Liquefaction: That Sinking Feeling

***Putting Down Roots*, p. 17**

Idaho State Standards:

Earth Science 1.3.1, 1.3.2, 1.6.4, 4.2, 5.1

Objectives:

Students will:

1. Construct a model to demonstrate liquefaction.
2. Distinguish between soil liquefaction and soil saturation.
3. Assess potential damage to homes, lifelines, and schools.

RATIONALE

Like other earthquake-related phenomena, liquefaction may cause the loss of property and even injury or death. This model allows instructors and students to observe the effects of liquefaction and the phenomenon of sand boils on a small scale.

FOCUS QUESTION(S):

- What happens when a damaging earthquake strikes areas prone to liquefaction?

TEACHING CLUES AND CUES

If possible, substitute a small, hollow, ceramic house, measuring approximately 5 x 5 x 7 cm., for the sinker. These are sold at hobby shops for Christmas scenes, and can be filled with BBs to add weight.

MATERIALS:
for teacher

- Teacher Background Reading: Liquefaction, p. 68
- Teacher Background Reading: New Madrid Narrative, pp. 69 - 70

for the students: (work in small groups)

- 226 g (about 8 oz.) of well-sorted fine sand. Sandbox sand works well.
- One .25-1 (9 oz.) clear plastic cup
- One pie plate, diameter 23 cm (9 in.)
- 225 ml (5 oz.) of water in a pitcher
- Sinker or comparable small object weighing at least .06 kg. (2 oz.)
- One 250-ml beaker
- Newspapers to cover work surface

PROCEDURE:

Teacher Preparation

Read Teacher Background Readings "Liquefaction" and "New Madrid Narrative." Decide how you will share this information with your students. Students who like to read will find the New Madrid Narrative delightful. Gather enough materials so you can have two students per station. Before class, cover work areas with newspapers, set up the stations, and practice each activity at least once to ensure everything works.

A. Introduction

Tell students that an earthquake with a magnitude of 5.0 or greater may cause saturated sand or clay soils to liquefy. During the winter of 1811 and 1812, a series of earthquakes affected the central United States in an area known today as the New Madrid Zone that includes parts of the states of Missouri, Arkansas, Kentucky, Illinois, and Tennessee. As the soft sediments along the rivers were violently shaken, tremendous volumes of sand were liquefied and ejected onto the Mississippi River flood plain. These sand boils, as they are called, are still visible in the rural countryside today. Fortunately, the area of the earthquakes was not heavily populated in 1811-12, so loss of life, injuries, and loss of property were minimal. During the 1989 World Series in San Francisco, a 7.1 earthquake struck the Bay Area. Thanks to media coverage, millions of people viewed firsthand the fires and severe damage to buildings in the Marina District. Some of this damage occurred because soil liquefaction caused lifelines (gas, water, electrical, oil, sewage) to rupture and buildings to collapse.

B. Lesson Development

1. Write the word liquefaction on the board, and ask students to identify its root word (liquid). Emphasize that liquefaction does not cause an earthquake, but is the result of an earthquake. Liquefaction occurs only in highly saturated sand or clay soils. An earthquake with a magnitude of 5.0 or greater is usually needed to cause liquefaction. Earthquake vibrations cause soil particles to lose contact with each other, so the soil takes on the characteristics of a liquid.

2. Assign a partner to each student and designate a work station for each team. Give these directions:

a. Cut off about 5 mm from the bottom portion of the plastic cup.

b. Invert the cup and place it in the middle of the pie pan.

c. Holding the cup firmly, slowly pour the sand into the bottom of the cup to a level of 10-20 mm from the top. One student may hold while another pours. Level the sand with your fingers. Do not shake the cup to settle or level the sand (Figure 1).

d. Lightly place the sinker, model house, or other weight onto the leveled surface of the sand (Figure 1).

Figure 1

e. Again holding the cup, slowly pour the entire 225 ml of water into the pie pan around the outside of the cup and sand. (Figure 2)

f. Observe what happens and record the time it takes for the soil to reach saturation.

g. Once the soil is saturated, one student will hold the cup firmly in place while the other gives the side of the cup several sharp taps to simulate earthquake shaking. Observe what happens to the weight.

