IRIS

Asperities

Background page to accompany the animations on the website: IRIS Animations

LINK To P. 2 Vocabulary

Introduction

What is an asperity?

An asperity (is an area on a fault that is stuck or locked. In the Earth, tectonic earthquakes are caused by slip along a fault plane, where two rock bodies are in rigid contact. The friction along the fault plane is not uniform in strength, so overall movement involves slip on one or more asperities, or "stuck patches" where the friction is highest. Most of the energy that is released by earthquakes comes from the patches that become "unstuck."

More About Asperities*

Total fault offset accumulates through time in an uneven fashion, primarily by movement on first one, and then another section of the fault. The portions of the fault that produce great earthquakes can remain "locked" and quiet for one hundred or more years, while the strain is building up; then, in great lurches, the strain is released, producing a great earthquake.

Asperities, which may be caused by roughness, or protrusions on the fault, act like welded contacts between the sides of the fault. Younger faults have rougher surfaces with more asperities. As a fault repeatedly ruptures, the asperities can be worn down, creating fault gouge and smoothing the fault. The gouge material often decomposes to a fine clay and forms a thin layer which "greases" the fault for easier sliding. Fluids can also facilitate slip by reducing the normal stress on the fault.

The San Andreas Fault is actually a fault system that is more than 800 miles long and the seismically active portion extends to depths of at least 10 miles within the Earth and ranges from a few hundred feet to a mile or more wide. It doesn't slip all at once, but rather, earthquakes jump around on it as local asperities break. On some stretches of some faults, however, such as around Hollister on the Calaveras fault, date movement occurs primarily by constant repeated creep events rather than by sudden earthquake offsets. In historical times, these creeping sections have not generated earthquakes of the magnitude seen on "locked" sections.

The dynamics of fault rupture are complex, but general fault behavior can be explained with a simple model in which slip promotes fault weakening.

Fault slip occurs in three stages:

1) initiation of sliding on a small portion of the fault,
2) growth of the slip surface, and
3) termination of slip and fault healing. Earthquakes occur on preexisting faults operating in a "stick- slip" mode. Earthquakes are "slip" episodes; they are followed by periods of no slip ("stick"), during which elastic strain increases away from the fault. Although some growth of the fault may occur with each earthquake, we can generally assume that for large earthquakes (M>6) the faulting process primarily involves repeated breaking of the same fault segment rather than creation of a new fault surface."

Asperity Quakes Compared to Chopstick Breaks

Most earthquakes happen on faults. The process that causes them is similar to what happens if you bend a chopstick until it breaks.

Comparing the multiple asperities along a fault zone with the multiple failures of a bamboo chopstick:

Regional compression and extension are acting on the "fault zone" (plate tectonics is acting on fault zones; hands are acting on the chopstick)

There is a build-up of stress (hold the tips of the chopstick with the tips of your fingers and feel the stress build up as elastic energy is stored in the chopstick). If you release the energy before the chopstick breaks, it will return to its pre-stressed shape.

Knowledge of the rate of strain buildup allows one to "forecast" that it (the chopstick or the fault) will break. But it is difficult to predict the time and place where it will breaks next.

The weakest zones will break first.

One may hear some precursors (weakest asperities breaking).

There is elastic deformation and brittle failure.

There is elastic rebound as the stored energy in the deformed material is released, the material rebounds to its previous shape.

Sound waves generated by the breaking chopstick can be compared to the compressive seismic waves (P waves) of an earthquake.

Bottom line: Tectonic earthquakes will occur anywhere within the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. Most boundaries do have such asperities and this leads to a form of stick-slip behaviour. Once the boundary has locked, continued relative motion between the plates leads to increasing stress and therefore, stored strain energy in the volume around the fault surface. This continues until the stress has risen sufficiently to break through the asperity, suddenly allowing sliding over the locked portion of the fault, releasing the stored energy. This energy is released as a combination of radiated elastic strain seismic waves, frictional heating of the fault surface, and cracking of the rock, thus causing an earthquake.

*From "Can Earthquakes be Predicted?" by Michelle Kathleen Hall-Wallace

Vocabulary

Asperity—literally "roughness. It is an area on a fault that is stuck or locked. A type of surface roughness appearing along the interface of two faults. Physics the elastically compressed region of contact between two surfaces caused by the normal force

Elastic strain—Earthquakes are caused by the sudden release of energy within some limited region of the rocks of the Earth. The energy can be released by elastic strain, gravity, chemical reactions, or even the motion of massive bodies. Of all these the release of elastic strain is the most important cause, because this form of energy is the only kind...

Fault plane—The plane along which the break or shear of a fault occurs. It is a plane of differential movement, that can be vertical as in a strike slip fault or inclined like a subduction zone fault.

Fault zone—Since faults do not usually consist of a single, clean fracture, the term fault zone is used when referring to the zone of complex deformation that is associated with the fault plane.

Strain—Strain is defined as the amount of deformation an object experiences compared to its original size and shape. For example, if a block 10 cm on a side is deformed so that it becomes 9 cm long, the strain is (10-9)/10 or 0.1 (sometimes expressed in percent, in this case 10 percent.) Note that strain is dimensionless.
Learn more: **http://www.uwgb.edu/DutchS/structge/stress.htm**

.**Stress**—Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on.
Learn more: **http://www.uwgb.edu/DutchS/structge/stress.htm**

Tectonic earthquake—an earthquake that is due to the movement of the tectonic plates. Tectonic earthquakes will occur anywhere within the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. Other earthquakes can be caused by blasts.

Strike-slip Fault with Spaghetti Asperities—Vice Method

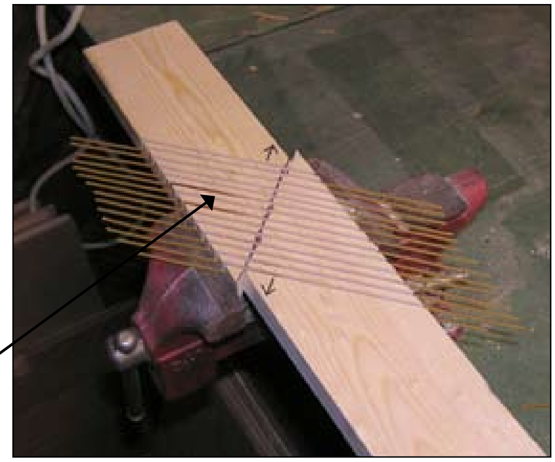
From John Lahr's Fun With Science "Spaghetti Fault" (www.jclahr.com/science/earth_science/spagh_fault/index.html).
This fault model is a variation of one invented by Paul Doherty http://www.exo.net/~pauld/index.html).

Time

Construction 1 hour; demo 5-15 minutes

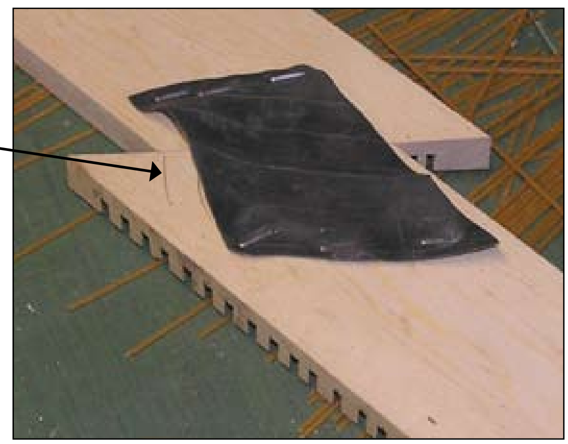
Content

Students will learn about forces in the Earth and be able to describe sequential earthquakes on a fault when steady force is applied. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur.



Materials

- 1 x 6 board 12-18 inches long. Cut shallow grooves in it with table saw at an angle of 45° to the length of the board. Then cut the board in two on the opposite 45° diagonal as shown in the picture (upper photo).
- Scrap of plastic or rubber sheet to staple on the back to hold the wood together, but loose enough so it doesn't resist the vice. (center)
- Vice
- Spaghetti noodles



Tools: Table saw, vice, staple gun

Set up and Demonstration

Prepare board as described under **Materials**. Staple the plastic to the back. Place it in the vice with just enough pressure to hold it in place and have the grooves lined up perfectly. Set spaghetti noodles in the grooves. Turn vice very slowly at a controlled rate throughout the process. TIn this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur. Sometime just one noodle breaks, somewhat analogous a small earthquake.

Quite a few break (foreshocks) a few seconds prior to a "massive event" (main shock) in which many break in rapid succession. This is followed by one or two remaining pops (aftershocks).

RETURN to ASPERITIES: http://www.iris.edu/about/ENO/aotw/

Strike-slip Fault with Spaghetti Asperities—Clamp Method

Modified from "Strike-slip Fault with Spaghetti Asperities"

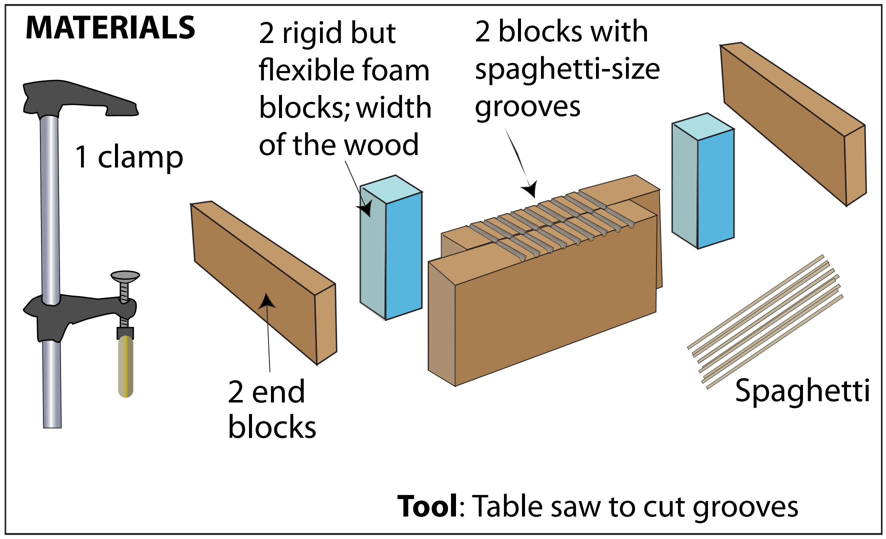
This is the same concept as the Vice Model, but lacks the control on the rate of block movement.

