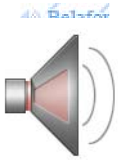
Activities— Earthquake Hazard Maps & Liquefaction

Geology and Earth Resources Division geologists actively identify, assess, and map geologic hazards for land-use and emergency-management planning, disaster response, and building-code amendment. As our population grows, there is increasing pressure to develop in hazardous areas. Delineation of these areas has never been more important. This activity covers: Amplification, Slope Instability and Liquefaction

What are earthquake-hazard maps?

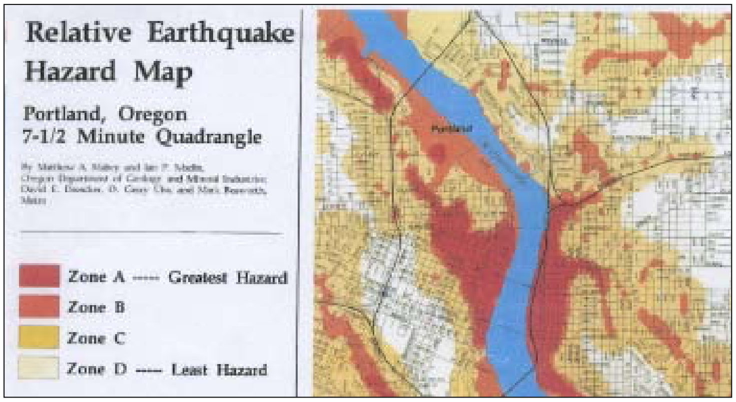
Not all ground is created equal. Not all ground makes a good foundation for building on soft sediment in earthquake prone regions. As Harry Belafonte sang, "*House built on a weak foundation will not stand, oh no!*"



Double click icon on digital version to play sound (turn volume down).

Science Standards (NGSS; pg. 287)

- From Molecules to Organisms—Structures and Processes: MS-LS1-8
- Ecosystems—Interactions, Energy, and Dynamics: MS-LS2-4
- Motion and Stability—Forces and Interactions: HS-PS2-1, MS-PS2-2
- Energy HS-PS3-2, MS-PS3-5, HS-PS4-1, MS-PS4-2
- Earth's Systems: HS-ESS2-1, MS-ESS2-2, HS-ESS2-2
- Earth and Human Activity: HS-ESS3-1, MS-ESS3-2



The red on this map tells you that if you build near the river, or in a valley on unconsolidated sediment, you better make sure that you have engineered your house for earthquake stabiity. Otherwise, "will not stand, oh no!"

Shaking sands can take down large buildings as shown in the photograph of buildings tilted by ground failure caused by liquefaction. Nigata, Japan earthquake (www.noaa.gov

Causes and Characteristics of the Hazard

Seismic events were once thought to pose little or no threat to Oregon communities. However, recent earthquakes and scientific evidence indicate that the risk to people and property is much greater than previously thought. Oregon and the Pacific Northwest in general are susceptible to earthquakes from three sources:

1) the off-shore Cascadian Subduction Zone;
2) deep intra-plate events within the subducting Juan de Fuca Plate; and
3) shallow crustal events within the North American Plate.

While all three types of quakes possess the potential to cause major damage, Subduction zone earthquakes pose the greatest danger. The source for such events lies off the Oregon coast and is known as the Cascadia Subduction Zone (CSZ). A major CSZ event could generate an earthquake with a magnitude of 9.0 or greater resulting in devastating damage and loss of life.

Geologic evidence suggests that most of the Pacific Northwest is at risk from large earthquakes. In 1700, a mega-quake occurred on the Cascadia subduction zone just off the Pacific Northwest.

The hazard maps, and much of this text and two activities are from DOGAMI and WA DNR : ***http://www.oregongeology.org/sub/default.htm*** *and* ***http://www.dnr.wa.gov/ResearchScience/Topics/GeologicHazardsMapping/Pages/geologic_hazards.aspx***

Hazard Map Activity 1: Slope Instability:
Demonstration: Earthquakes and Slope Instability

Steep slopes can be particularly hazardous during and after earthquakes. In the long rainy season of winter and spring, soils can become saturated and quakes can produce rapidly moving landslides. However landslides may be triggered by shaking, even on relatively gentle slopes. In dry areas, rock fall can be deadly; one death in the 1993 Klamath Falls earthquake was from rock fall.