Figure 2

C. Conclusion

Help students to clean up and then initiate the discussion. Ask: If the weight in our experiment were an occupied building and liquefaction occurred over a large inhabited area, as it did in the San Francisco Bay Area in 1989, what would be the effect on:

- People?
- Private homes?
- Schools?
- Buried lifelines (gas, water, electrical, oil, sewage)?
- Agricultural lands?
- Medical facilities, fire stations, police stations?
- Large urban areas (Memphis, San Francisco, Boston)?
- Industrial areas?
- Materials that had been discarded in old sand boils (These could range from dead cows to old refrigerators to poisonous waste)?

Adaptations and Extensions

1. Make sand of various particle sizes and objects of different masses available for student experiments. Investigate the degree of liquefaction each will exhibit and the effects on the structures that rest upon them. A layer of diatomaceous earth under the sand will bubble up when the table is rapped. Try it!

2. Invite students to find ways to vary the amount of force they apply to the sand and water mix in the model.

3. Provide an aquarium or plastic gallon jars so students can experiment with larger models. Use transparent containers of any size—even a plastic sandwich box—for an interesting side view.

4. Bury objects in the sand and observe the results.

5. Develop models of overhead power lines, pipelines, sewage lines, light posts, and highways, and observe how liquefaction affects them.

6. Challenge students with this question: If a building has already been constructed on soil that has a potential to liquefy, what can be done to reduce the likelihood of damage? Invite them to design and test model structures that would reduce structural damage during liquefaction.

7. Bury a layer of sugar cubes below the sand surface to model land subsidence as the sugar cubes dissolve.

Teacher Background Reading: Liquefaction

How Liquefaction Occurs during Quakes

Liquefaction happens during an earthquake when vibrations cause the pressures to build up in the ground water that occupies the pore spaces between the grains of sand, silt, or loess. The longer the duration of the earthquake, the more likely that liquefaction will be induced. The only solid strength of such a deposit is provided by the friction between grains touching each other. When the pressure in the water that fills the pore space between the grains is sufficient to spread them apart, the solid nature of the sand, silt, or loess deposit is changed into that of a viscous liquid: "quicksand" or "quickclay."

Because it takes time for the pressures that produce liquefaction to build up underground, and because quicksand is a heavy, thick fluid that moves slowly, conditions of liquefaction, sand boiling, and associated phenomena may not be apparent during the shaking. In fact, they often do not manifest until after the shaking has already passed, sometimes not until 10-20 minutes later. The quick conditions or boiling of the sand can persist for hours or even days after the quake, sometimes as much as a week.

How Big Does It Take & How Near to the Quake?

A natural question regarding seismically-induced liquefaction concerns how big of an earthquake is required to induce quick conditions and the proximity necessary for such effects to be possible. With regard to size, several technical publications suggest that liquefaction does not occur for earthquakes less than Richter magnitudes of 5.2. However, minor liquefaction effects in areas underlain by particularly ideal predisposing conditions (loose sand deposits saturated with a near-surface water table) have been observed for earthquakes as small as 4.7 on the Richter scale in the New Madrid Seismic Zone. Minor damage to vulnerable structures has occurred in such areas. With regard to distance, an earthquake in June of 1987 with a magnitude of 5.2 in southeastern Illinois caused liquefaction phenomena near Bell City, Missouri, 150 miles (240 km) from the epicenter. A swimming pool, two large grain bins, a carport, and three houses were damaged, one severely. There were also fissuring and lateral spreading. At the same time, points nearer the epicenter of that quake did not experience such ground failures. Three years later in 1990 this same area experienced no liquefaction phenomena when a 4.7 earthquake struck only 20 miles (32 km) away.

Nearness to the epicenter implies greater amplitudes of ground motion, but distance implies a longer duration of shaking, since the wave train consists of many waves traveling at a variety of speeds. The epicenter of the magnitude 8.1 earthquake that struck Mexico City in 1985 was 240 miles (384 km) away and induced liquefaction that severely damaged some buildings. Although lasting less than a minute at its distant source, that quake lasted several minutes in Mexico City. Ground shaking amplitudes within the city, were never large, yet 400 buildings collapsed, resonating with the long-lasting wave train (or sequence of waves) amplified by underlying clays.