Time:

Construction 1 hour;
demo 5-15 minutes

Content:

Students will learn about forces in the Earth and be able to describe sequential earthquakes on a fault when steady force is applied. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur.



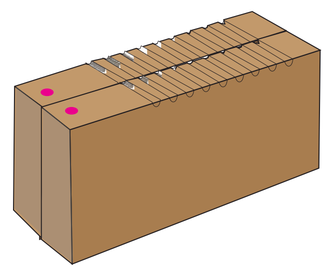
Procedure

Clamp two equal-length blocks together matching the ends. Cut shallow, narrow grooves in the two larger blocks with a table saw. Note that the pink dots (●) on the ends are together for groove cuts, but are flipped 180° horizontally for the assembly.

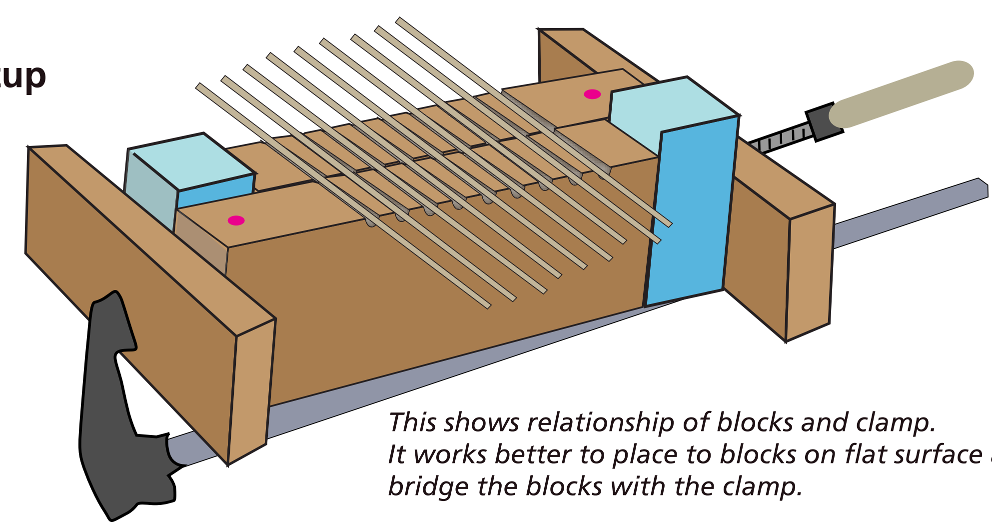
Assemble according to drawing below. Foam needs to be compressible, yet firm, and cut to the width of the gaps left at the grooved-wood ends when the grooves are aligned.

Set spaghetti noodles in the grooves. Turn clamp very slowly at a controlled rate throughout the process. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur. Sometime just one noodle breaks, somewhat analogous a small earthquake.

Quite a few break (foreshocks) a few seconds prior to a "massive event" (main shock) in which many break in rapid succession. This is followed by one or two remaining pops (aftershocks).



Setup



This shows relationship of blocks and clamp.
It works better to place to blocks on flat surface and bridge the blocks with the clamp.

RETURN to ASPERITIES: http://www.iris.edu/about/ENO/aotw/

Buildings and earthquakes—Which stands? Which falls?

Background pages with links to particular animations or lectures on site: **IRIS' Animations** and/or **Videos**
This has been assembled quickly and will be replaced as updated.

Activities pages 4-5 (touch to go there)

Haiti devastation exposes shoddy construction:
see page 6 for text and link to video!!!!

Introduction

The two most important variables affecting earthquake damage are (1) the intensity of ground shaking caused by the quake coupled with (2) the quality of the engineering of structures in the region. The level of shaking, in turn, is controlled by the proximity of the earthquake source to the affected region and the types of rocks that seismic waves pass through en route (particularly those at or near the ground surface).

Generally, the bigger and closer the earthquake, the stronger the shaking. But there have been large earthquakes with very little damage either because they caused little shaking or because the buildings were built to withstand that kind of shaking. In other cases, moderate earthquakes have caused significant damage either because the shaking was locally amplified, or more likely because the structures were poorly engineered.

Tall or Small? Which is Safer? It depends!!

Resonance is the oscillation, or up-and-down or back-and-forth motion caused by a seismic wave. During an earthquake, buildings oscillate (figure at right). Not all buildings respond to an earthquake equally. If the frequency of an oscillation is close to the natural frequency of the building, resonance may cause severe damage. (see video lecture on "**Resonance**" figure on page 3.)

Damage during an earthquake results from several factors:

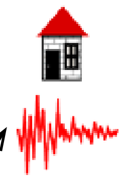
Strength of shaking. The strong shaking produced by a magnitude 7 earthquake becomes half as strong at a distance of 8 miles, a quarter as strong at a distance of 17 miles, an eighth as strong at a distance of 30 miles, and a sixteenth as strong at a distance of 50 miles.

Length of shaking. Length depends on how the fault breaks during the earthquake. The maximum shaking during the Loma Prieta earthquake lasted only 10 to 15 seconds. During other magnitude 7 earthquakes in the Bay Area, the shaking may last 30 to 40 seconds. The longer buildings shake, the greater the damage.

Type of soil. Shaking is increased in soft, thick, wet soils. In certain soils the ground surface may settle or slide.

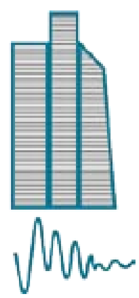
Type of building. Certain types of buildings, discussed in the reducing earthquake damage section, are not resistant enough to the side-to-side shaking common during earthquakes.

Information in this collected from USGS.gov, Fema.gov, IRIS.edu, Exploratorium (www.exo.net) and other sources.



Small Buildings:

Small building are more affected, or shaken, by high-frequency waves (short and frequent). For example, a small boat sailing in the ocean will not be greatly affected by a large swell. On the other hand several small waves in quick succession can overturn, or capsize, the boat. In much the same way, a small building experiences more shaking by high-frequency earthquake waves.



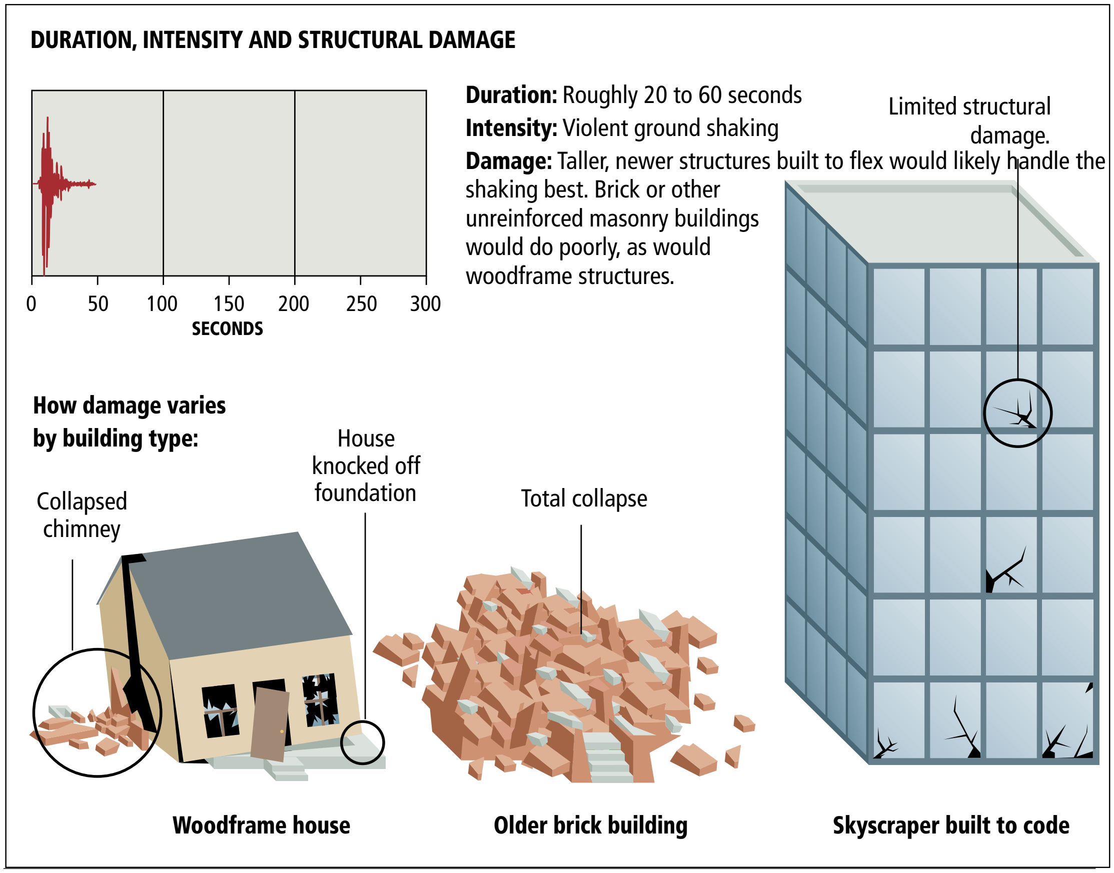
Tall High Rises:

Large structures or high rise buildings are more affected by long period, or slow shaking. For instance, an ocean liner will experience little disturbance by short waves in quick succession. However, a large swell will significantly affect the ship. Similarly, a skyscraper will sustain greater shaking by long-period earthquake waves than by the shorter waves.