Procedure:

- Place the paper towel tube upright in the center of the pan. Carefully pour the sediments into the tube. Lift the paper tube allowing the sediments to fall out into a symmetrical cone demonstrating the material's angle of repose. This angle serves as a constant for the steepness of a slope for a particular material – undisturbed.
- Carefully place one or more houses onto the slope.
- Explain that an earthquake can cause the materials on a slope to become unstable by disturbing the cohesion that holds soil particles together.
- Gently tap the pan with your hand or a ruler to simulate an earthquake and watch the hill slope "fail" or collapse.

Materials:

- Pan or tray with edges
- 500 ml or more gravel or any other small sediments
- Paper towel tube
- Monopoly© sized buildings

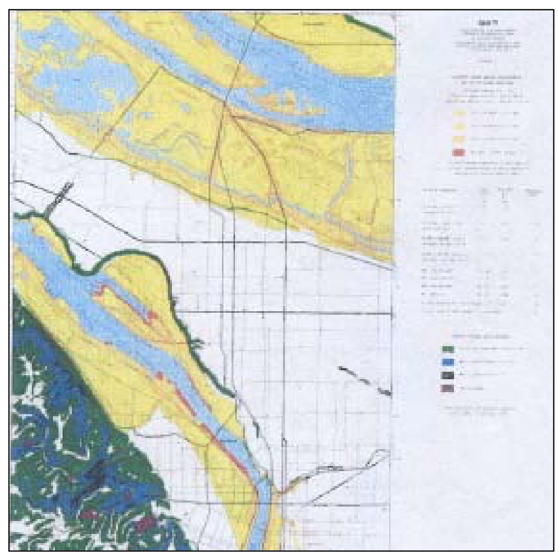
- See note next page for editable Word doc.

Extensions:

Try using different sediments or combinations of sediments. Use water to help over -steepen the hillside, or replicate ground saturation.

Ground Amplification:

Ground shaking amplification refers to the soils and soft sedimentary rocks near the surface that can modify ground shaking from an earthquake. Such factors can increase or decrease the amplification (i.e., strength) as well as the frequency of the shaking.



To learn more about how the Earthquake Hazard Maps were developed visit:
http://nwdata.geol.pdx.edu/DOGAMI/IMS-08/Text/IMS-08-CD-Text.html

Hazard Map Activity 2: Ground Amplification:

Demonstration: Earthquakes and Ground Amplification

Ground shaking amplification refers to the soils and soft sedimentary rocks near the surface that can modify ground shaking from an earthquake. Such factors can increase or decrease the amplification (i.e., strength) as well as the frequency of the shaking.

Procedure:

- Pace a small heavy object on the cinder block and another on the gravel.
- Strike the cinder block with a hammer and observe
- Repeat with the pan of gravel and observe

Questioning:

- What happens when the energy of a "seismic" P wave passes through each sample material?
- What could each material sample represent in a real-world setting?
- What features of good building design help protect buildings in areas susceptible to ground amplification?

Liquefaction:

Earth Liquefaction takes place when ground shaking causes granular soils to turn from a solid into a liquid state. This in turn causes soils to lose their strength and their ability to support weight.

Labs and Demonstrations:

See the Liquefaction lab activity using a cup, sand and coins.

Another demonstration of liquefaction uses two pie pans containing sand. One pan is dry, the other is saturated with water, but not covering the surface. Place a weight in each pan. Ask students to predict what will happen to the weight when an earthquake shakes the pan. Tap each pan with a ruler. Ask students to explain why there was such a big difference between the two pans. What does water do to the sand grains? What are the implications for building in an area identified as being at risk for liquefaction? What can be done to help protect structures built in areas prone to liquefaction?

