Lesson 8: Landslide Hazards

Earthquakes are a major cause of landslides. Landslides occur when masses of rock, earth material, or debris flows move down a slope due to gravity. Landslides can occur on any terrain if the conditions are right, and cause significant damage and casualties to people and property. In this lesson, students learn about earthquake-induced landslides and the associated hazards, and how and why landslides occur. In addition, students discuss steps they can take to reduce landslide hazards.

Unlike previous lessons, Lesson 8 begins with a Tabletop Exercise. The objective of a Tabletop Exercise is to simulate a complex situation with multiple possible responses *before* the students have obtained all of the knowledge of the lesson concepts. The historical basis that served as the impetus for the Tabletop Exercise was the 2004 Southeast Asian tsunami, and the story of ten-year-old Tilly Smith. A British tourist traveling with her family in Thailand, she recognized the receding shoreline and strange surface bubbles from a tsunami lesson conducted just weeks before the event. She immediately warned her parents, who warned beachgoers and hotel staff of the impending tsunami. She is directly credited with saving hundreds of lives as a result of her timely and knowledgeable actions.

Please see Introduction to the Tabletop Exercise developed by Zachary Adam for more information about its objectives and key features.

Introduction

1. Ask your students to describe and review what an earthquake is and what causes them. In addition to the direct effects of earthquakes such as ground shaking, ask them to list other hazards associated with earthquakes. Other hazards may include landslides, liquefaction, structural hazards (buildings collapsing), non-structural hazards (a falling bookshelf or a shattered window), and destruction of utility lines (gas, water, electricity) and roads.

2. Tell your students they are going to learn about earthquake-induced landslides and related hazards in this lesson. Show students pictures of landslides (for examples see pictures at the end of this lesson) and ask them to list what the photos share in common. Their list might include cliffs, ridges, steep slopes, rocks, trees, structures, people, etc. Encourage students to define a landslide based on what they see in the pictures. Explain to students that landslides are rock, earth, or debris flows on slopes that move due to gravity.

3. (Optional) Explain gravity to your students. Gravity is the driving force behind landslide flow. Gravity is the attractive force between all massive objects. It causes apples to fall from trees toward the Earth, stars to pull planets into orbits, and cannonballs that are thrown skyward to return to the Earth. Gravity produces the weight of an object, which can cause an object to move down an inclined surface. The resisting forces are forces that cause the landslide material to resist the downward pull of gravity. Two

primary resisting forces in this example are frictional forces (discussed already in Lesson 6) and forces applied by the weight of the material (stress).

In general, the landslide driving force is most heavily influenced by the weight of the potential landslide objects and the inclination angle, as shown in Figure 1. When an object or group of objects rests on a horizontal surface with an inclination angle of 0 degrees, the pull of gravity produces no landslide driving force because all of the weight is pushing perpendicularly into the surface. The higher the inclination angle, the more dominant gravity becomes in 'pulling' material down the slope. This is because part of the weight starts to 'pull' the object in the direction of travel along the surface, as depicted in blue and labeled the Landslide Driving Force in Figure 1. Landslides begin to occur when the resisting forces reach a limit due to the strength of the material, the frictional properties between the slide material and the bedrock, or both. The resisting forces are depicted in red and labeled Landslide Resisting Forces in Figure 1. When the landslide resisting forces are equal in magnitude and opposite in direction to the landslide driving force, the object or group of objects will not move. When the landslide driving force becomes greater than the landslide resisting forces, the object will begin to move, which is analogous to a landslide in this setup. Triggering events such as earthquakes, heavy rain, or upsetting the inclined surface through digging can help to initiate a landslide, but gravity is always the primary force that enables any landslide to occur, regardless of how that landslide was triggered.