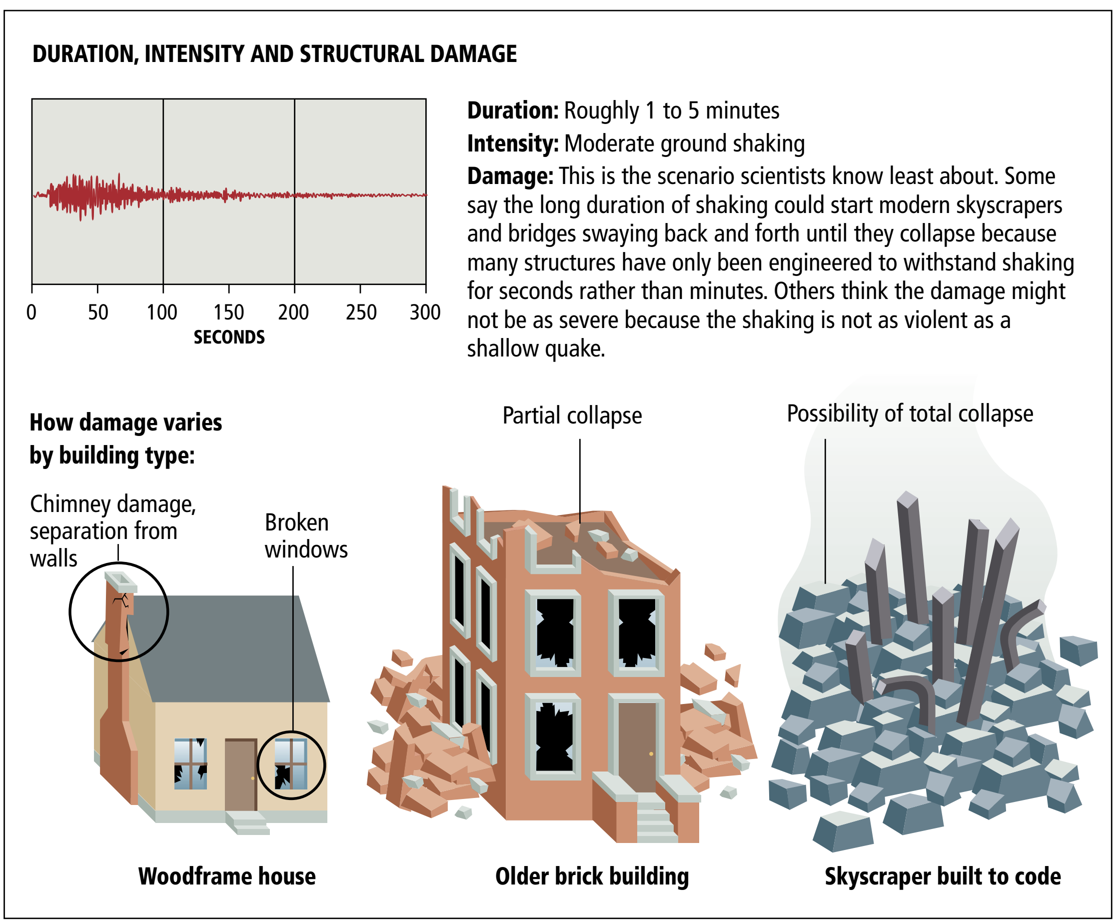
The two scenarios below are Seattle-area earthquake scenarios show the possible effects on buildings of different structural integrity of a shallow, magnitude 7 (**M7**) earthquake and a **M9** subduction-zone earthquake. These scenarios could apply to any cities on the coast or inland valleys of Washington and Oregon (as well as Chile, Alaska, British Columbia, Japan, N.Zealand).

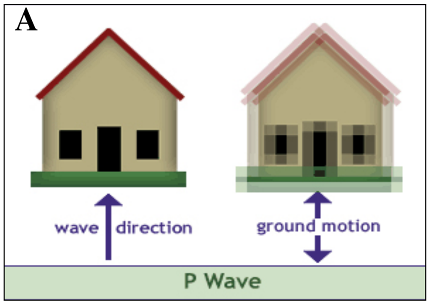
M7 shallow earthquake

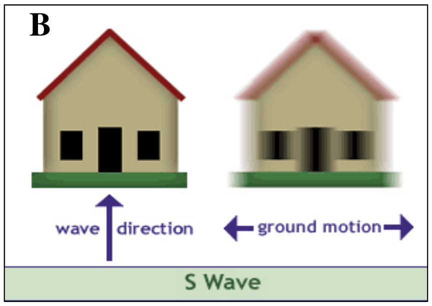
UPDATE: This can be equated to the Magnitude 7 earthquake in Haiti on Jan. 12, 2010



M9 subduction earthquake







Above. *House Shake Motion.* ***A:*** *The P wave, or compressional wave (think sound wave), is a seismic body wave that shakes the ground back and forth in the same direction that the wave is moving. P waves travel fastest and are generally felt first. They usually cause very little damage.* ***B:*** *An S, secondary or shear, wave is a seismic body wave that shakes the ground back and forth perpendicular to the direction the wave is moving. Watch the animations on IRIS animations pages:*
Seismic Wave Behavior: Effect on Buildings

Below: **Resonance video lecture demonstration:**
NOTE: Play Quicktime on the site for sound. YouTube link has no audio.
John Lahr demonstrates the simplest and most spontaneous way to demonstrate the concept of resonance and building height uses spaghetti and small weights (raisins or marshmallows. Two other more-effective (but more time consuming) video lectures are included on the videos page.

Tall and small stay up; medium fall: Mexico, 1985—10,000 die.

On September 19, 1985, a magnitude 8.1 earthquake occurred off the Pacific coast of Mexico. 350 km from the epicenter damage was concentrated in a 25 km^2 area of Mexico City. The underlying geology contributed to this unusual concentration of damage at a distance from the epicenter. An estimated 10,000 people were killed, and 50,000 were injured. In addition, 250,000 people lost their homes. The set of slides (link below), shows different types of damaged buildings and the major kinds of structural failure that occurred in this earthquake including collapse of top, middle and bottom floors and total building failure.

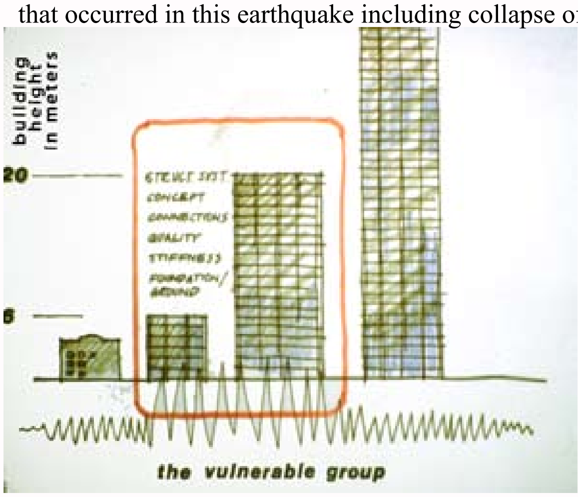


Diagram credit: C. Arnold, Building Systems Development, Inc.

Interestingly, the short and tall buildings remained standing. Medium-height buildings were the most vulnerable structures in the September 19 earthquake. Of the buildings that either collapsed or incurred serious damage, about 60% were in the 6-15 story range. The resonance frequency of such buildings coincided with the frequency range amplified most frequently in the subsoils.

To see slide show go to the NOAA website:
Earthquake Damage in Mexico City

Return to Page 1

Activities

1) Resonance Activities: See "**Building Stability during Earthquakes**" on next page of this document for ideas on how to prepare and present a demonstration on resonance (video links on previous and next pages!):

A) **Spaghetti noodle** resonance

B) **Manilla file** BOSS Lite— Describe the impact of building resonance when assessing Earthquake Hazards

C) Block & Dowell **BOSS model** The activity is in the PDF file: FEMA's Seismic Sleuths (Unit 4, page 248)

D) The Exploratorium has a simple activity to show the resonance of buildings of different heights:
http://www.exploratorium.edu/xref/phenomena/resonance.html

2) A shake table can be used to test the resistance of structures to seismic shaking. It can also be used to demonstrate the sensitivity of structures of different heights to the frequency of the ground motion. Visit John Lahr's webpage:
http://www.jclahr.com/science/earth_science/shake/index.html

3) Liquefaction: **learn how soft sediment can affect how a building stands**
www.exploratorium.edu/faultline/activezone/liquefaction.html

4) INTERACTIVE Game: You have 25 min. to select retrofits to Stop a Disaster and save a town!!!

You can reduce human, physical, and financial catastrophe by making quick choices to plan and construct a safer environment, but you have limited funding. Expect good and bad advice along the way.

1) Go to **www.stopdisastersgame.org/en/home.html** and touch
PLAY GAME > **Launch game** > **Play game** (again)
2) **Select a Scenario**: Type: **Earthquake** / Select **SELECT DIFFICULTY LEVEL** (start "EASY" to learn)
3) Roll over each buildings to decide to get Info, Demolish, or provide Upgrades (each has a cost)

WARNING: 25 minutes goes by quickly. Fix big older buildings first.

5) INTERACTIVE Design a bridge; add structural elements; then set off an earthquake!!

Fun interactive program allows you to design the Bay Bridge...and then destroy it with an earthquake. Select bridge types, seismic safety features and earthquake type:**http://eduweb.com/portfolio/bridgetoclassroom/engineeringfor.html**

6) HOW BIG WAS IT? How do you get across the idea of magnitude? M5 vs M7?

See "Pasta Quake" on page 6 of this document.

Building Stability during Earthquakes**

The three highly effective activities address earthquake resonance on buildings.
We offer different styles and levels of the same basic processes using a variety of materials.

Time: 5-30 Minutes

Target: Grade Level: 6-12

Content Objective: Students will predict how a structure will react to vibrations (oscillations) of different frequencies, and describe the phenomenon of resonance.

Introduction

Why do buildings of different heights respond differently in an earthquake? These activities show that how seismic waves travel through the layers of the Earth can effect how a building might wobble. Aside from architectural constraints, i.e., how well built the structure is, the particular resonance of an earthquake can knock down a small building and spare the skyscraper. The resonance is the oscillation (up-and-down or back-and-forth motion) caused by a seismic wave. During an earthquake, buildings oscillate. If the frequency of this oscillation is close to the natural frequency of the building, resonance may cause severe damage. These models allow students to observe the phenomenon of resonance.