The New Madrid earthquakes of 1811-12 induced extreme examples of liquefaction, manifesting as sand boils and explosion cratering in the area of St. Louis, Missouri, and across the river in the flood plain of Illinois. Liquefaction also occurred from those quakes as far as Cincinnati, Ohio, more than 300 miles (480 km) away.

Three Ways to Induce Liquefaction

Liquefaction in soils can be stimulated three ways: seismically, mechanically, and hydrologically. Seismically-induced liquefaction is caused by seismic waves. Mechanically-induced liquefaction is caused by vibrations that come from railroad trains, motor vehicles, tractors, and other mechanical sources of vibratory ground motion. Hydrologically-induced liquefaction occurs when ground-water pressures increase due to rising stream levels during flooding conditions. This type of liquefaction most commonly occurs on properties protected by levees, where rivers can rise to levels above the land surface without actually flooding the land. With rivers flanked by levees and drainage ditches throughout the area, most of the New Madrid Seismic Zone falls into this category. Because of this, seismically-induced sand boils become hydrologically active during river flood stages, and can turn into quicksand and boil again, just as they did during the earthquakes that formed them. Similarly, tractors, trains, and trucks crossing over sand fissures during times of high water table can mechanically induce liquefaction, causing highways to sag, railroad tracks to get out of parallel, and farm equipment to sink into the ground.

Adapted from Stewart, David, and Knox, Ray, The Earthquake That Never Went Away: The Shaking Stopped in 1812, but the Impact Goes On, Marble Hill, MO: Gatlinburg-Richter Publications, 1993. A G U

Teacher Background: New Madrid Narrative
A 1912 Account of the 1811-1812 Earthquakes

The First Day

At 2:30 on the morning of December 16, 1811, a tremendous earthquake occurred with an epicentral region thought to lie just west of the location of present day Blytheville, Arkansas, a city that did not exist at the time. Had it been there, it would have been devastated totally, as evidenced by the numerous earthquake boils and fissures that visibly surround the city today. The Richter surface wave magnitude is thought to have been 8.6. 800 miles (1280 km) away in the White House in Washington, DC, President James Madison was shaken out of bed by the quake.

Many aftershocks immediately followed, some probably magnitude 6.0 or greater. At least two more shocks that day are thought to have equaled 8.0 on the Richter scale.

Then, sometime around 11:00 a.m., another great shock occurred in the vicinity of present-day Caruthersville, founded later in 1857. To the residents of the existing village known as Little Prairie, Missouri, this shock seemed worse than the initial earthquake. It is thought to have been another magnitude 8.0.

The River Rampages and Towns Disappear

The Mississippi River was churned into a virtual maelstrom, with miles of banks caving in, boats being swamped and sunk, and even entire islands disappearing along with their human occupants.

Two towns disappeared at this time. One settlement to disappear on December 16, 1811, was Big Prairie, Arkansas. Situated at the confluence of the Mississippi and St. Francis Rivers, the town site liquefied and sank, but slowly enough for all residents, approximately one hundred in number, to escape safely. Today, the Mississippi River occupies that site.

Another community destroyed that day was Little Prairie, Missouri, near present-day Caruthersville. Eyewitness accounts of the horror tell us of people violently thrown from their beds in the middle of the night. Although a bright full moon shone that night, shortly after the shock, large amounts of dust in the air caused everything to become pitch black. People were injured and bleeding and some were knocked temporarily unconscious.

The earth continued to jerk and rumble through the darkness until daylight, when around 8:00 a.m. the second hard shock hit the area. Throughout the morning, more shocks continued, with the ground heaving and cracking, sometimes opening and then suddenly slamming shut, spewing ground water over the tops of tall trees. In some places the ground literally exploded, blasting debris high into the air, raining sand and carbonized wood particles down upon the heads of those nearby, while leaving a deep crater in the ground where smooth land had been before. Sometimes, spreading crevasses formed in the earth beneath the bases of large trees, splitting their trunks from their roots upwards beyond the levels of their limbs. At one point during the morning, a great fissure began to form within the town. The townspeople stood around the pit and watched horrified as dark, viscous fluids gurgled from beneath the earth and gaseous fumes accompanied by the smell of sulfur and brimstone filled the air.