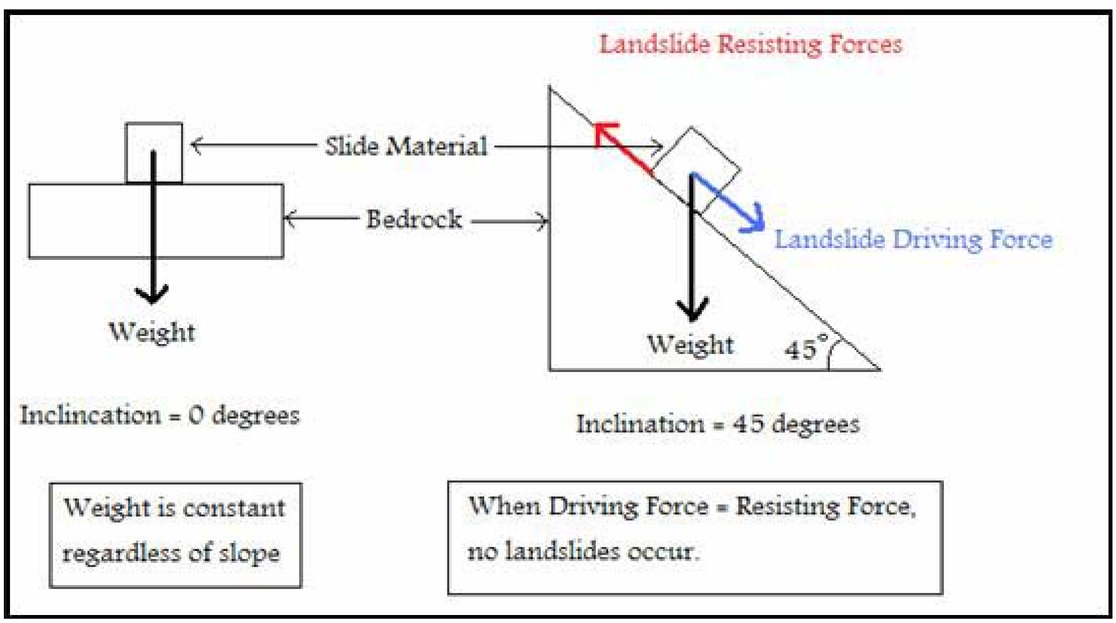

Figure 1. Diagram depicting the relationship between weight, landslide driving forces, landslide resisting forces, and inclination.

4. Explain to the students that there are three phases of landslide behavior: slope failure, transport of materials, and final deposition of slide materials. Ask them to look for where these phases take place in the photographs. Explain that slope failure can be gradual or sudden, and can exhibit noticeable properties such as visible cracks, slumps, or loud snapping sounds as slide materials break free from the bedrock or base material. Transport of materials can also be gradual or sudden, and can exhibit a wide range of transport modes such as rock or debris falling, rock or debris tumbling, material clump tumbling or sliding, fluid flow, or some combination of any of these modes.

Tabletop Exercise: Three Friends in a Valley

Note! This Tabletop Exercise specifically relates to the landslide hazards associated with earthquakes, however, landslides describe many different types of motion of sand, soil, mud, rocks, and other earth structures. Landslides occur in response to a wide variety of natural and man-made triggering events, such as earthquakes, heavy rainfall, volcanic activity, or road or building construction. There are more variations in landslide mechanisms and triggering events than can be covered in an introductory course. Therefore, the most important outcome of any lesson on landslides is that students develop the curiosity and willingness to critically evaluate what their surroundings can tell them about landslides.

Read the following scenario, stopping to ask questions and discuss the material with your students at the indicated points, or when students ask questions that are relevant to the discussion of earthquake hazards:

Three friends (Sara, Amira, and Gozen) live in the small city of Shahrabad, which is located in a beautiful mountain valley. The bottom of the valley has a small river running through it. The walls of the valley have land that includes forests and farms. The friends have lived there since they were young and they know that earthquakes sometimes happen there. They have only felt one small earthquake, but their parents and grandparents have told stories about some strong earthquakes that have happened in the area. Sometimes, during extreme weather like heavy snow or rain, the road that comes into Shahrabad from a nearby city is closed because rocks have fallen on the road or the road has washed away.

Sara and Amira live next to each other on farms located on slopes in the valley. Sara's farm used to have a natural spring that produced drinking water for both Sara's and Amira's families at a crack between two rocks, but the spring stopped producing water about a year ago. Recently, a neighbor has started complaining that some parts of his land have become very soggy and soaked with water, especially near the bottom of the valley.

Question 1: What are natural springs, and what are a couple of reasons why the spring on Sara's farm stopped giving water?

