumatra
Magnitude 7.7
Oct, 2010
A corollary to the seismic gap theory is that faults that are constantly moving (creeping), or experience frequent earthquakes, are not going to build up large amounts of elastic strain. Consequently, these fault segments are unlikely to produce large earthquakes.

At Parkfield for example, there are earthquakes about every 22 years and, as a consequence, their magnitudes have been relatively small (5.5 - 6.0).
Seismic Evidence

Foreshocks and Aftershocks
Foreshocks

- In some cases a large earthquake is preceded by a series of smaller quakes (M = 3-5) called foreshocks.
- Foreshocks may occur from months to days before a big earthquake (or not at all!). In general the longer the period of foreshocks the larger the ensuing earthquake.
- The problem is to identify foreshocks from low-level, random earthquake activity that is common in earthquake prone areas.
- The method has been used with success some times, but has also produced “false alarms”.

Question: Was the (M = 5) earthquake in August south of San Francisco a foreshock of the October, 1989 Loma Prieta (M = 7.1) earthquake?
Aftershocks

- After a large earthquake, the crust around the active fault is heavily disturbed and very unstable.
- Consequently, movement and re-adjustment takes place leading to more earthquakes.
- These earthquakes, called aftershocks, are usually smaller in magnitude (M = 3-5) than the main earthquake.
- With time, both the frequency and intensity of these earthquakes decrease.
- Despite their smaller magnitude, they are not without hazard. Buildings damaged or weakened by the main earthquake can collapse as a consequence of aftershocks. People may have returned home.
Physical Measurements

The basic idea is to measure changes in distance, ground elevation, or the physical properties of a rock in order to monitor:-

- Movement along faults.
- The build-up of elastic strain.

Several types of measurement are possible, including:-

- Geodetic (distance).
- Tilt (change in slope).
- Electrical conductivity
The philosophy behind physical measurements

Change in Physical Properties

Earthquake Occurs

Next Earthquake?
Geodetic Measurements

Simply measuring the change in distance between two points. This is now done using a laser beam (or GPS). The time taken for a laser beam to be reflected back from a mirror provides a very accurate measure of the distance. Any change in distance between two fixed points on either side of a fault reflects movement along the fault.

As the fault moves, the distance between the laser source and the reflector increases. Measurements need to be made from exactly the same points on a regular basis.
Changes in distance (cm) across segments of the San Andreas Fault system between 1959 and 1970.
Tiltmeters

The simplest design is a water-tube tiltmeter. It acts like a fancy spirit level to continuously measure changes in slope (tilt) on the earth’s surface. Despite its simplicity, it is very precise and can measure changes of 1/10,000 of a degree!!

In reality the two reservoirs are connected by a 30 foot tube and the changes in liquid levels between the two reservoirs are measured electronically.
Electrical Conductivity

- Solid rocks are very poor conductors of electricity. Consequently, the electrical resistance (measured in ohm’s) is very high for rocks.

- If, however, rocks are cracked and shattered due to excessive strain, water will percolate through the cracks and decrease the electrical resistance.

- That is, water-logged rocks become better conductors of electricity.

- The idea is then, that by continuously monitoring electrical conductivity in rocks close to an active fault, one might detect the gradual build-up of elastic strain and fracturing prior to an earthquake.
Other Methods

- Unusual behavior of animals!
- Changes in the level and quality of well water.
- Increase in the release of radon gas

**Radon Gas**

- Radon is continuously produced in rocks by the decay of radioactive minerals.
- If the rock is suddenly fractured due to the build-up of strain – then the accumulated radon will be released and dissolved in groundwater.
- Thus the sudden increase in radon abundances in streams, wells and groundwater might be a useful method for predicting earthquakes.
- PROBLEM: we don’t have enough information on the background levels of radon in streams, wells etc.
Earthquake Forecasting

Long-Term Predictions

Careful measurement of the movement along faults enable a movement “budget” to be calculated. Thus by identifying seismic gaps, coupled with the rate of movement where faults are locked, a long-term prediction can be made (tens to hundreds of years).
Earthquake Probability

Using the past earthquake records, combined with a knowledge of fault movement, the U.S. Geological Survey has come up with probability estimates for earthquakes >6.7 in the San Francisco Region between 2000 and 2030.

Where was 6.0 magnitude, Nappa, August 24, 2014 earthquake?
Location of West Nappa Fault (Yellow)

Is it part of the Hayward or the Calaveras system?
Earthquake Probability Map for Europe
Earthquake Forecasting

Short-Term Predictions

Are not yet possible. The basic idea is that by identifying foreshocks and making detailed measurements of changes in physical properties (movement, tilt, conductivity etc.) prior to large earthquakes, a method for short-term predictions can be developed. (the present situation is rather similar to that for forecasting hurricanes about 50 years ago)