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.

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 on 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.
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**

**DURATION, INTENSITY AND STRUCTURAL DAMAGE**

- **Duration:** Roughly 20 to 60 seconds
- **Intensity:** Violent ground shaking
- **Damage:** Taller, newer structures built to flex would likely handle the shaking best. Brick or other unreinforced masonry buildings would do poorly, as would woodframe structures.

**How damage varies by building type:**
- **Collapsed chimney**
- **House knocked off foundation**
- **Total collapse**

**DURATION, INTENSITY AND STRUCTURAL DAMAGE**

- **Duration:** Roughly 1 to 5 minutes
- **Intensity:** Moderate ground shaking
- **Damage:** Chimney damage, separation from walls, broken windows, limited structural damage.

**How damage varies by building type:**
- **Chimney damage, separation from walls**
- **Broken windows**
- **Partial collapse**
- **Possibility of total collapse**
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 km² 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.

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
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 affect 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
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.

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.
Magnitude: Pasta Quake—The San Francisco Treat
Demonstration to learn the concept of magnitude & log scale
This activity is used with permission from Paul Doherty http://www.exo.net/~paul/index.html

Time: 5-10 Minutes

Target Grade Level: 4th grade and up

Content Objective: Students will learn the earthquake magnitude scale by breaking different amounts of spaghetti. Visual scale of the pasta emphasizes the relative differences between magnitudes; each whole step in magnitude

Background

The severity of an earthquake can be expressed in terms of both intensity and magnitude. However, the two terms are quite different, and they are often confused.

Intensity is based on the observed effects of ground shaking on people, buildings, and natural features. It varies from place to place within the disturbed region depending on the location of the observer with respect to the earthquake epicenter.

Magnitude is related to the amount of seismic energy released at the hypocenter of the earthquake. It is based on the amplitude of the earthquake waves recorded on instruments which have a common calibration. The magnitude of an earthquake is thus represented by a single, instrumentally determined value.

To Do and Notice

Hold up one piece of spaghetti. Bend the piece between your hands until it breaks. Notice the work it takes to break the spaghetti. Call this a 5 on the Pasta Magnitude scale.

Hold up a bundle of 30 pieces of spaghetti. Bend the bundle until it breaks. Notice the work it takes to break the bundle. If the pasta magnitude scale were like the earthquake magnitude scale this would be a Pasta Magnitude 6 break.

Hold up 900 pieces of pasta, the remainder of the package. Bend the bundle until it breaks. Notice the work it takes to break the bundle. This is a Pasta Magnitude 7 break.

What’s Going On?

The magnitude scales for earthquakes are logarithmic scales. In particular for the Richter scale, each increase of 1 unit on the scale, say from 6 to 7, represented an increase of one order of magnitude, i.e. times 10, in the amount of motion recorded on a particular type of seismograph.

The now-common Moment Magnitude scale was defined because the Richter scale does not adequately differentiate between the largest earthquakes. The new “moment magnitude” scale is a new technique of using the Richter scale.

In the moment-magnitude scale a magnitude increase of one unit corresponds to a factor of 30 increase in the energy released by the breaking of the fault in an earthquake. That’s why we increased the number of spaghetti noodles from 1 to 30 to 900 (900 =30 x 30).

So What?

In order to release the energy of one M 7 earthquake you would have to have 30 M 6 quakes or 900 magnitude 5’s. Notice also all the little “quakes” before and after the big-quake break.

Materials

1# package of thin spaghetti or
2# package of regular spaghetti.