Seismic Hazard

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Pictures and slides:
NESEC
USGS
FEMA
Weston Observatory
Kean University

National Cathedral, 5.8
Plate tectonics and earthquakes – how and where but not when.....

Measurement scales

Earthquake aftershocks

Earthquake Swarms

What to expect; what to do in an earthquake

Hazard Maps

Vermont’s geology and earthquake history

Examples of Damage
Most earthquakes occur along collisional plate boundaries

Map shows 7.0 or greater from 1900 to 2013
Tectonic environments-

Plate boundaries - rift, subduction zone, volcanic arc

Intraplate – within plate
Earthquakes-

Last from seconds to minutes; Occur anytime, day or night

Pressure builds and energy is released when rocks crack and slide past each other along a fault

Energy radiates out in all directions

Epicenter – directly above the focus where the earthquake originates
EARTHQUAKE CHARACTERISTICS: FOCUS, EPICENTER, DEPTH, SHOCKWAVES

- Shallow focus = ~100 km depth or less
- Deep focus = 100-700 km depth

- P-waves (primary / push-pull) = felt first (5-8 km/s): feels like a shock wave rattling windows
- S-waves (secondary / shake) = felt a few seconds later (3-5 km/s): can be very destructive

Ex 1: Loma Prieta (California 1989): 6.7 magnitude at 18 km depth (inland)
Ex 2: Sendai (Japan 2011): 9.0 magnitude at 32 km depth (70 km the coast)
Magnitude – each quake has a single magnitude expressed as a number

Shaking intensity varies from place to place

Shaking may be amplified by soft soils
Measurement of Earthquakes

- **Modified Mercalli scale** measures intensity (I-X);
  Describes the effects of earthquakes. Values vary with distance from epicenter, building materials used, and population density.

- **Richter scale** measures magnitude (1.0-?) using the amplitude (height) of the S wave recorded on a seismogram.

Each division is a 10-fold increase in amplitude and an approximate 30-times increase in energy released.
# Modified Mercalli Scale (MMI-MMX)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Shaking</th>
<th>Description/Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Not felt</td>
<td>Not felt except by a very few under especially favorable conditions.</td>
</tr>
<tr>
<td>II</td>
<td>Weak</td>
<td>Felt only by a few persons at rest, especially on upper floors of buildings.</td>
</tr>
<tr>
<td>III</td>
<td>Weak</td>
<td>Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.</td>
</tr>
<tr>
<td>IV</td>
<td>Light</td>
<td>Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.</td>
</tr>
<tr>
<td>V</td>
<td>Moderate</td>
<td>Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.</td>
</tr>
<tr>
<td>VI</td>
<td>Strong</td>
<td>Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.</td>
</tr>
<tr>
<td>VII</td>
<td>Very strong</td>
<td>Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.</td>
</tr>
<tr>
<td>VIII</td>
<td>Severe</td>
<td>Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.</td>
</tr>
<tr>
<td>IX</td>
<td>Violent</td>
<td>Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.</td>
</tr>
<tr>
<td>X</td>
<td>Extreme</td>
<td>Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.</td>
</tr>
<tr>
<td>Magnitude</td>
<td>Earthquake Effects</td>
<td>Estimated Number Each Year</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>2.5 or less</td>
<td>Usually not felt, but can be recorded by seismograph.</td>
<td>900,000</td>
</tr>
<tr>
<td>2.5 to 5.4</td>
<td>Often felt, but only causes minor damage.</td>
<td>30,000</td>
</tr>
<tr>
<td>5.5 to 6.0</td>
<td>Slight damage to buildings and other structures.</td>
<td>500</td>
</tr>
<tr>
<td>6.1 to 6.9</td>
<td>May cause a lot of damage in very populated areas.</td>
<td>100</td>
</tr>
<tr>
<td>7.0 to 7.9</td>
<td>Major earthquake. Serious damage.</td>
<td>20</td>
</tr>
<tr>
<td>8.0 or greater</td>
<td>Great earthquake. Can totally destroy communities near the epicenter.</td>
<td>One every 5 to 10 years</td>
</tr>
</tbody>
</table>
The Great Alaskan earthquake and tsunami of 1964 – magnitude 9.2
Foreshock, mainshock, and aftershock

Large earthquakes rarely occur alone; several felt aftershocks within an hour.