Teacher Preparation—Choice of Models

First, decide which oscillation model fits your class time, as well as preparation time. FEMA's Seismic Sleuth's BOSS model has much background material.With all models, practice before using in class!!

1) The spaghetti-and-marshmallow (or raisin) model is the quickest to assemble and is described in the movie, Modeling Resonance using Spaghetti.

2) The **BossLite model** (Movie-Manilla Folder) has the advantage of looking more like buildings; you could even draw windows on them. Because of the different weight of manilla folders, we found we had to experiment with doubling up the files as they were too floppy.

3) The **BOSS model** (Movie Boss Model) is the most elegant, and will be a permanent tool for the classroom. But it does take some assembly time and must be stored. The activity is in the PDF file: FEMA's Seismic Sleuths (Unit 4, page 248)

Second, find out what students already know about the concepts of amplitude, frequency, and resonance. If they are not familiar with these terms, introduce them by building on what students already know from other areas. They may know, for example, that resonance and frequency are used in describing the tone of musical instruments and the quality of sound produced by different recording techniques and players. The phenomenon of resonance also accounts for laser light and for the color of the sky.

Third, review the terms and concepts introduced in this lesson. Explain that seismic waves caused by earthquakes produce oscillations, or vibrations, in materials with many different frequencies. Every object has a natural rate of vibration that scientists call its natural frequency. The natural frequency of a building depends on its physical characteristics, including the design and the building material. Resonance is a buildup of amplitude in a physical system that occurs when the frequency of an applied oscillatory force is close to the natural frequency of the system. In the case of an earthquake, the ground shaking may be at the same frequency as the natural frequency of a building. Each vibration in the ground may come at or dangerously close to the natural frequency of the structure.

Fourth, ask the class to hypothesize what would happen when buildings of two different heights, standing next to each other, resonate from an earthquake. (Remember to practice a lot before demonstrating. The BOSS model, though most time consuming to construct, works best!) Students invariably select the tallest building. Wiggle the model so that the shorter building vibrates the greatest. If you have some images of this effect from actual earthquakes, show them now. The Mexico City quake described on page 27 is a good example of mid-size buildings falling preferentially.

Fifth, entice students to further investigation by leaving them with the question: "**How could you add structural elements to reduce resonance in a building**?" Adding sheer structure keeps things from falling. Watch the video **Building Strength Demo** on the IRIS "Videos" page.

Materials:

Watch the 3 videos on resonance to determine how elaborate an activity you want.

Video clips of the Resonance Demonstrations introduce the concept of resonance in these three demonstrations:

Modeling Resonance using Spaghetti Noodles
Modeling Resonance using Manilla Folder
Modeling Resonance using BOSS Model

Activity modified from activities from IRIS, FEMA, and John Lahr

Haiti devastation exposes shoddy construction

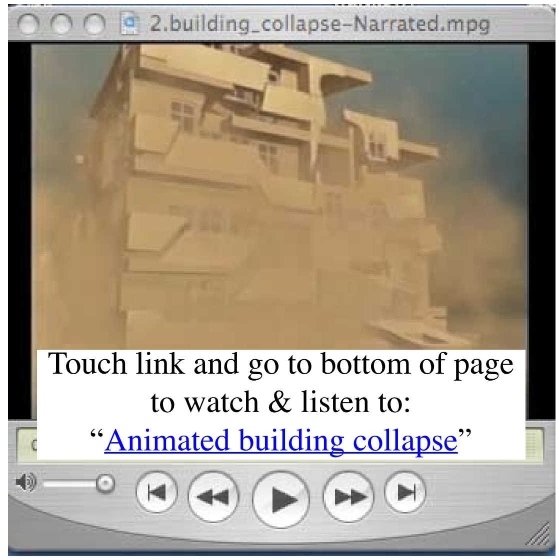
By Ayesha Bhatty
BBC News, London

Experts say it is no surprise that shoddy construction contributed to the level of destruction in Haiti following Tuesday's earthquake. But the scale of the disaster has shed new light on the problem in the impoverished Caribbean nation. Tens of thousands are feared dead after being crushed by buildings that collapsed. Scores more remain trapped under the rubble.

"It's sub-standard construction," says London-based architect John McAslan, who has been working on a project linked to the Clinton Global Initiative in the country.

"There aren't any building codes as we would recognise them," he added. Mr McAslan says most buildings are made of masonry - bricks or construction blocks - which tend to perform badly in an earthquake.

"...the loss of life from earthquakes is typically 10 times higher in developing countries than the West and the damage can be up to 100 times worse."



Touch link and go to bottom of page to watch & listen to: "Animated building collapse"

Cheap concrete

There are also significant problems with the quality of building materials used, says Peter Haas, head of the Appropriate Infrastructure Development Group, a US-based non-profit group that has been working in Haiti since 2006.

"People are skimping on cement to try to cut costs, putting a lot of water in, building too thin, and you end up with a structure that's innately weaker," said Mr Haas, who was on his way to Haiti to help assess the safety of damaged buildings.

"Concrete blocks are being made in people's backyards and dried out in the sun," he said.

Mr Haas said there were also "serious problems" with the enforcement of building codes in Haiti. He said the government did not function at all in several parts of the country, and many communities lacked basic services such as electricity, sanitation services or access to clean water.

"So the problem of code enforcement is low down on the list," he said.

Poor record

Even before the quake, Haiti's building safety record was poor. Almost 100 people - mostly children - died when two schools collapsed within days of each other in November 2008. At the time, Haitian authorities blamed poor construction for the accidents. Roger Musson, head of seismic hazard at the British Geological Survey, said he was "not at all" surprised at the level of destruction in Haiti. He said Haiti, the poorest country in the western hemisphere, was not used to dealing with earthquakes of this magnitude. Tuesday's quake was the worst in two centuries. The country is more used to dealing with hurricanes, which have been getting more frequent in recent years, according to Mr Musson.

"Most buildings are like a house of cards," he said. "They can stand up to the forces of gravity, but if you have a sideways movement, it all comes tumbling down."

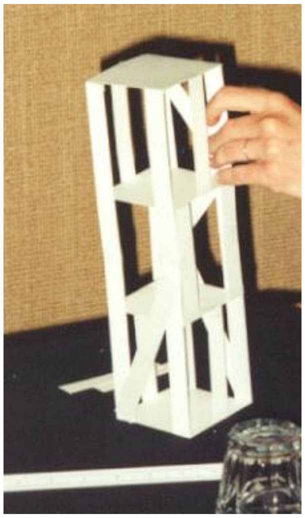
Ironically, people living in the shanty towns might have had a better chance of survival than those trapped under concrete buildings, many of which "pancaked". "A simple shack's collapse is likely to cause less damage to human safety than a multi-floor building that collapses," Mr McAslan said.

Aftershocks

Mr McAslan says it is more complex and expensive to earthquake-proof a building than equip it for hurricane damage. "The priorities have inevitably been elsewhere, but I'm absolutely certain that the attention of the government will be to build back better."

He said the main task for the authorities now was to save as many lives as possible, then to stabilise damaged buildings so they could withstand any aftershocks, and finally, to assess how to create buildings that could reasonably withstand another earthquake. According to Mr McAslan, the extent of deforestation in Haiti also contributed to devastation. He said that on the hillsides of Petionville, a suburb east of Port-au-Prince, buildings simply "collapsed and collapsed and collapsed" on to each other as there was no forest to protect them.

According to the US Geological Survey, the loss of life from earthquakes is typically 10 times higher in developing countries than the West and the damage can be up to 100 times worse.



Earthquake Shaking – Building Contest and Shake Table Testing Activity©

(Posterboard Buildings,
May, 1999; revised, March 2003, October 2003)

L. Braile
Purdue University
braile@purdue.edu
www.eas.purdue.edu/~braile

Objectives: Explore earthquake hazards and damage to buildings by constructing model buildings and subjecting the buildings to ground vibration (shaking similar to earthquake vibrations) on a small shake table. The buildings are constructed by of two- or three-person teams of students or workshop participants. After construction, the buildings are tested by subjecting them to earthquake shaking to see which designs and constructions are successful. Comparison of the results of the building contest with photographs of earthquake damage is used to reinforce the concepts of building design and earthquake risk.

Materials:

- Posterboard (lightweight posterboard; note: there is a difference in quality and therefore strength of lightweight pasteboard; the best posterboard has one smooth, almost glossy side and on dull side; lightweight posterboard can be purchased at most bookstores, convenience stores, Wal-Mart and K-Mart.)

    4 – 8 x 8 cm squares (floors)
    12 – 1½ x 10 cm strips (uprights)*
    12 – 1½ x 15 cm strips (reinforcing)*
    1 – 30 x 8 cm (cut and use as you wish)
- Scotch Tape (2 cm or 3/4" wide) 100 cm length (Plan accordingly!)
- Scissors
- 30 cm ruler

*The widths of these strips can be varied from about 1 cm to 2 cm. It will be more difficult to design and build a "successful" building with the thinner strips. A reasonable choice for most applications is 2 cm strips for uprights and 1½ cm strips for reinforcing. You can also use the 30 x 8 cm piece of poster board for reinforcing. Cut as you wish.

Rules:

- Building must be:
  At least 30 cm high
  at least 3 stories
  no central post or uprights (so that weights can be placed on floors)
- Materials are limited (realistic)
- Complete construction in limited time (realistic)

Design:

- Note importance of shear or diagonal support. This concept can be illustrated (and explained) using the shear wall model from *Seismic Sleuths* (FEMA/AGU, 1994; Figure 1). One can also build model walls using short strips (1½ x 10 cm and 1½ x 14.4 cm) of 1/16" thick mounting board, or other similar materials such as popsicle sticks, and magnets or mounting putty for joints. Without diagonal bracing, the model wall is relatively strong for a static, vertical load. However, a horizontal load or shaking causes the wall to collapse. With the diagonal bracing (shear-support) installed, the wall is much stronger and more resistant to shaking.

Figure 1. Experimenting with the Shear Wall (Seismic Sleuths activity).

- Simple, rectangular building designs are effective (Figure 2). Many design options, particularly for the bracing, are possible.