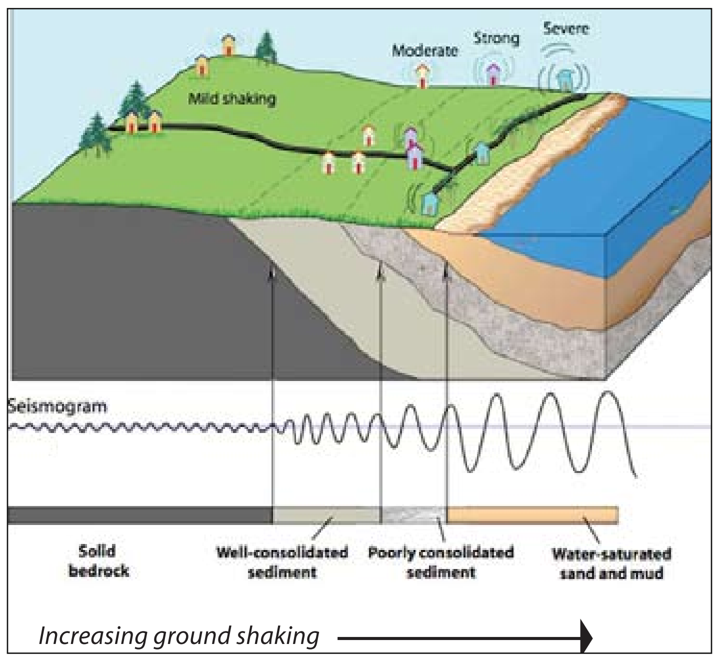
Materials:

- Cinderblock to simulate bedrock
- Pan with aquarium gravel to simulate loose alluvium or soil "geologic Jell-O"
- Small heavy object such as a weight, film canister with sand

An editable Word document called:

Liquefaction_Teacher and student_WORD.doc
is in the folder:

3. ACTIVITIES_Earthquake & Tsunami
Earthquake Hazard Maps & Liquefaction
RESOURCES



Why does ground shaking from an earthquake change so much with location?

How seismic waves shake the ground during an earthquake depends on the geologic layering. The figure above shows how an earthquake wave going through solid bedrock has high frequency and low amplitude. When the waves go through weaker material, they oscillate with higher amplitude but lower frequency. Imagine dropping a rock on concrete and recording the vibration compared to dropping a rock on a trampoline or a mattress. Water-saturated sediments are susceptible to liquefaction, which causes sediment to behave like quicksand.

A highly exaggerated animation of this graphic is in the folder: **3. ACTIVITIES_Earthquake & Tsunami**
Amplification

Hazard Map Activity 3: Liquefaction A (demo) and B (student activity, next page)

Demo on this page used with permission from http://www.exploratorium.edu/

What happens to filled land when an earthquake shakes it up?

Try this simple experiment to see.

What do I do?

Fill the pan with sand: the deeper the better.
Put the pan on a table. Then pour in water to just below the surface of
the sand.
Wiggle the skinny end of the brick down into the wet sand so it stands
up like a building would.
Now, very gently, repeatedly tap the side of the pan with a mallet and
notice what happens to the sand and the brick.

What's going on?

Did the sand get all squishy and the brick fall over? Allow a mixture of sand and water to sit for a while and the sand grains will settle until they touch each other. There will be water in cavities between the grains, but the mixture will behave as a solid.

When you shear or squeeze the sand (essentially what you are doing by striking the container with a hammer) you are trying to push the sand particles closer together. To do this, the particles have to push the water between them out of their way, just like what happens when you squeeze saturated sand in your hand or what happens to the sand under your feet as you walk close to the water on a beach.

In the case of an earthquake (striking the container with a hammer), the squeezing done by the shockwave happens very quickly and the water does not have time to flow out of the way of the sand particles. This results in the particles pushing on the water and causing an increase in water pressure as the particles try to move into a denser configuration.

This increased pressure causes the force at the contact points between the sand particles to decrease, and if the pressure is high enough it can reduce the interparticle forces to zero, essentially trying to "float" the sand particles away from each other for a very short time. This is liquefaction. The loss of strength occurs because there is no contact between the grains of sand and you basically have a mixture of sand suspended in water for a short time.

engineering at the University of Illinois at Urbana-Champaign

Materials

- l Metal or heavy plastic pan—full-sized loaf pans work fine
- l Sand
- l Water
- l A smooth brick
- l A rubber mallet

What is liquefaction?

Soil liquefaction describes the behavior of soils that, when loaded, suddenly suffer a transition from a solid state to a liquefied state, or having the consistency of a heavy liquid. Liquefaction is more likely to occur in loose to moderate saturated granular soils with poor drainage, such as silty sands or sands and gravels capped or containing seams of impermeable sediments. During loading, usually cyclic undrained loading, e.g. earthquake loading, loose sands tend to decrease in volume, which produces an increase in their porewater pressures and consequently a decrease in shear strength, i.e. reduction in effective strength.