Mainshock - Largest magnitude quake of the set

Change in stress on fault in the mainshock may be great enough to trigger aftershocks on nearby faults.

The stress change dies off quickly with distance from the fault; rarely see aftershocks more than a few km from the main fault.

Bigger quake = more and larger aftershocks.

How many aftershocks will there be? for each magnitude 5 aftershock in a sequence, there are 10 magnitude 4 aftershocks, 100 magnitude 3 aftershocks, 1000 magnitude 2 aftershocks, etc.
What is an earthquake swarm?

It’s not an aftershock.

“Typically..., you have a large earthquake followed by a bunch of aftershocks, ... earthquakes in the same spot,” Don Blakeman, geophysicist.

“That’s not a swarm. A swarm usually doesn’t have the large earthquake beginning, but is instead a series of earthquakes of similar low magnitudes that occur in the same region.” (ex. 50 earthquakes an hour)

Swarm sequences generally last a few days or weeks.

Swarms will have many earthquakes within a day or a week.

Typically, magnitude 2-3 which result in no damage to minor damage (books falling off shelves etc)

They DO NOT foreshadow a large earthquake.
Before a quake

Identify safe places such as under a sturdy piece of furniture or against an interior wall

Practice how to “Drop, Cover, and Hold On!”

Before an earthquake occurs, secure or move items that could fall and cause injuries (e.g., bookshelves, mirrors, light fixtures).
Examples of potential hazards from earthquake shaking
If you are inside a building:

Stay where you are until the shaking stops.

Do not run outside. Do not get in a doorway or near glass.

If in bed, stay there. Otherwise: Drop, Cover, and Hold on to any sturdy covering.

People who use wheelchairs or other mobility devices should: lock their wheels, remain seated until the shaking stops, use a pillow or arms to protect their your head.
If outside:

Move away from buildings, streetlights, and utility wires.

In a city, you may need to go inside to avoid falling debris.

Then...DROP, COVER and HOLD ON

If you are in a car:

stop and stay inside

Stay away from bridges and utility lines

Afterwards, avoid bridges, ramps and roads which may have been damaged.
**When the shaking stops**

If there is a clear path to safety, leave the building and go to an open space away from damaged areas.

If you are trapped, do not move about or kick up dust.

If you have a cell phone, call or text for help.

Tap on a pipe or wall or use a whistle, so that rescuers can locate you.

Be prepared to “Drop, Cover, and Hold on” in the likely event of aftershocks.
Hazards Maps

Ground shaking varies from place to place; hazard mapping shows this variability.

The mapped hazard refers to an estimate of the probability of exceeding a certain amount of ground shaking, or ground motion, in 50 years.

The hazard depends on the magnitudes and locations of likely earthquakes, how often they occur, and the properties of the rocks and sediments that earthquake waves travel through.
National Seismic Hazard Map developed by the U.S. Geological Survey in 2008. This map shows contours of the percentage of the force of gravity that is predicted to have a 2% chance of being exceeded in 50 years.
Shake Map – shows intensity and damage
Mineral, VA 5.8 quake, August 23, 2011

Light to moderate damage near epicenter – ex. Washington Monument

No damage at distance of ~50 miles
Did You Feel It? East vs West: This image illustrates how earthquakes are felt over much larger areas in the eastern U.S. than those west of the Rocky Mountains. The map compares USGS "Did You Feel It?" data from the magnitude 5.8 earthquake on August 23, 2011 in central Virginia (green) to data from an earthquake of similar magnitude and depth in California (red).
What about Vermont?
Earthquakes >3.0 In/ Near the NE USA, 1638 - 2001
### Some Earthquakes Felt in Vermont