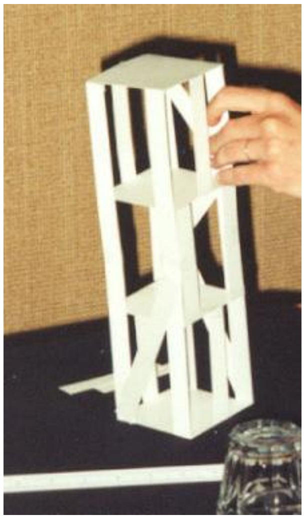


Figure 2. A partially completed lightweight posterboard model building.

Testing:

- Buildings are tested on the horizontal motion shake table (Figure 3). Tape the base of the building to the base plate of the shake table. We choose the direction to orient the building.

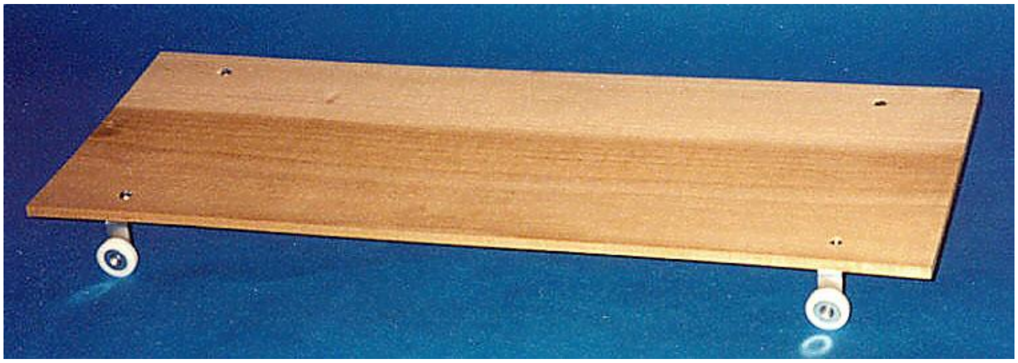


Figure 3. A simple, horizontal motion shake table. Wheels are nylon cabinet or drawer wheels and are attached to the board with "L" brackets, machine screws and nuts.

- Add masses to the floors and roof of the building (Figure 4). Masses should be about 30 to 80 g each. Begin testing with small masses. Steel washers of 3-4 sizes make convenient and effective masses. Tape washers to floors and roof or use small plastic spring clips available at hardware stores or in hardware departments of Wal-Mart and K-Mart.

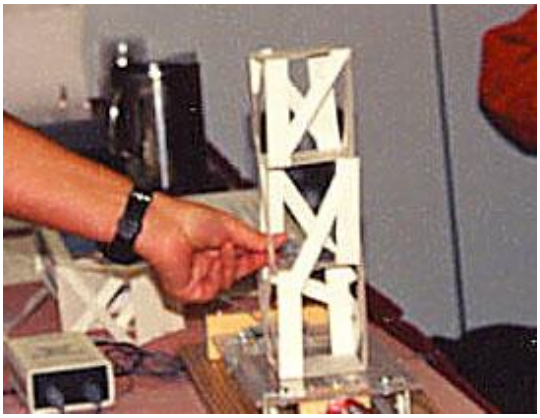


Figure 4. A model building on a shake table. Weights (steel washers) are attached to each floor and the roof. Small (5-g) horizontal accelerometers are attached to the shake table and to the top of the building. The results of shake table testing (acceleration versus time of the shake table and the top of the building as the shake table is moved back and forth) can be monitored on the computer screen or projected using an LCD projector for everyone to see.

- Shake building at three frequencies – low, medium and high – and at three amplitudes – low, medium and high. An accelerometer on the base plate can be used to quantify the shaking and make comparisons between the testing of different buildings more consistent. A second accelerometer can be attached to the top of the building to observe amplification and resonance effects. Small, relatively inexpensive accelerometers, an analog to digital interface for the accelerometers (Serial Box Interface or LabPro), and software (LoggerPro) for the interface are available at Vernier Software (www.vernier.com) or other vendors of "probeware". High School or College physics departments often have Vernier or similar equipment so you may only need to obtain the accelerometers.

- In our experience, using the instructions and materials described here, it will usually be possible for most buildings to survive the shaking using small masses (30-50 g). However, few buildings with these materials will withstand strong (about 1 *g*, 1 *g* is the acceleration of gravity which is 980 cm/s^2 or 9.8 m/s^2), high frequency (about 10 Hz), shaking with larger masses (50-80 g). Interesting resonance and amplification effects will be visible for some frequencies and amplitudes of shaking.

- If your shake table is large enough (a convenient size is about 16 x 50 cm), you can attach and test two or three buildings at the same time which provides an interesting comparison of building responses.

- After the initial testing, it is possible to illustrate specific design issue/problems with model buildings that were successful. For example, you can create the "soft first story" problem by reducing the shear support in the first story of the building. Sometimes buildings are damaged by a mainshock earthquake and then further damaged or destroyed in an aftershock. Also, poor quality construction or mistakes made in construction can result in specific weak elements of a building. These situations can be simulated in a model building by weakening an upright or a joint by cutting or partially cutting the posterboard material or tape. Other building design and construction variations, such as very rigid or very flexible buildings, can be specifically built and tested. Comparing the responses and failure levels of these structures with the original designs that were successful is an excellent method of reinforcing the principles of effective building design and earthquake hazards related to structures.

- If time permits, students can construct a second set of buildings that benefit from the lessons learned in the first building contest and shake table testing.

- An excellent videotape on earthquakes that includes a segment on building design and shake table testing of a model building (using Legos) to show the importance of shear support is "Seismic Sleuths," Discovery Channel (www.discovery.com).

To view corresponding photographs of earthquake damage to buildings and other structures (for comparison to the lessons learned in shake table testing of the model buildings) and other information on earthquake hazards see:

1. *•EQ Hazard Info-Part 1*
   •EQ Hazard Info-Part 2
   •EQ Photos-Part 1
   •EQ Photos-Part 2
   at: http://www.eas.purdue.edu/~braile/indexlinks/educ.htm (use Quick Links), and/or:

2. A Power Point presentation (eqdamage.ppt) with some of the earthquake damage photographs (Figure 5) contained in the above online pages (available at: www.eas.purdue.edu/~braile, click on "Workshops" in the Quick Links).

Also note the significant building failures and risk represented by falling objects (on the exterior or within buildings) and poor foundations and liquefaction.

Figure 5. "Soft" or weak first story failure of a four-story building in San Francisco damaged by the October, 1989 Loma Prieta earthquake. In this case the weak story is caused by reduced shear wall strength and lack of diagonal bracing related to constructing parking garages (note garage doors) in the first story of the building.

References:

FEMA/AGU, *Seismic Sleuths - Earthquakes - A Teachers Package on Earthquakes for Grades 7-12*, American Geophysical Union, Washington, D.C., 367 pp., 1994. (FEMA 253, for free copy, write on school letterhead to: FEMA, PO Box 70274, Washington, DC 20024).

Levy, Matthys and Mario Salvadori, Why Buildings Fall Down, W.W. Norton & Co., New York, 334 pp., 1992.

Levy, Matthys and Mario Salvadori, Why the Earth Quakes, W.W. Norton & Co., New York, 215 pp., 1995.

Salvadori, Mario, Why Buildings Stand Up, W.W. Norton & Co., New York, 323 pp., 1980.

Earthquake Education Workshops

September 2014

Charlotte, Candler, and Winston-Salem

"Earthquake Preparedness – Lessons to Learn from the M = 5.8 Mineral, Virginia Earthquake of August 23, 2011"

presented by

Dr. Kenneth B. Taylor

State Geologist of North Carolina
N.C. Geological Survey
Division of Energy, Mineral,
and Land Resources

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Magnitude 5.8 VIRGINIA
Tuesday, August 23, 2011 at 13:51:04 EDT

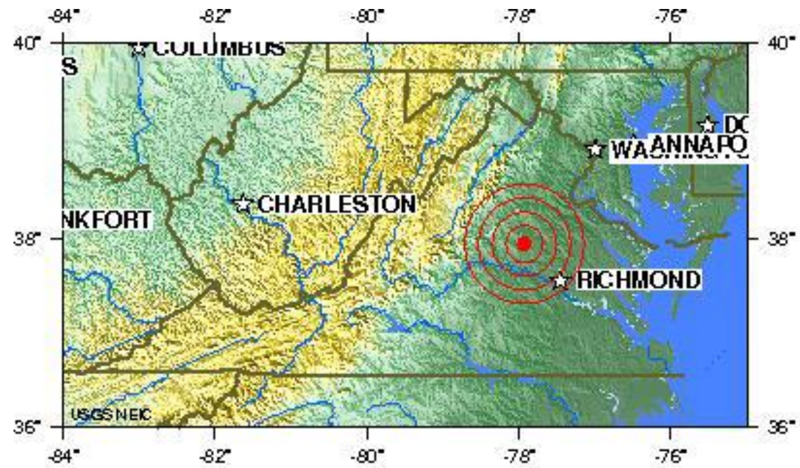


Image courtesy of the US Geological Survey

Largest earthquake to shake the eastern U.S. since 1944 and the 2nd largest in Virginia history.

Shaking was felt from Georgia to Canada, caused light damage and panicked hundreds of thousands of people to evacuate buildings in New York, Washington and other cities.

There were no reported deaths, and scattered reports of minor injuries.

Police tape is seen in front of the National Cathedral in the Washington after a piece of the left spire fell off during earthquake shaking in the Washington area. The magnitude 5.8 earthquake centered in Virginia forced evacuations of all the monuments on the National Mall in Washington and rattled nerves from Georgia to Massachusetts.