(from WIKIPEDIA.)

Liquefaction—Individual student activity

By Chris Hedeen, Oregon City High School, Oregon City OR

What do I need?

- *Paper Cups*
- *Sand*
- *Water*
- *Coins*

Editable Word docs for this activity are also available in the **RESOURCES** folder below.

What do I do?

Instructions and discussion are intercalated in the student worksheets on the next pages. **Teacher answer key** begins on page 12 of this document. Editable Word documents are in the **RESOURCES** folder noted below.

Background

Information on ***"Liquefaction: What it is and what to do about it"*** and *"ShakeMaps"—Instant Maps of Earthquake Shaking* are on this DVD in the folder

- **3. ACTIVITIES_Earthquake & Tsunami**
  - **Earthquake Hazard Maps & Liquefaction**
    - **RESOURCES**

Paper cups & coins

plus

sand & water

Name:__________________

Liquefaction

A common cause of damage during earthquakes is the result of liquefaction of the soil. When earthquake vibrations pass through sand or silt, which has a high liquid content, the soil loses the properties of a solid and takes on those of a dense liquid, like quicksand or pudding. The solid strength sand or silt comes from the friction between the grains touching each other. As shaking continues, the pressure of the water between the grains increases until the pore pressure almost equals the external pressure on the soil. At this point the grains spread apart and, after sufficient strength is lost, the sand and water flows.

Procedures Model 1

Obtain a small plastic or paper cup. Fill it three-quarters full with dry sand (sediment). Place several coins in the sediment so they resemble vertical walls of buildings constructed on a substrate of uncompacted sediment. This is Model 1.

Observe what happens to Model 1 when you simulate an earthquake by lightly tapping the cup on counter while you also rotate it counter clockwise.

Answer all questions with complete sentences for full credit.

1. What happened to the vertically positioned coins in the uncompacted sediment of **Model 1** when you simulated and earthquake?

2. Why does this happen?

Name:__________________

Model 2

Remove the coins from model one, and add a small bit of water to the sediment in the cup so that it is moist (but not soupy). Press down on the sediment in the cup so that it is well compacted, and then place the coins into this compacted sediment just as you placed them in Model 1 earlier. Simulate an earthquake as you did for Model 1, and then answer questions 2 and 3.

1. What happened to the vertically positioned coins in the compacted sediment of **Model 2** when you simulated an earthquake?

2. Based in your experimental **Models 1 and 2**, which kind of Earth material is more hazardous to build on in an earthquake-prone regions: compacted sediment or uncompacted sediment? (Justify your answer by citing the evidence from your experimental models.)

3. Consider the moist compacted sediment in Model 2. Do you think this material would become more hazardous to build on, or less hazardous to build on, if it became totally saturated with water during the rainy season? To find out and justify your answer, design and conduct an experimental model of your own. Call it **Model 3**

   Write out your question (objective) and procedures on next page before conducting the experiment.

Name:___________________

Question:

Procedures:

1. What happened to the vertically positioned coins in the compacted sediment that is saturated with water when you simulated an earthquake?

2. What will the effects of liquefaction will be on buildings?

3. Where would liquefaction be likely to occur?

Write a statement (100-150 words) that summarizes how water in a sandy substrate beneath a home can be beneficial or hazardous. Justify your reasoning with the reference to your experimental models.

Name:_______________

Loma Prieta Earthquake

San Francisco is located in a tectonically active region, so it occasionally experiences strong earthquakes. Figure 1 is a map showing the kinds of Earth materials upon which buildings have been constructed in a portion of San Francisco. These materials include hard compact Franciscan Sandstone, uncompacted beach and dune sands, river gravel, and artificial fill. The artificial fill is mostly debris from buildings destroyed in the great 1906 earthquake that reduced large portions of the city to blocks of rubble. Also note that three locations have been labeled **X**, **Y**, and **Z** on Figure 1. Imagine that you have been hired by an insurance company to asses what risk there may be in building newly constructed apartment buildings located at **X**, **Y**, and **Z** on Figure 1. Your job is to infer whether the risk of property damage during strong earthquakes is low (little or no damage expected) or high (damage can be expected). All that you have as a basis for reasoning is Figure 1 and knowledge of your experiments with the liquefaction models.