Potential answers: *Springs occur when water flows through cracks below the Earth's surface. The water can be a mix of rain water, water from underground channels that* *travel downhill toward the river, or water that is pushed up from deep underground in the deepest parts of the Earth that has not ever before been to the surface. Sometimes springs that are located very close to each other on the surface of the Earth have completely different paths that the water in each follows. The water that is soaking the neighbor's land may or may not be related to the water that used to come out of the spring, however, both of the changing events indicate that the land that Sara, Amira, and the neighbor live on is undergoing movements that may not be visible on the surface.*

The spring might have stopped because of some small change in the path of the water due to small movements of the ground, or because the source of the water has become empty. The changes in the path of the water could have occurred deep in the Earth or just a couple of meters beneath where the spring is located. When the water flows through narrow cracks, very small shifts in the ground can stop the flow of water.

Sara's and Amira's farm share a wooden fence to keep their farm animals from wandering around. Sara and Amira often climb over the fence to play in the forest around their farm. About three years ago, they noticed that the fence posts were sloped at an angle at one spot in the fence near their path to the forest, and they were concerned that climbing over the fence was pushing the fence over. They changed their path so they didn't have to climb over the fence and then gradually forgot about the sloping fence posts. But the fence posts continued to tip over, little by little, without anyone noticing the low part of the fence. Until one day, about a month ago, a donkey got away by jumping over the low part of the fence. They helped their fathers fix the fence and straighten the fence posts so the donkey couldn't get away.

Question 3: What are some possible reasons for why the fence is slowly tipping over?

Potential answers: *There are many answers possible that don't relate to landslide hazards. The fence could be old and the wood falling apart. The donkey could be pushing on the fence to eat some tasty grass that grows outside of that part of the fence. But also, the ground could be moving very slowly beneath the farm, causing the fence posts to point uphill over the years. The fact that the spring stopped giving water may support this idea even further, especially if the path of the water to the surface was broken because the ground had shifted very slightly.*

Gozen lives down in the city in a house. Sometimes all of the friends gather there to have dinner and listen to the radio or watch television. From where her family eats dinner, they can see the river. Her father helps to build and fix pipes that move water for farmers in the valley, and he also helps to build and fix houses. A wealthy man has just built a house above a very steep hill that has a beautiful view of the valley, and he even paid just to have electricity from the city strung on wires up the hill to the house. But the rooms already have cracks in the walls on the side of the house near the steep hill. Some of the windows and doors have also become very difficult to open and close. Gozen's father has been working there the past few days and he jokes about how the wealthy man complains that his house was not built very well by workers from a nearby city.

Question 4: What are some possible reasons for the cracks in the walls? What are some ways to find out what is really happening?

Potential answers: *Again, the wealthy man may be right and the walls were indeed poorly built. Oftentimes, houses also settle naturally as they age and cracks form as the house comes to rest on the ground.*

However, the cracks are forming on the walls on the sides nearest the steep hill, which may indicate that the part of the house that rests on ground above the steep hill may be on unstable ground that is slowly creeping down the hill. Doors and windows can become difficult to open and close because the house is changing shape as the ground moves beneath it, causing the frames to become misshapen. Also, if the ground were naturally unstable prior to building the house, the added load of the new house may be speeding the rate of movement of the creeping slope. Unstable ground or ground that is creeping is much more likely to release during a triggering event such as an earthquake or heavy rainfall.

There are many ways to tell what the real cause of the cracks may be. Other indications, such as the bending of pipes, fences, footpaths, or roads can be found to see if the ground is moving. If the ground is shifting, then electrical wires attached to polls in the ground near the edge of the hill will become very tight as the polls move with the ground.

One day, the three friends decide to go play in the forest together. They travel farther up the hill than they had ever gone before. They find a very interesting bunch of very tall trees, whose trunks grow out of the ground at an angle before the trees turn straight and point up into the air like a normal tree, as in the figure below. Some of the trees have such a sharp angle that the girls can sit in the angle of the trees like a comfortable chair with their feet dangling down the slope of the hill! Most of the trees are curved in the same direction in the middle. The three friends name it the Sideways Forest.