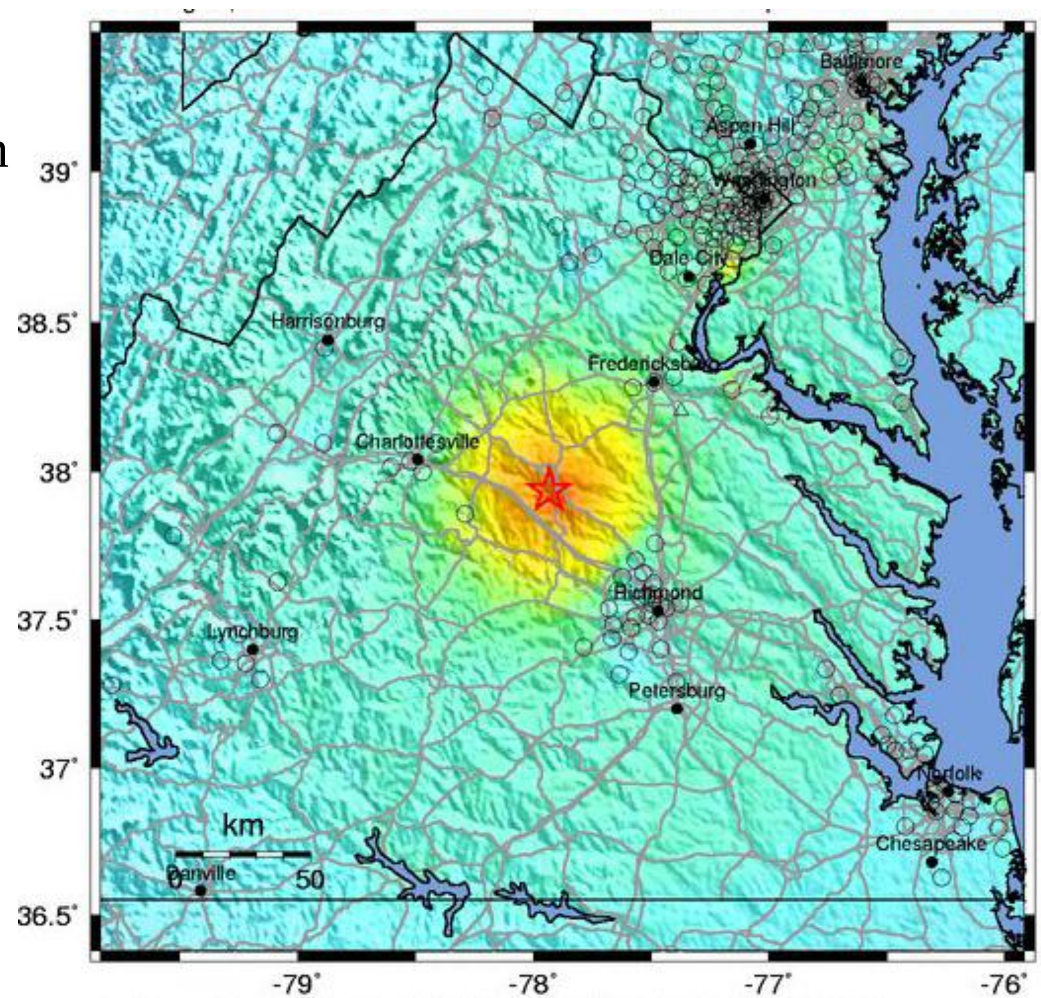
(*AP Photo/Pablo Martinez Monsivais*)

Magnitude 5.8 VIRGINIA
Tuesday, August 23, 2011 at 13:51:04 EDT

Intensity scales were developed to standardize the measurements and ease comparison of different earthquakes. The Modified-Mercalli Intensity scale documents the perceived level of shaking from I (lowest) to XII (highest – total destruction).

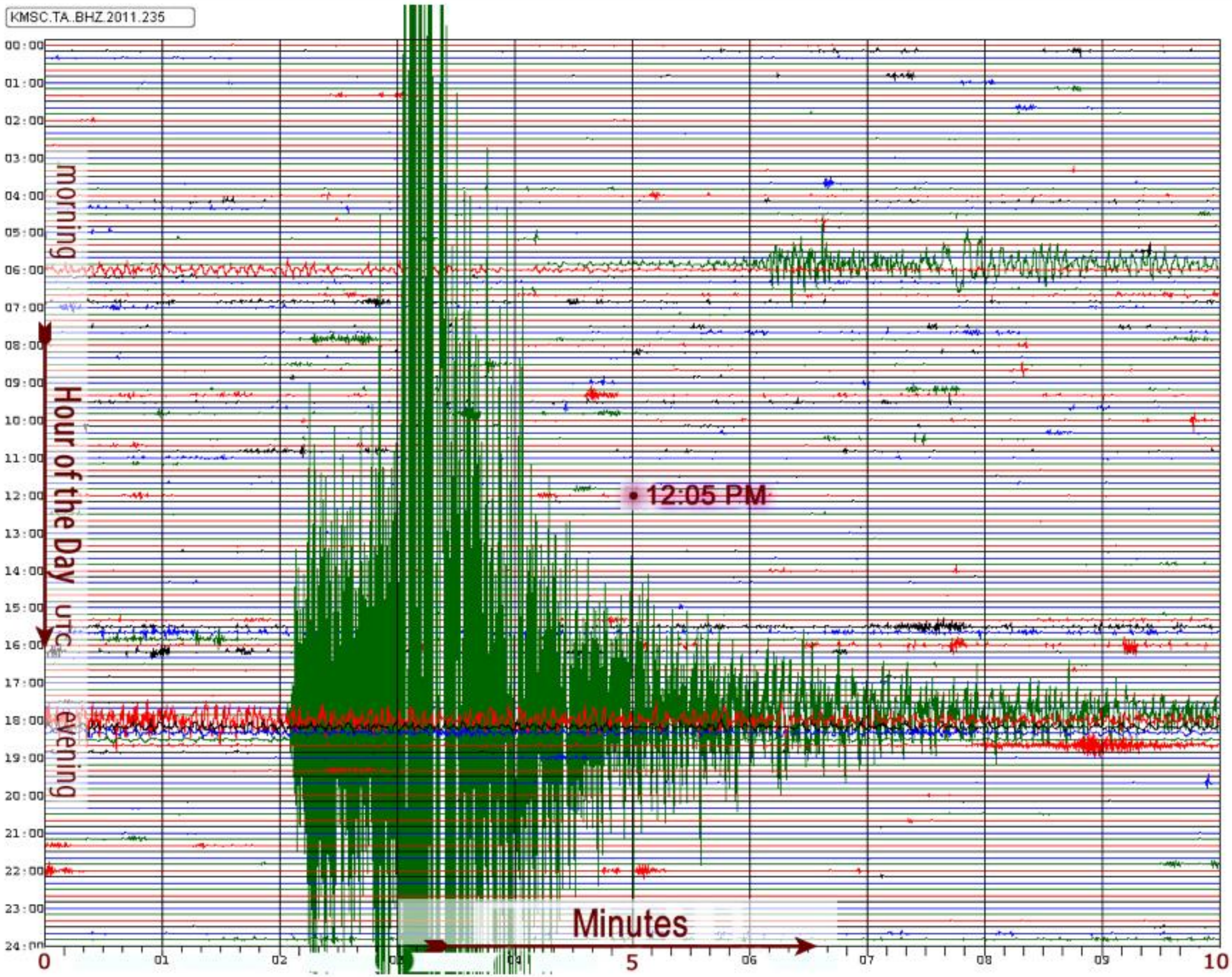
Modified Mercalli Intensity	Perceived Shaking
X	Extreme
IX	Violent
VIII	Severe
VII	Very Strong
VI	Strong
V	Moderate
IV	Light
II-III	Weak
I	Not Felt