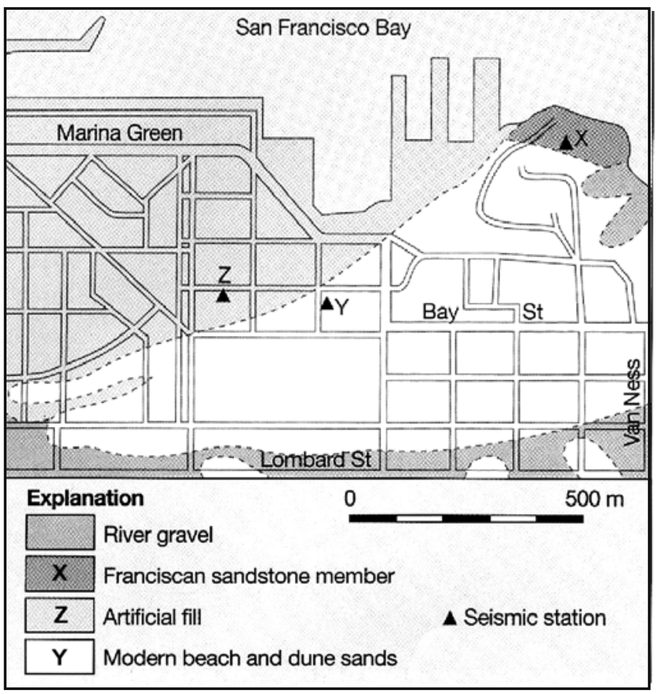


Figure 1 Map of the nature and distribution of Earth materials on which buildings and roads have been constructed for a portion of San Francisco, California.

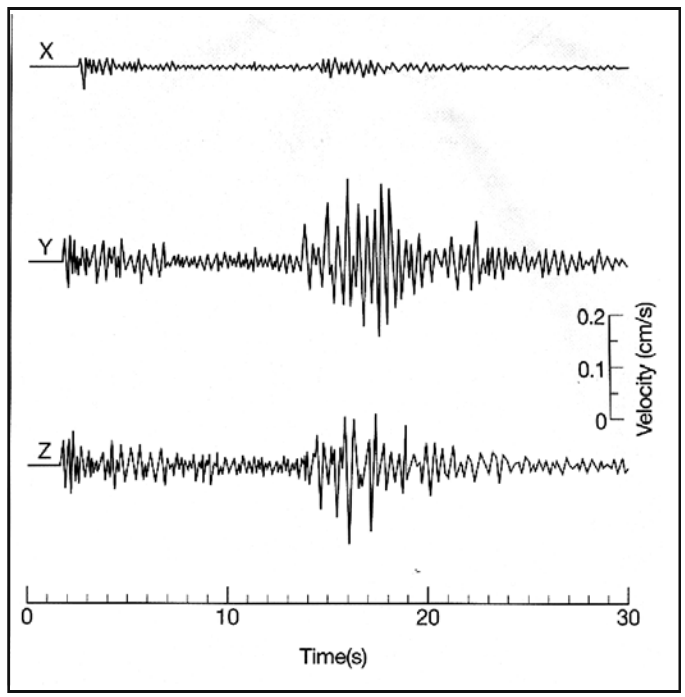


Figure 2 Seismograms recorded at Stations **X**, **Y**, and **Z**, for a strong (Richter Magnitude 4.6) aftershock of the Loma Prieta, California, earthquake. During the earthquake, little damage occurred at **X**, but significant damage to houses occurred at **Y** and **Z**.

1. In relation to the seismograms (Figure 2), rank the seismograms according to the amount of shaking.

    _____ X   _____ Y   _____ Z

2. What is the risk at location **X**? Why?

3. What is the risk at location **Y**? Why?

4. What is the risk at location **Z**? Why?

On October 17, 1989, just as Game 3 of the World Series was about to start in San Francisco, a strong earthquake occurred at Loma Prieta, California, and shook the entire San Francisco Bay area. Seismographs at locations **X**, **Y**, and **Z** (Figure 1) recorded the shaking, and resulting seismographs are shown in Figure 2.

Use complete sentences for full credit.