Question 5: What would cause trees to grow like this?

Potential answers: *Trees always grow up toward sunlight, so presumably the trees initially grew at a different angle when they were young. The fact that the trees were all curved in the same direction, and that they were all located next to each other, might indicate that the ground beneath the Sideways Forest is all shifting in one direction. The trees are all much older than the girls, implying that the ground has been moving for a very long time. This might mean that the ground above the farm is unstable, and could be dislodged in the event of heavy rain, an earthquake, or human activities like road construction. Figure 2 shows the shape of a tree that may indicate a history of ground creep, when exhibited by groups of trees located together.*

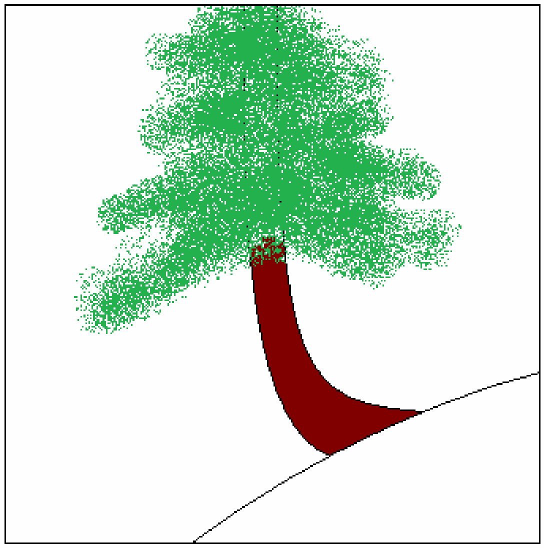

Figure 2. A common tree shape formed due to ground creep.

One day, while the friends are walking back home from school, there is an earthquake. It is strong enough to shake many of the buildings around them, and the earthquake is over after about a minute. They are just as far away from Gozen's home as from Sara's and Amira's farms.

Question 6: Where should the friends go first?

Potential answers: *There are many reasons to go to Gozen's house first. Gozen has a radio and television, so they can hear about the damage caused by the earthquake and whether emergency services are being delivered. The radio or television, if they are functioning immediately after the earthquake, may also have information on any developing weather system that may be coming in that could make the situation created by the earthquake even worse, such as heavy rain or snowfall.*

In addition, the combination of observations the girls have noticed around Amira's and Sara's farms indicate that the ground might be unstable and prone to landslide if another earthquake occurs. Knowing that the farmland is unstable, it is natural for the girls to want to make sure that their families and homes are safe. At that moment it is very dangerous to go there because the possibility for aftershocks is high. Since the girls are safe, they should make contact with a parent or family friend to let their parents know they are safe, and find out what has happened so that they can make an informed decision about what to do next, while conserving water, food, and medical supplies.

The families are all fine, and they meet at Gozen's house to talk about what happened. Through the radio, they find out that there has been an earthquake that has caused numerous landslides throughout the region. The neighbor whose land was becoming soaked with water reported that, in some places on his land, the surface had broken into cracks, and the smooth slope had become shaped like stairs. The road has been blocked by some falling rocks, but the families have some food stored away for when the road is closed. Gozen's dad says that many pipes have been broken in places so there is no water to be gathered through the city's water system. They send the friends down to the river to gather some water to support the families. While the three friends are at the river, they notice that the water level is much lower than it had been the day before.

Question 7: What are some possible causes for the low river water level, and what should the girls do about it?

Potential answers: *In river valleys that are likely to experience landslides after earthquakes, a sudden decrease in river water levels may indicate a landslide dam has formed upstream of the city. A landslide dam is when a landslide has blocked a river or stream, causing water to build up behind it. This causes flooding upstream and a drought or decreased water flow downstream. Landslide dams can be extremely dangerous because usually they are highly unstable. As the water builds up behind the dam, the landslide becomes saturated with water and can break catastrophically, flooding all areas downstream with little or no warning. Recall the instability of water-saturated unconsolidated materials observed during the liquefaction exercise in Lesson 7.*

The three friends should notify their parents or other city officials immediately of this possibility so that they can determine whether or not a landslide dam has formed. If action is taken quickly, the water behind the landslide dam can be released gradually before it builds up to dangerous levels. Even children can save entire communities!

