EOSC 562  Earthquakes

- course outline and policies
- my absences / Jan 13 or 14 seminar instead
- First intro lecture and (hopefully) discussion
- reading for next time

January 12, 2010
M 7 Haiti Earthquake: one year ago today
Haiti is along the boundary between the Caribbean Plate and the North American Plate.

From Calais et al., Nature Geoscience, 2011
Fatalities  (Since 1900)  Compiled by Roger Bilham
Built to withstand hurricanes, not earthquakes
People ran indoors (hurricane procedure)
Extremely high *intensity* in populated areas

Categories of faults, geometric description and symbols
Plate boundaries and earthquakes

**Geology of faults (descriptive)**

Stress, strain, and faulting (mostly definitions)

**Mercalli Intensity**

**Magnitude**
ʻreverseʼ or ʻthrustʼ fault

ʻnormalʼ fault

ʻstrike-slipʼ or ʻtransformʼ fault

A Dip-slip faults

B Strike-slip faults

C Oblique-slip fault

Copyright © McGraw-Hill Companies, Inc. Permission required for reproduction or display.
Fault surface orientation: strike and dip

Indicating direction of slip quantitatively: the slip vector

- let's define the slip direction (vector) in terms of the slip plane itself: “rake” of the slip vector, often just called “slip vector”

- convention: slip vector shows displacement of the hanging wall relative to the footwall, and values are from -180° to 180°
Slip vector convention

Fault plane may be shown in 2D by how it would intersect a bowl, as viewed from above

slip vector = intersection of this (slip) plane with another plane
“Beachball” symbol to express focal mechanism (fault plane orientation and slip vector)
Haiti Earthquake focal mechanism

---

Haiti Region
Mw 7.0
USGS Centroid Moment Tensor Solution

Left-lateral faulting earthquake makes sense...
some oblique component, too.
Faulting at plate boundaries

What are the possible ways to change the configuration of this stuff?

- translation
- rotation
- strain (distortion, i.e. change in shape and/or volume)

Types of stress (F/area) and resulting strain

- compression ("normal" stress and strain)
- tension ("normal" stress and strain)
- shear stress (and shear strain)
Stress and strain

• For ELASTIC materials, stress is proportional to strain (Hooke’s law)
• Stress required to generate a certain amount of strain depends on Young’s modulus $E$ (infinite $E$ means perfectly rigid)

$$
\sigma = E \epsilon
$$

• Typical values of $E$ for geological materials are 100 GPa (rocks) and 10 GPa (ice)

• For VISCOUS materials, stress is proportional to strain RATE
• Stress required to generate a certain strain RATE (i.e., flow) depends on viscosity $\eta$

$$
\sigma = \eta \dot{\epsilon}
$$

• Typical values of $\eta$ for geological materials are $1e18-1e22$ Pa s (upper mantle) $1e12-1e18$ Pa s (ice)

Hooke’s Law in 1D: all that matters is the lengthening of the spring.

In the Earth, stretching (or contraction) and distortion are three-dimensional.

This is strain, a second-order tensor.

Hooke’s law in 1D: $F = kx$

Hooke’s law in 3D:

$$
\sigma = E \epsilon
$$

Stress is also a second-order tensor.
6 numbers are needed to describe stress (and strain) in 3D.

\[
\begin{pmatrix}
\epsilon_1 & \epsilon_6 & \epsilon_5 \\
\epsilon_6 & \epsilon_2 & \epsilon_4 \\
\epsilon_5 & \epsilon_4 & \epsilon_3
\end{pmatrix} = \epsilon
\]

## Faults & Byerlee’s law

- Byerlee’s law says that faults don’t move unless the shear stress exceeds the normal stress times the static friction coefficient \(f\).
  
  \[\tau = f\sigma_n\]

- For almost all geological materials, \(f = 0.6-0.7\).

- In general, the normal stress is the weight of the overburden:
  
  \[\sigma_n \approx \rho gh\]

- The shear stress \(\tau\) is provided by tectonic forces.
Earthquakes can be unusually devastating due to either (1) high intensities in areas with high populations or (2) other events caused by the earthquake (landslides, fires, tsunamis, etc.) also poor construction.

Both: Magnitude only 6.7 to 6.9 but intensity of 9 or more in very populous areas extreme damage and thousands of deaths

• We must distinguish between magnitude and intensity
  – magnitude indicates how much energy was released.
  – intensity is how strong the ground motion is at the felt location.
• Consider a light bulb …
  Fixed magnitude Local intensity Local intensity
Earthquake Intensity: factors that contribute

1. Earthquake magnitude
2. Distance from epicentre
3. Ground type
4. Duration

Subjective description of violence and duration of shaking, and damage. Not based on quantitative measures of ground displacement, velocity or acceleration.

The Mercalli Intensity Scale was devised before accurate seismometers were widespread.

Modified Mercalli Intensity Scale: I to XII

Example: VII “Strong”

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, cornices (also 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.

**Masonry A**: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; 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.

Mercalli scale was originally devised (and refined) 1883-1902, modified 1931 and 1958
Why bother with intensity?