5. The Loma Prieta earthquake caused no significant damage at location **X**, but there was moderate damage to buildings at location **Y** and severe damage at location **Z**.
   Explain how this damage report compares to your predictions of risk in Questions 1, 2, and 3.

6. The Loma Prieta earthquake shook the entire San Francisco Bay region. Yet Figure 2 is evidence that the earthquake had very different effects on properties located only 600 m, apart. Explain how the kind of substrate (uncompacted vs. firm and compacted) on which buildings are constructed influences how much the buildings are shaken and damaged in an earthquake

7. Imagine that you are a member of the San Francisco City Council. What actions could you propose to mitigate (decrease the probability of) future earthquake hazards like the damage that occurred at locations **Y** and **Z** in the Loma Prieta earthquake?

Liquefaction - KEY

A common cause of damage during earthquakes is the result of liquefaction of the soil. When earthquake vibrations pass through sand or silt, which has a high liquid content, the soil loses the properties of a solid and takes on those of a dense liquid, like quicksand or pudding. The solid strength sand or silt comes from the friction between the grains touching each other. As shaking continues, the pressure of the water between the grains increases until the pore pressure almost equals the external pressure on the soil. At this point the grains spread apart and after sufficient strength is lost the sand and water flows.

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Answer all questions with complete sentences for full credit.

1. What happened to the vertically positioned coins in the uncompacted sediment of **Model 1** when you simulated and earthquake?

The coins tip horizontally and sank slightly into the sediment. Overall movement isn't great.

2. Why does this happen?

Answers will vary. The vibrations of the shaking cause both the particles of the sediment and the coins to shift.

KEY

Model 2

Remove the coins from model one, and add a small bit of water to the sediment in the cup so that it is moist (but not soupy). Press down on the sediment in the cup so that it is well compacted, and then place the coins into this compacted sediment just as you placed them in Model 1 earlier. Simulate an earthquake as you did for Model 1, and then answer questions 2 and 3.

2. What happened to the vertically positioned coins in the compacted sediment of **Model 2** when you simulated an earthquake?

   Answers will vary. There was less displacement of the coins.

3. Based in your experimental **Models 1 and 2**, which kind of Earth material in more hazardous to build on in an earthquake-prone regions: compacted sediment or uncompacted sediment? (Justify your answer by citing the evidence from your experimental models.)

   Answers will vary. Building on compacted sediment is going to less hazardous. Answers should include evidence from models 1 and 2.

4. Consider the moist compacted sediment in Model 2. Do you think this material would become more hazardous to build on, or less hazardous to build on, if it became totally saturated with water during the rainy season? (To find out and justify your answer, design and conduct another experimental model of your own.) Call it **Model 3**

   The more saturated the soil, the more hazardous it becomes to build on it.

   Write out your question (objective) and procedures before conducting the experiment.

KEY

Question:

Procedures:

1. What happened to the vertically positioned coins in the compacted sediment that is saturated with water when you simulated an earthquake?

2. What will the effects of liquefaction will be on buildings?

3. Where would liquefaction be likely to occur?

Write a statement (100-150 words) that summarizes how water in a sandy substrate beneath a home can be beneficial or hazardous. Justify your reasoning with the reference to your experimental models.

KEY

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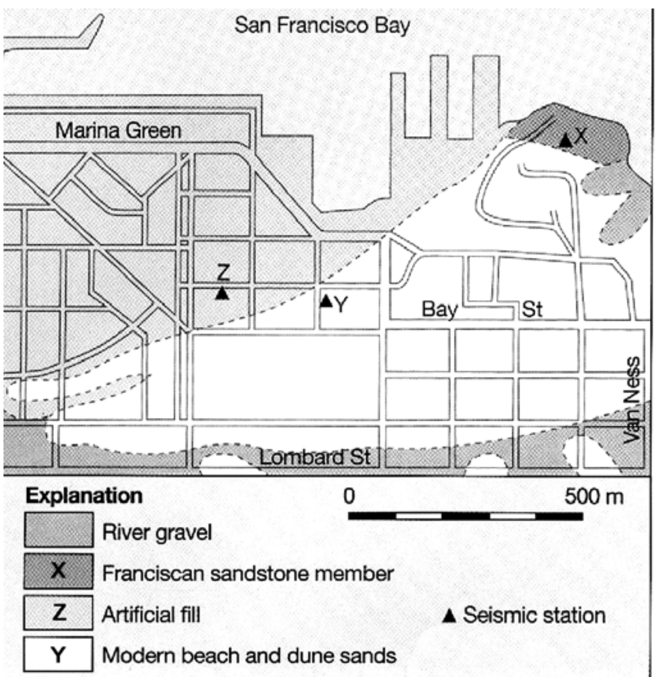