<table>
<thead>
<tr>
<th>Location</th>
<th>Mag.</th>
<th>Mercalli Int.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montreal, Que. 1732</td>
<td>5.8</td>
<td>IV - VI</td>
</tr>
<tr>
<td>La Malbie, Que. 1925</td>
<td>6.5</td>
<td>III - IV</td>
</tr>
<tr>
<td>Timiskaming, Que. 1935</td>
<td>6.1</td>
<td>III - IV</td>
</tr>
<tr>
<td>Ossipee, N.H. 1940</td>
<td>5.5</td>
<td>IV - VI</td>
</tr>
<tr>
<td>Ossipee, N.H. 1940</td>
<td>5.5</td>
<td>IV - VI</td>
</tr>
<tr>
<td>Meddha, N.Y. 1944</td>
<td>5.2</td>
<td>IV - V</td>
</tr>
<tr>
<td>ME-NH-Que Bord 1973</td>
<td>4.8</td>
<td>III - V</td>
</tr>
<tr>
<td>Gaza, N.H. 1982</td>
<td>4.7</td>
<td>III - IV</td>
</tr>
<tr>
<td>Goodnow, N.Y.</td>
<td>5.1</td>
<td>III - IV</td>
</tr>
<tr>
<td>Saguenay, Que. 1988</td>
<td>6.2</td>
<td>IV - V</td>
</tr>
<tr>
<td>Date</td>
<td>Time</td>
<td>Lat (N)</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>04/10/62</td>
<td>09:30am</td>
<td>44.11</td>
</tr>
<tr>
<td>07/06/43</td>
<td>05:10pm</td>
<td>44.84</td>
</tr>
<tr>
<td>03/31/53</td>
<td>07:59am</td>
<td>43.07</td>
</tr>
</tbody>
</table>
Vermont is in the more stable interior of the North American plate, not at a plate boundary, but there is still stress.

Waves travel further and faster and have less attenuation in old, cold crust (northeast US)

Depth of New England quakes are shallow – usually less than 15 km or 9 miles (shallow is 0-70 km)
Are there faults in Vermont?

Inactive faults are commonplace..... Because we WERE at an active plate collision boundary 500 – 350 mya
Faults in Vermont

Most are 350 my to 500 million years old; some are younger.

Generally not indicative of where an earthquake would occur.

There are no identified surface expressions of fault movement.

Faults are inactive although some may be zones of weakness.
Champlain Thrust Fault at Lone Rock Point, Burlington
Moved 35-50 miles and up ~8800 ft
We can estimate how severe the damage may be in a given event, but there is not an early warning system.

Predict impact but not the time of the earthquake.

Most injuries are due to collapsing walls, falling glass, flying objects. What does your workplace look like?
HAZUS ANALYSES OF ELEVEN SCENARIO EARTHQUAKES IN NEW ENGLAND

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http://www.anr.state.vt.us/dec/geo/hazinx.htm
Montreal 6.2
Postulated Strong Earthquakes Which Can Affect Vermont (500 Year) from Ebel and others, 1995

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<tr>
<th>Location</th>
<th>Magnitude</th>
</tr>
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<tbody>
<tr>
<td>Montreal, Quebec</td>
<td>6.8</td>
</tr>
<tr>
<td>Goodnow, N.Y.</td>
<td>6.6</td>
</tr>
<tr>
<td>Charlevoix, Quebec</td>
<td>6.6</td>
</tr>
<tr>
<td>Tamworth, N.H.</td>
<td>6.2</td>
</tr>
<tr>
<td>Middlebury, Vt.</td>
<td>5.7</td>
</tr>
<tr>
<td>Swanton, Vt.</td>
<td>5.7</td>
</tr>
</tbody>
</table>
Damage to residences in NE Kingdom from 6.6 event in Goodnow, NY
As Figure 14 illustrates, the worst-case probability of functionality across the three events studied ranges from a low of 25% to a high of 93%. No facilities have a 100% probability of functionality.
3.2 in Concord, CA
Mineral, VA 5.8 Earthquake

Images courtesy of FEMA E-74 Nonstructural Hazard Mitigation Presentation
Wells, Nevada – 6.0 (2008)
Hawaii 6.2
Japan 6.6
Charleston, SC - Great Quake of 1886
~7.0
7.9 in Sichuan, China in 2008 – school collapse trapped 900 students, collapse of two chemical plants and release of 80 tons of liquid ammonia
7.9 near Denali, Alaska in 2003 - Road damage, fuel tanks, rail damage