Image courtesy of the US Geological Survey

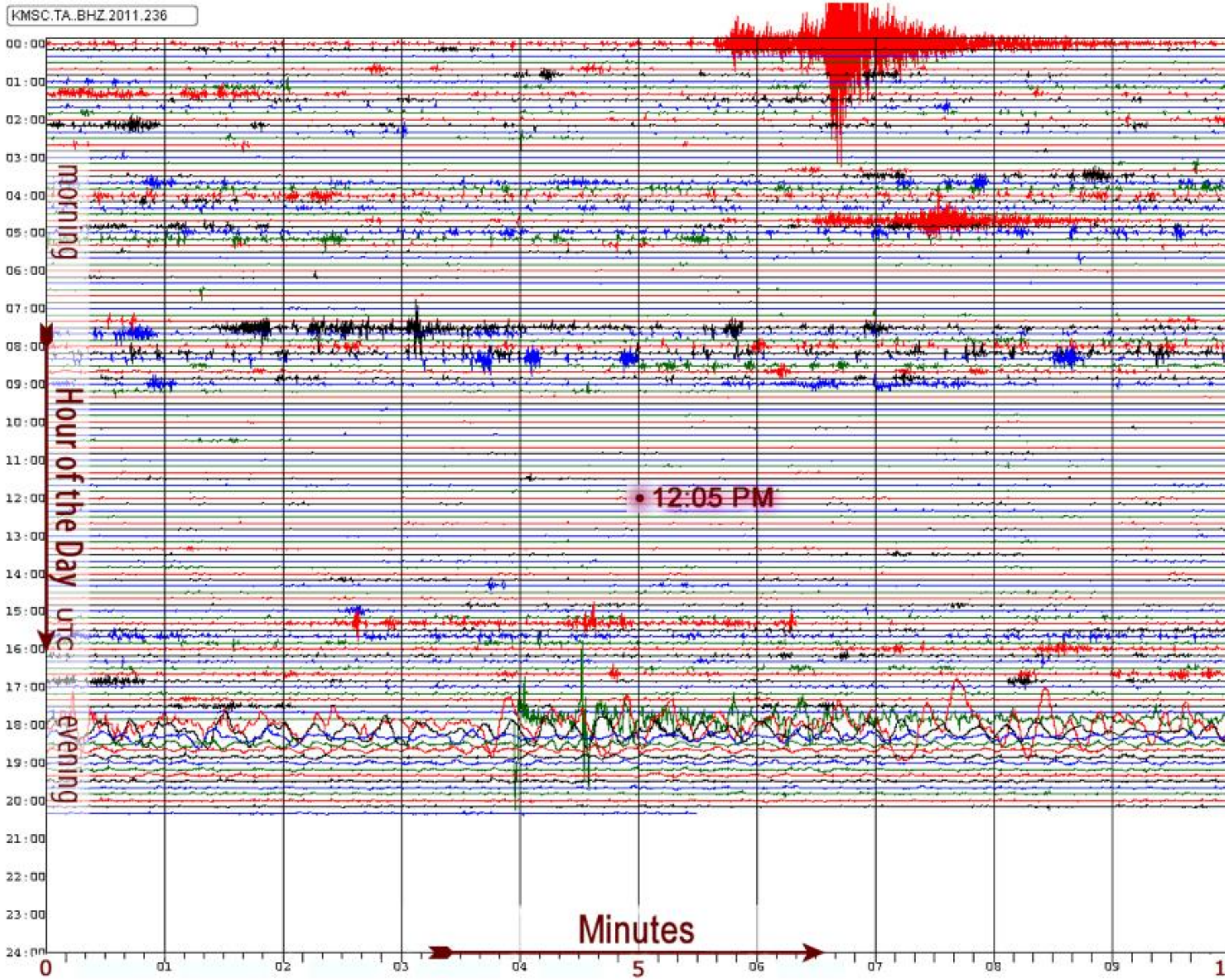


USGS Estimated shaking Intensity from M 5.8 Earthquake

08/23/2011 Seismic Activity at Station KMSC- Kings Mountain, Blacksburg, SC



08/24/2011 Seismic Activity at Station KMSC - Kings Mountain, Blacksburg, SC



Impacts and Damages

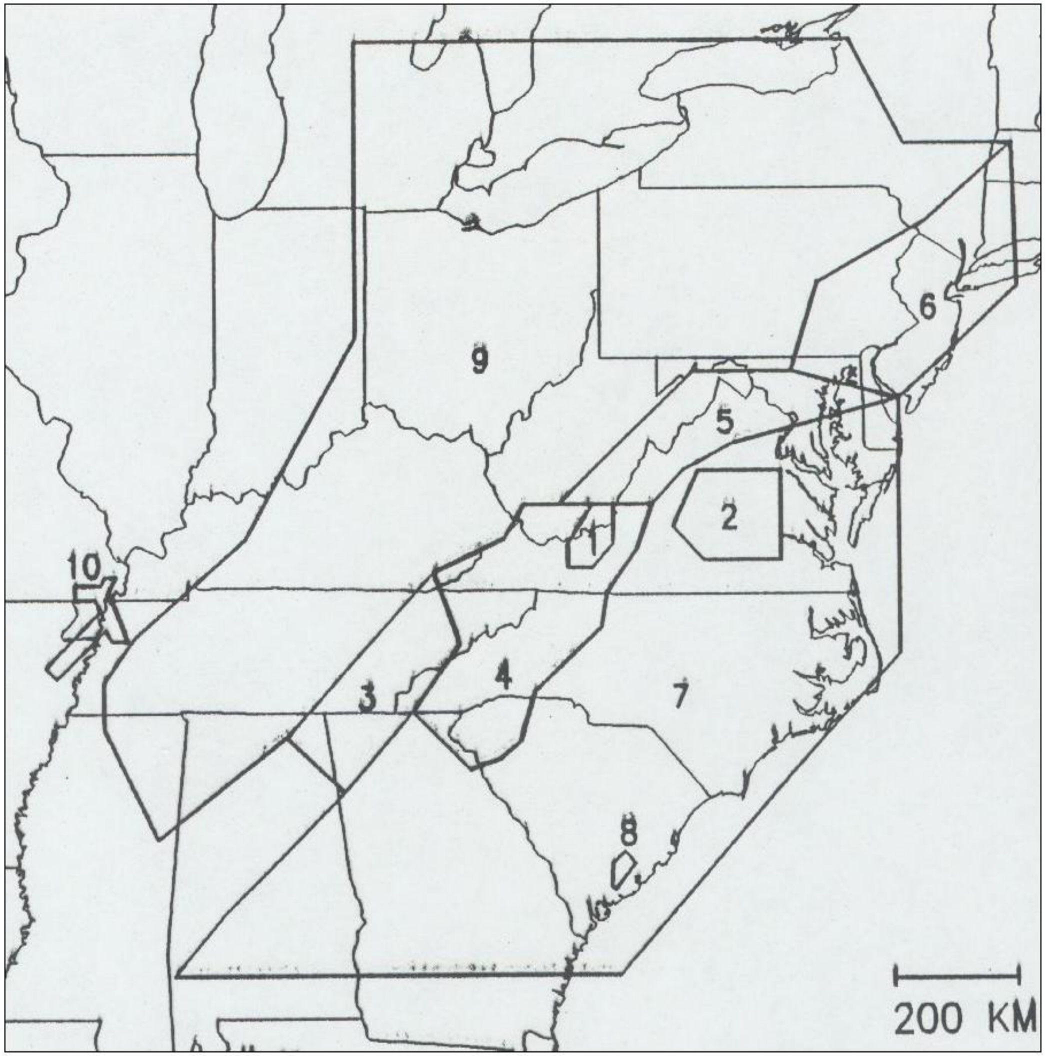
- Private Property Damage (Destroyed – 33; Major Damage – 180; Minor Damage – 510) Losses = $15 million.
- Power outages (3 ¾ hrs)
- Cell phone blockages (30 min)
- Disruption of east coast air traffic (two hrs) and Metrorail (16 hrs).
- North Anna Nuclear Station Unit 1 and Unit 2 (off-line until September 17th – 25 days).
- Disaster declaration for Individual Assistance requested September 20th. [Hurricane Irene impacted Virginia on August 27th]

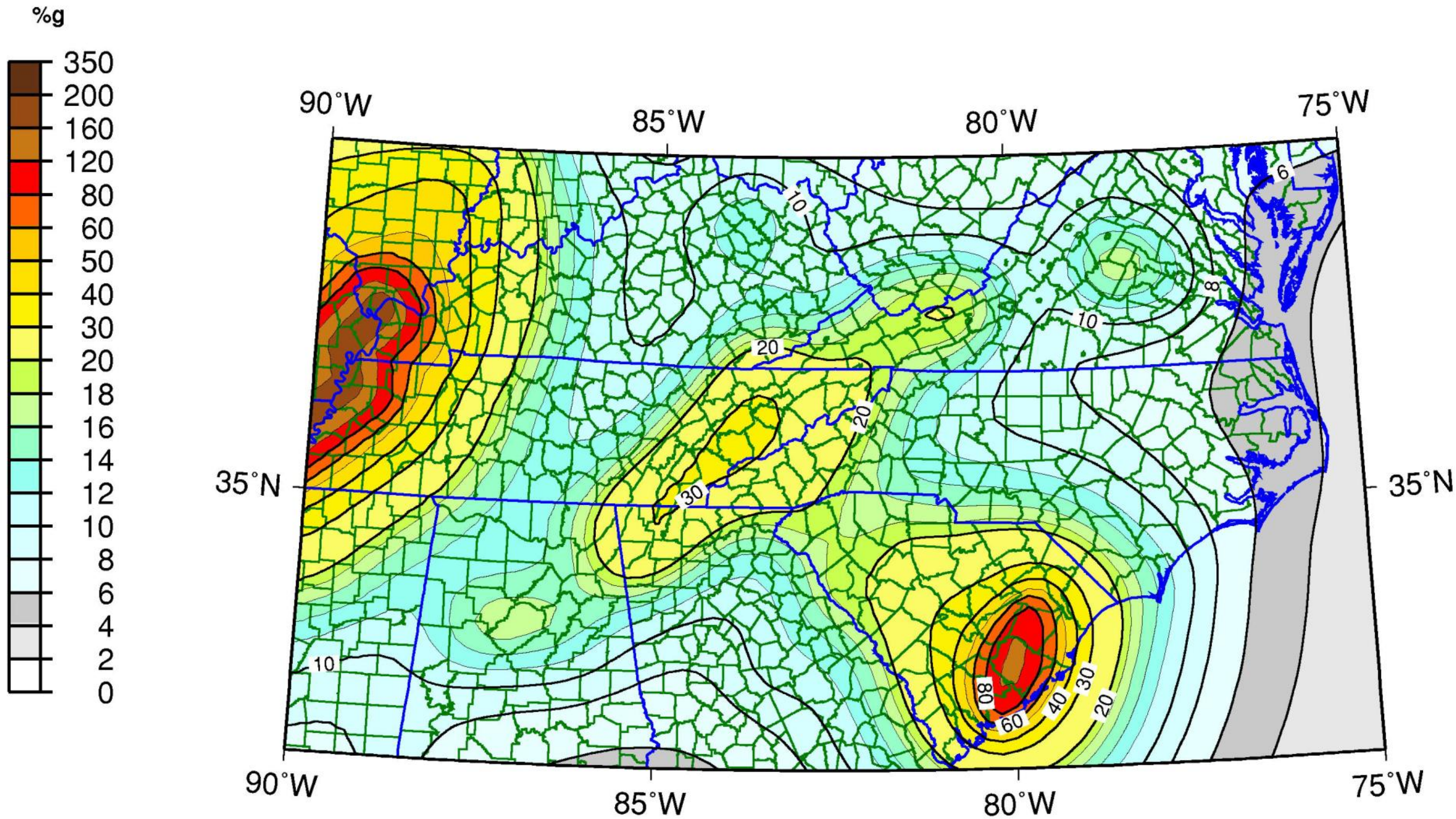
Challenges in planning for earthquakes

- Motivating people for a low probability but high consequence event. *[Show them scenarios of what could happen].*
- NO WARNING. *[Preplanning of the event].*
- Information Gap -- communication disruption and need for wide-area intelligence collection. *[Use modeling to predict impact].*
- Aftershocks -- disaster has not yet ended. *[Public education and information].*
- Access to impacted area. *[Use pre-event assessment].*

Map of the earthquake source zones in the south-central United States. The earthquake hazard within North Carolina, Virginia, Tennessee, and South Carolina is the accumulation of the hazard from the ten zones inside and adjacent to the states. (source: "Seismic Hazard Assessment for Virginia" by M.C. Chapman and F. Krimgold, Virginia Tech, 1994)