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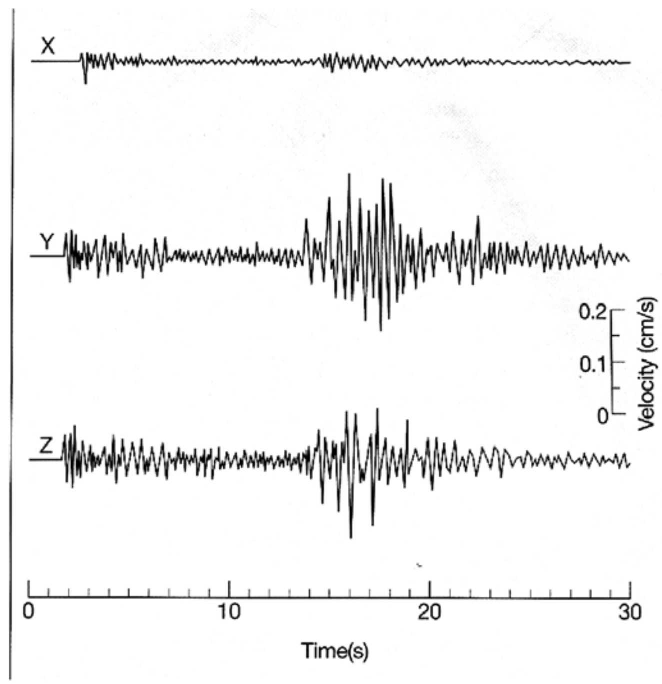

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1. In relation to the seismograms (Figure 2), rank the seismograms according to the amount of shaking.

___*3*__ X   ___*1*__ Y   ___*2*__ Z

KEY

2. What is the risk at location **X**? Why?
   Low – rocks are sandstone

3. What is the risk at location **Y**? Why?
   High –bed rock is modern beach and dune sand

4. What is the risk at location **Z**? Why?
   High – bed rock is artificial fill, likely uncompacted

On October 17, 1989, just as Game 3 of the World Series was about to start in San Francisco, a strong earthquake occurred at Loma Prieta, California, and shook the entire San Francisco Bay area. Seismographs at locations **X**, **Y**, and **Z** (Figure 1) recorded the shaking, and resulting seismographs are shown in Figure 2.

Use complete sentences for full credit.

5. The Loma Prieta earthquake caused no significant damage at location **X**, but there was
   moderate damage to buildings at location **Y** and severe damage at location **Z**. Explain how this damage report compares to your predictions of risk in Questions 1, 2, and 3.

Answers will vary. Greatest damage in those areas that have highest risk for liquefaction (uncompacted artificial fill) and least damage in areas that have well compacted rocks (sandstone).

KEY

6. The Loma Prieta earthquake shook the entire San Francisco Bay region. Yet Figure 2 is evidence that the earthquake had very different effects on properties located only 600 m apart. Explain how the kind of substrate (uncompacted vs. firm and compacted) on which buildings are constructed influences how much the buildings are shaken and damaged in an earthquake.

Answers will vary. Answer should include a discussion of better compacted substrates making better foundation materials as they do not experience liquefaction. When earthquake vibrations pass through sand or silt, which has a high liquid content, the soil loses the properties of a solid and takes on those of a dense liquid, like quicksand or pudding. The solid strength sand or silt comes from the friction between the grains touching each other. As shaking continues, the pressure of the water between the grains increases until the pore pressure almost equals the external pressure on the soil. At this point the grains spread apart and after sufficient strength is lost the sand and water flows.

7. Imagine that you are a member of the San Francisco City Council. What actions could you propose to mitigate (decrease the probability of) future earthquake hazards like the damage that occurred at locations **Y** and **Z** in the Loma Prieta earthquake?

Answers will vary. Possible answers include: different building codes in different areas, evacuation plans for existing buildings, retrofit foundations for existing buildings.