Many were thinking that the end of the world was at hand and that the very gates of hell itself were opening up to swallow their village. Amidst the terror, after the third great shock around 11:00 a.m., the soils of their settlement began to turn into quicksand, with dark waters oozing from the pores of the earth. As the whole town began to sink, the streets and cabins were flooded, not from the river, but from the ground itself.

Escape from Little Prairie

Hastily, the residents of Little Prairie gathered what meager possessions they could carry, lifted small children to their shoulders, and waded westward. Ahead of them, they could see rising waters far off into the horizon. For eight miles (12.8 km), the refugees waded through waist-deep waters, never knowing from one step to the next if they were going to plunge headlong into an unseen crevasse or trip over a buried stump, all the while surrounded by snakes, coyotes, and other wild creatures swimming for their lives in the turgid flood. During their escape, Little Prairie's displaced residents could not know if they would live through the day or not. However, all survived.

The First Day Was Over, but the Worst Was Yet to Come

Thus far, what has been described was only the first day of the Great New Madrid Earthquake series. More and bigger tremors were yet to come. At about 9:00 a.m. on January 23, 1812, another big one hit, with an epicenter probably lying north of Little Prairie and south of Point Pleasant, another small settlement in the area. It is thought to have been an 8.4 magnitude earthquake.

The Mississippi River bank, on which the village of Point Pleasant was situated, collapsed during the January 23 event. Fortunately, the residents had all evacuated the site prior to that catastrophe so none were injured. However, the town was lost forever.

The January 23 event also caused several huge sand boils in Tennessee that created a dam across Reelfoot Creek, creating Reelfoot Lake.

On February 7, 1812, the largest quake occurred. At approximately 3:15 in the morning, the region was rocked by an 8.8 magnitude shock. Outside Alaska, this event stands as the largest earthquake in American history and one of the largest in the world.

The quake caused the Mississippi River to run backwards. Towering waves of water were thrown over the banks, shattering thousands of acres of trees into splinters and stumps. The shaking threw boats onto dry land along St. John's Bayou at New Madrid and created two temporary waterfalls. These falls had a vertical drop of about six feet (2 m) followed by a mile (2 km) or so of shallow rapids.

During the largest of the New Madrid earthquakes, the river is said to have boiled, whirled, and heaved, with massive waves bashing from one bank to the other, sweeping boats and debris into oblivion. Some eyewitnesses from the banks said they actually saw the river open up in yawning chasms, into which the swirling waters disappeared, drawing hapless flat boats and their passengers into the maelstrom, never to be seen again. Others described water spouts that shot upwards from the water's surface like tall fountains.

The earthquakes literally destroyed the landscape with sand deposits, crevasses, and permanent flooding. Most residents of the region abandoned their properties and moved away. In the aftermath of the quakes, the boot-heel portion of Missouri became known as "Swampeast Missouri."

Two More Towns Gone Forever

The February 7 quake also destroyed two more towns. Fort Jefferson, Kentucky was swept away by landslides. The slumps are still visible today along Highway 51 leading into Wickliffe. In addition, New Madrid was itself destroyed. What remained of the settlement slumped downward 15-20 feet (5-10 m.) into the water's edge and was washed away by the spring floods of 1812.

The throbs and throes of terra firma wrought by the Great New Madrid Earthquakes of 1811-12 no longer trouble the landscape. However, though the motions of these devastating ground vibrations ceased in 1812, their impact can still be seen in the permanent traces of their violence that lie scattered over a 5,000 square mile (12,000 sq. km.) area spanning five states.

Note: This account was adapted with only minor changes from Fuller, Myron L., The New Madrid Earthquakes of 1811-1812, A Scientific Factual Field Account, USGS Bulletin 494, Washington, DC: Government Printing Office, 1912; reprinted by Southwestern Missouri University Center for Earthquake Studies, 1990. Please keep in mind that the numerical Richter magnitudes quoted in this book were not determined by instrumental measurements as they are today, because these events predated the invention of reliable seismographs.