• The probability that an earthquake can be estimated by looking at how often earthquakes have occurred in the past on the fault.
• This assumes that there is a relatively regular cycle in earthquake occurrence.
How far the crust can be deformed before it breaks is described by the shear modulus

\[ V_p = \sqrt{\frac{K + \frac{4}{3} \mu}{\rho}} \]

\[ V_s = \sqrt{\frac{\mu}{\rho}} \]

\( K = \) bulk modulus

\( \approx 5 \times 10^{10} \text{ N/m}^2 \)

\( \mu = \) shear modulus

\( \approx 3.3 \times 10^{10} \text{ N/m}^2 \)
The amount of force being applied to the rock

The distance the rock deforms

- We will use a sliding sandpaper block as a model of a fault, to investigate whether a repeating cycle is a good way to describe earthquake occurrence.
In our sliding block experiment:
- the distance the block jumps represents the
- The length of the block represents the
- The length of the long board represents the
- The time between jumps represents the
- choices are:
  - A) time between earthquakes,
  - B) offset,
  - C) fault rupture length
  - D) fault

What was each of the following represent?
- The stretching of the rubber band
- The velocity the pencil moves
- The slow steady force moving the pencil
- The properties of the system that make it more difficult to move/rupture (weight of the rock, sandpaper roughness)
- choices are:
  - A) offset,
  - B) tectonic plate motion forces,
  - C) tectonic plate velocity,
  - D) fault rupture length,
  - E) shear modulus,
  - F) energy stored in the deforming rock,
  - G) fault

Everyone fills out this form as we go

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>pencil pos</td>
<td>pencil pos</td>
<td>1/cm</td>
<td>block position</td>
<td>time distance</td>
<td>time</td>
<td>block distance</td>
<td>1/cm</td>
<td>1/cm</td>
</tr>
<tr>
<td>1/5 cm/sec</td>
<td>(cm)</td>
<td>(cm)</td>
<td>(cm)</td>
<td>(sec)</td>
<td>(cm)</td>
<td>(sec)</td>
<td>(cm)</td>
<td>(cm)</td>
<td>(cm)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
• In our sliding block experiment:
  • the distance the block jumps represents the
  • The length of the block represents the
  • The length of the long board represents the
  • The time between jumps represents the

• choices are: A) time between earthquakes,
  B) offset,
  C) fault rupture length
  D) fault

• In our sliding block experiment:
  • The stretching of the rubber band represents the
  • The velocity the pencil moves represents
  • The slow steady force moving the pencil represents the
  • The properties of the system that make it more difficult to move/rupture
    (weight of the rock, sandpaper roughness) represent the

• choices are: A) offset,    B) tectonic plate motion forces,
  C) tectonic plate velocity, D) fault rupture length,
  E) shear modulus,    F) energy stored in the deforming rock,
  G) fault
• This goes on forever* because of steady tectonic plate motion
• In the real case, we want to know how often these earthquakes occur – ON AVERAGE.

On real faults, we look for evidence that earthquakes have occurred again and again.
Paleoseismology - recovering prehistoric fault movements
Paleoseismology - recovering prehistoric fault movements

Layer 1 (oldest)
Offset = 20cm

Layer 2 (intermediate)
Layer 1 (oldest)
Offset = 20cm

Paleoseismology - recovering prehistoric fault movements
Paleoseismology - recovering prehistoric fault movements

Layer 1 (oldest)

Layer 2 (intermediate)

Layer 3 (young)

Offset = 20cm + 20cm

Offset = 20cm
Paleoseismology - recovering prehistoric fault movements

Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

Offset = 20cm + 20cm + 10cm

Layer 4
Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

Offset = 10cm
Offset = 30cm + 10cm
Offset = 20cm + 20cm + 10cm
Paleoseismology - recovering prehistoric fault movements

Layer 4
Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

Offset = 20cm+20cm+10cm+2cm
Offset = 20cm+20cm+10cm+2cm
Offset = 20cm+10cm+2cm
Offset = 10cm+2cm
Offset = 2cm
Paleoseismology - recovering prehistoric fault movements

Layer 1 (oldest)

Offset = 20 cm

677 AD
Paleoseismology - recovering prehistoric fault movements

Layer 1 (oldest)

Layer 2 (intermediate)

Offset = 20cm

Offset = 20cm + 20cm
Paleoseismology - recovering prehistoric fault movements

Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

Offset = 20cm + 10cm
Offset = 20cm + 20cm
Offset = 20cm + 20cm + 10cm
Paleoseismology - recovering prehistoric fault movements