- emergency response planning, insurance, loss estimating
- inferring magnitude from subjective historical accounts
  (such as the Lawson Report on the 1906 SF earthquake)

PAGER map for the Sichuan Earthquake

M 7.9 - EASTERN SICHUAN, CHINA
Monday, May 12, 2005 at 06:28:01 UTC
Location: 31.9N 102.4E Depth: 16km
Alert version: 12

Estimated Population Exposed to Earthquake Shaking

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>2.4k</td>
<td>Extreme Heavy</td>
<td>V, Heavy, V, Heavy</td>
</tr>
<tr>
<td>IX</td>
<td>1,24k</td>
<td>Very Strong Heavy</td>
<td>V, Heavy, Heavy Heavy</td>
</tr>
<tr>
<td>VII</td>
<td>3,815k</td>
<td>Strong Heavy</td>
<td>Moderate, Heavy Heavy</td>
</tr>
<tr>
<td>VI</td>
<td>18,642k</td>
<td>Strong Light</td>
<td>Moderate Moderate/Heavy</td>
</tr>
<tr>
<td>V</td>
<td>63,137k*</td>
<td>Moderate Light</td>
<td>V, Light, Light Light</td>
</tr>
<tr>
<td>IV</td>
<td>1,903k*</td>
<td>Light</td>
<td>None</td>
</tr>
<tr>
<td>II-III</td>
<td>1.3k - 1.9k*</td>
<td>Weak</td>
<td>None</td>
</tr>
<tr>
<td>I</td>
<td>Not Felt</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Estimated exposure only includes population within the map area.

Selected City Exposure

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Tai'an City</td>
</tr>
<tr>
<td>M2</td>
<td>Sichuan</td>
</tr>
<tr>
<td>M3</td>
<td>Mianyang</td>
</tr>
<tr>
<td>M4</td>
<td>Chengdu</td>
</tr>
<tr>
<td>M5</td>
<td>Quanzhou</td>
</tr>
<tr>
<td>M6</td>
<td>Yongkang</td>
</tr>
<tr>
<td>M7</td>
<td>Deyang</td>
</tr>
<tr>
<td>V1</td>
<td>Shaping</td>
</tr>
<tr>
<td>V2</td>
<td>Zigong</td>
</tr>
<tr>
<td>V3</td>
<td>Neijiang</td>
</tr>
<tr>
<td>V4</td>
<td>Zhangzhou</td>
</tr>
</tbody>
</table>

Shaking intensity: M5
Generally, maximum intensity correlates with magnitude

<table>
<thead>
<tr>
<th>Magnitude / Intensity Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1.0 - 3.0</td>
</tr>
<tr>
<td>3.0 - 3.9</td>
</tr>
<tr>
<td>4.0 - 4.9</td>
</tr>
<tr>
<td>5.0 - 5.9</td>
</tr>
<tr>
<td>6.0 - 6.9</td>
</tr>
<tr>
<td>7.0 and higher</td>
</tr>
</tbody>
</table>

But proximity to the *epicenter*, local amplification of shaking, and other effects can make violence and duration of shaking worse than expected

**Earthquake Intensity: Effect of ground type**

- **Harder rocks**
  - no amplification
  - a mixture of frequencies
- **Softer rocks**
  - shaking is *amplified*
  - low-frequencies may reverberate in basins, plus soft rocks absorb high frequencies
Buildings in central Kobe, Japan.

**Foreground:** The complete collapse of a two- or three-story traditional Japanese wood-frame building with a heavy tile roof.

**Background:** A six- or seven-story office building of 1960s' or 1970s' vintage. This reinforced concrete building is a typical example of a mid-height story collapse.

**Left:** The high rise is post-1981 office building that has no apparent damage. Ground settlement in the vicinity of these buildings was between 30 and 60 centimeters.


### Intensity estimates come from

- felt reports from people (e.g., USGS “Did You Feel It” online questionnaires, generates “community internet intensity map”)

- felt reports from seismometers (e.g., USGS ShakeMap, generates “rapid instrumental intensity map” from seismograms)

**PAGER:** population exposure to various intensities
Part of the USGS “Did You Feel It” questionnaire

While answering all these questions is optional, we encourage you to fill out as many as possible so we can provide a more accurate intensity estimate.

What was your situation during the earthquake? No answer
If you were inside please select the type of building or structure:
No building
If other, please describe:

Were you asleep during the earthquake?
No

Did you feel the earthquake? (If you were asleep, did the earthquake wake you up?)
☐ No ☐ Yes

Did others nearby feel the earthquake?
No answer/Don't know/No one else nearby

Your experience of the earthquake:

How would you best describe the ground shaking?
No description

About how many seconds did the shaking last?

How would you best describe your reaction?
No answer/Don't remember

How did you respond? (Select one.)
No answer/Don't remember
If other, please describe:

Was it difficult to stand or walk?
No answer/Did not try

Earthquake effects:

Did you notice the swinging/swaying of doors or hanging objects?
No answer/Did not look

Did you notice creaking or other noises?
No answer/Did not pay attention

Did objects rattle, topple over, or fall off shelves?
No answer/No shelves

Did pictures on walls move or get knocked askew?
No answer/No pictures

Did any furniture or appliances slide, tip over, or become displaced?
No answer/No furniture

Was a heavy appliance (refrigerator or range) affected?
No answer/No heavy appliance
Were free-standing walls or fences damaged? If you were inside, was there any damage to the building? Check all that apply.

- No damage
- Hairline cracks in walls
- A few large cracks in walls
- Many large cracks in walls
- Ceiling tiles or lighting fixtures fell
- Cracks in chimney
- One or several cracked windows
- Many windows cracked or some broken out
- Masonry fell from block or brick wall(s)
- Old chimney, major damage or fell down
- Modern chimney, major damage or fell down
- Outside wall(s) tilted over or collapsed completely

2010 Haiti Earthquake Intensity
USGS PAGER maps show number of people exposed to different Mercalli intensities, and estimate (based on local construction) casualties and financial losses.

Onur and Seeman, 2004


These are minimum values: numbers will be higher on softer ground.
Earthquake intensity for 1811-1812 New Madrid earthquakes, based on historical accounts

- Shaking very frightening
- Structural damage possible
- Shaking frightening to most
- Damage rare
- Felt by all
- No damage
- Felt by some

Roman numerals refer to intensity of shaking on the Modified Mercalli Intensity Scale

1872 Washington, M=7.4