Earthquake source zones:
1 - Giles County, Virginia
2 - central Virginia
3 - eastern Tennessee
4 - southern Appalachians
5 - northern Virginia, Maryland
6 - central Appalachians
7 - Piedmont-Coastal Plain
8 - Charleston, South Carolina
9 - Appalachian foreland
10 - New Madrid

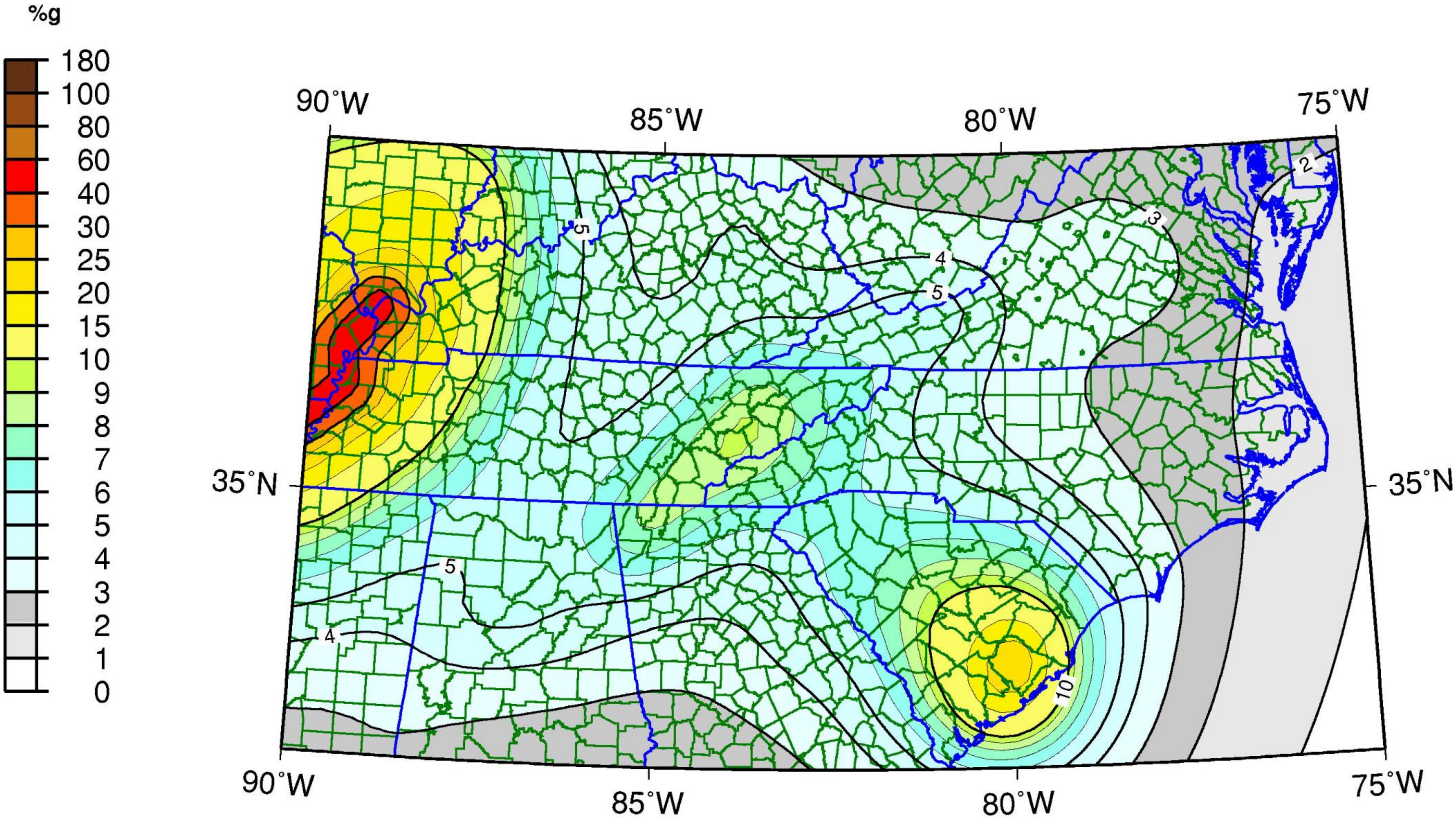




Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary

U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees



Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary

U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees

What are the lessons to learn from the event?

A) NC Earthquake Plan – written and exercised twice (tabletop and functional) addresses:

- Intelligence (where to get information)
- Impact estimation using modeling
- ATC-20 = Procedures for the Post Earthquake Safety Evaluation of Buildings

B) State disaster declaration option. [Nearly two months and two FEMA turndowns. Event impact “not severe” enough.]

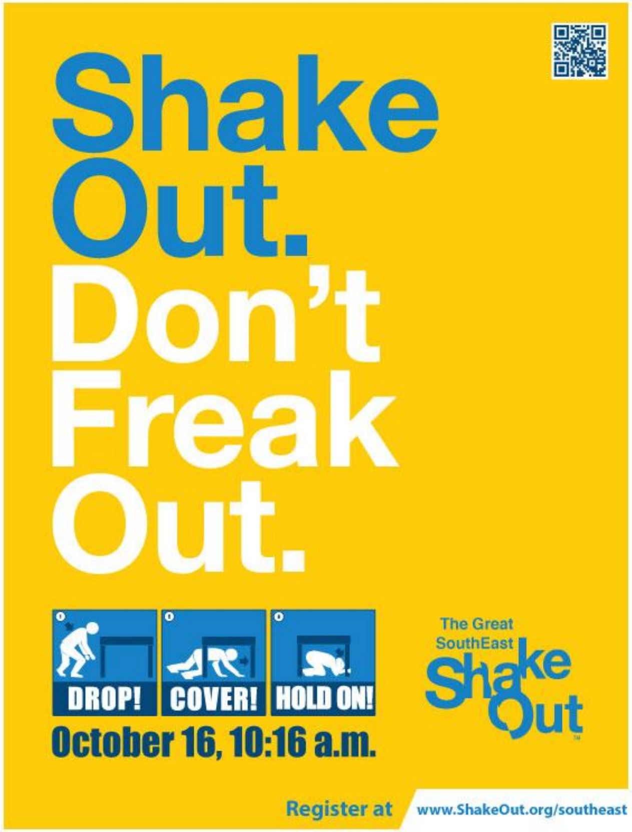
C) We rely on electronic communications and control systems that can be easily disrupted.

ReadyNC

Readync.org and the *ReadyNC* mobile app is an all-in-one tool to help people get ready for everything from traffic jams to hurricanes and ice storms. The app gives information on real-time traffic and weather conditions, river levels, evacuations and power outages. It works both for iPhone and Android phones. Download it today! For people living in or visiting North Carolina, this is **an all-in-one FREE tool for emergency preparedness.**

- Current weather conditions
- Real-time traffic conditions where you are, by route or region>
- Where to report nearby power outages
- Open shelters near you (including ones which accept pets)
- Counties being evacuated
- How to prepare for and be safe during typical hazards that impact NC
- How to create an emergency plan and kit
- Real-time stream and river flooding information
- Who to call for help when disasters strike

Created by the N.C. Department of Public Safety and North Carolina Emergency Management.



The ground starts shaking – it's an earthquake! What do you do? Drop, Cover, and Hold On! If you've never heard this before, visit

www.ShakeOut.org/SouthEast/register to practice how to be quake-safe with the rest of Southeast. The life you save may be your own.

Free registration at www.ShakeOut.org/SouthEast/register will pledge an individual's or group's participation in this important preparedness event. Participants will receive information on how to prepare an earthquake and what actions to take during and after the shaking.

Why Should You Participate? www.ShakeOut.org/SouthEast

While earthquake hazard varies from region to region most of the Southeast is prone to earthquakes. You could be anywhere when an earthquake strikes: at home, at work, at school or even on vacation.

The ShakeOut Drill is scheduled for 10:16 a.m. on October 16, 2014. This means that wherever you are at that moment—at home, at work, at school, anywhere—you should *Drop, Cover, and Hold On* as if there were a major earthquake occurring at that very moment, and stay in this position for at least 60 seconds.

The Great SouthEast ShakeOut is a regional opportunity to practice how to be safer during big earthquakes: "Drop, Cover and Hold On." The ShakeOut has also been organized to encourage you, your community, your school, or your organization to review and update emergency preparedness plans and supplies, and to secure your space in order to prevent damage and injuries.

Essential Earthquake and Seismology Websites   Earthquakes in NC workshop

Tim Martin   tmartin@greensboroday.org

IRIS Incorporated Research Institutions for Seismology **http://www.iris.edu/hq/**

IRIS Earthquake Browser – Interactive global map of earthquake data **http://www.iris.edu/ieb/**

Teachable Moments - Within 24 hours of a major earthquake, downloadable presentation with pictures, history and information about the earthquake **http://www.iris.edu/hq/retm**

JAmaSeis – View and analyze seismograms in real time **http://www.iris.edu/hq/programs/education_and_outreach/software/jamaseis**

REV Rapid Earthquake Viewer - Visual display of recent quakes **http://rev.seis.sc.edu/earthquakes.html**

IRIS Education and Public Outreach Page – links to videos, animations and lesson plans for many earthquake related concepts. **http://www.iris.edu/hq/programs/education_and_outreach**

USGS United States Geological Survey Hazards Program - Info for real time data, historical info, hazards, report an earthquake, shake maps, and more: **http://earthquake.usgs.gov/**

Real Time Seismograms from California - http://earthquake.usgs.gov/monitoring/helicorders/nca/

Virtual Earthquake – Become a "virtual seismologist" excellent one or two day class lesson about earthquakes and seismology. Locate earthquake epicenters and measure earthquake magnitude.

New version http://www.sciencecourseware.com/eec/Earthquake/ (Requires updated JAVA)

Older version http://www.sciencecourseware.com/virtualearthquake/

QCN Quake Catcher Network – Monitor earthquakes on your computer **http://qcn.stanford.edu/**

(As a teacher you may purchase 3 seismometers for use in the classroom for $5 each)

Northern California Earthquake Data Center - ANSS Advanced National Seismic System – Download large data files for GIS mapping. http://www.quake.geo.berkeley.edu/anss/catalog-search.html