Layer 4
Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

Offset = 20cm + 20cm + 10cm
Offset = 20cm + 10cm + 2cm
Offset = 10cm + 2cm
Offset = 2cm
Paleoseismology - recovering prehistoric fault movements

Layer 5
Layer 4
Layer 3 (young)
Layer 2 (intermediate)
Layer 1 (oldest)

T=1857 AD
Offset = 20cm+20cm+10cm

T=1812 AD
Offset = 20cm+10cm+10cm+2cm

T=1480 AD
Offset = 20cm+10cm+2cm

T=1346 AD
Offset = 20cm+20cm+10cm+2cm

• The San Andreas Fault at Carrizo plain

http://pubs.usgs.gov/gip/dynamic/San_Andreas.html

Hayward fault

Paleoseismology

Trench across earthquake fault
Locate disturbed units
Carbon-14 dating of the unbroken and broken layers

Paleoseismology - recovering prehistoric fault movements

Recurrence Interval

- Recurrence interval = average time between earthquakes for a specific segment of a fault
- Earthquake history
  - 1857
  - 1812
  - 1480
  - 1346
- Intervals between earthquakes
  - interval 1 = 1857-1812 = 46 yrs
  - interval 2 = 1812-1480 = 332 yrs
  - interval 3 = 1480-1346 = 134 yrs
- Average interval = (46+332+134)/3 = 171 years
- Probability of an earthquake this year on this segment of the San Andreas: 1 in 171 = 1/171 = 0.0058 = 0.58%
Hazard vs Risk

- Natural hazard - an event resulting from natural environmental processes that has the potential to cause harm to a population or a community
- Natural hazard assessment - evaluating the geographic extent and probability/likelihood that a natural hazard will occur

- Risk - quantification of the population or property that is at risk of being affected by a natural hazard
- Natural hazard risk assessment - evaluating the potential effects of a natural hazard on a population or a community and the likelihood that those economic/social effects would occur.
You can’t dig a trench if you can’t see the fault at the surface
The Loma Prieta, California, Earthquake of October 17, 1989 - Liquefaction

Normally, water fills the spaces between sediment grains, but the grains touch, and friction holds the sediment together.

Liquefaction increases the water-filled spaces between grains, allowing the sediment to flow like a liquid.
1964 Niigata earthquake

http://earthquake.usgs.gov/regional/world/event/images/1964_06_16_03.jpg

Loma Prieta earthquake liquefaction
Modern sand blow
- Silt and clay layers
- Filled fissure (sand dike)
- Liquified sand

Buried prehistoric sand blow
- Charcoal, sticks, etc.
- Artifacts
- Buried sand blow

Image source: http://web.mst.edu/~rogersda/nmsz
How often do they occur?

Time between earthquakes:

- 12000-8500 = 3500 yrs
- 8500-6100 = 2400 yrs
- 6100-4000 = 2100 yrs
- 4000-2000 = 2000 yrs

Average = (3500+2400+2100+2000) yrs/4 = 2500 yrs
New Madrid earthquake

- **New Madrid earthquakes**
  - Dec 16, 1811;
  - Jan 23, 1812;
  - Feb 7, 1812

- **Magnitude**
  - Mw 7.2-7.3,
  - 7.0,
  - 7.4-7.5

<table>
<thead>
<tr>
<th>Modified Mercalli Intensity</th>
<th>Peak Ground Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt; 0.17 %g</td>
</tr>
<tr>
<td>II-III</td>
<td>0.17 - 1.4 %g</td>
</tr>
<tr>
<td>IV</td>
<td>1.4 - 3.9 %g</td>
</tr>
<tr>
<td>V</td>
<td>3.9 - 9.2 %g</td>
</tr>
<tr>
<td>VI</td>
<td>9.2 - 18 %g</td>
</tr>
<tr>
<td>VII</td>
<td>18 - 34 %g</td>
</tr>
<tr>
<td>VIII</td>
<td>34 - 65 %g</td>
</tr>
<tr>
<td>IX</td>
<td>65-124 %g</td>
</tr>
<tr>
<td>X+</td>
<td>&gt; 124 %g</td>
</tr>
</tbody>
</table>

Wald, 1999b; Trifunac & Brady, 1975
Earthquakes in:
A.D. 900 +/- 100 years
A.D. 1450 +/- 150 years
1811-1812
Recurrence interval:
1450-900=550 yrs
1811-1450=361 yrs
Average=
(550+361) yrs/2
=455 yrs

Hazard vs Risk

• Natural hazard - an event resulting from natural environmental processes that has the potential to cause harm to a population or a community
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