The three friends told their parents immediately about the water level, who alerted city officials. A small landslide dam had formed upriver but it was not large enough to be a concern. All three families stayed at Gozen's house for a few days as aftershocks were felt, but none of them were as big as the original earthquake. While there had been no landslides that occurred on their farms during this series of earthquakes, the families became concerned about future earthquakes or other triggering events that could cause them to lose their farmlands and houses. They began to discuss ways of preventing landslides from occurring on their land.

Question 8: What are some of the things the families can do to prepare for landslides, and to prevent landslides from occurring on their land?

Potential answers: *Recognizing and communicating the signs of unstable land to city officials and neighbors in the community, and preventing further human development that can cause a landslide or put more lives in danger (such as building more human structures on unstable land) are the first steps to mitigating future hazards.*

Ask the students to make a list out of who they should contact if they suspect there is an emergency involving landslides. The game would be to rank the list in order of those that the students should contact first after an event or warning sign has occurred. Time and resources permitting, this ranking could be organized into a letter, sent to a local emergency services official, and evaluated for technical proficiency. The local emergency *services official should be able to provide guidance about additional resources in the community that were not identified, and how students' responses and actions in an emergency can help or hinder the planned relief activities.*

The second step is to prepare for future events by establishing safe, emergency meeting places in your community. People should also store food, water, blankets, and medical supplies in case emergency services are unable to reach them after for many days following an earthquake or landslide. The students will be taught how to prepare for emergencies in upcoming lessons.

The most difficult steps involve how to stabilize land that already shows signs of instability. Planting trees on otherwise open, exposed slopes may help to reduce water within soil that can trigger landslides more easily. Deep root systems of trees may help to bind loose soil and debris that would otherwise be easily released during a landslide. There are other, more costly engineering steps such as creating landslide barriers and ensuring proper drainage across roads that can be undertaken at the community level to mitigate landslide hazards. Whenever possible, these steps should be coordinated with other community members to help reduce the costs and to ensure that everyone is aware of the risk of landslides.

Tabletop Exercise Summary and Post-Exercise Discussion:

Many warning signs of unstable landslide-prone areas may be visible at the surface of the Earth. Now that students have completed the exercise, ask them to brainstorm about what evidence they would look for to indicate landslide-prone areas. Have them compare and contrast what they knew or did not know before the exercise started with what they learned as the exercise progressed. Emphasize that the point of this exercise was to put the students into a situation without any clear answers provided before the situation began, which is closer to how a real emergency situation unfolds.

Steep slopes, old landslide scars, and new cracks at the surface are the most obvious signs of the potential for landslides. Other subtle indications may include displaced fences, roads, or overhead power lines, leaning poles driven into the ground, new springs or water seepages in places that have never really been wet before, sticking windows and doors in houses due to shifting house frames, and unusual increases or decreases in creek water levels that cannot be attributed to rainfall or weather patterns.

Tabletop Experiment: The Homemade Landslide

Now that the students have simulated some common landslide experiences, they will have the opportunity to create, study, and describe a hands-on landslide demonstration. This simple experiment will permit students to observe the three phases of landslide development (slope failure, transport of materials, and final deposition of slide materials) and to explore the differences between the experiment and actual landslides.

Materials

Metal cookie or bread pans with 1-5 cm tall edges, about 40-60 cm in length and width
Pencils
Protractors
Sand
Soil
Gravel
Flat rocks
Cloths or paper towels
Newspapers to cover the working surfaces
Water pitcher with water (optional)
Toothpicks (optional)

Note! This activity can be done as an entire class with one pan or, with many pans and enough supervision, in groups. However, this activity can easily become messy, so it is not recommended that the class be split into more than 2-3 groups. The behavior of the sand, soil, gravel, etc. will depend on the particular properties of the materials that have been gathered. It is highly recommended that at least one educator go through all of the activities once before conducting the class to identify any problems with the setup, and to figure out methods of minimizing the mess created during certain parts of this activity. It may be necessary to move the activity outdoors, or to conduct all of the tilting experiments inside a large tray to catch water and spilling material.

Procedures

1. Cover the area that you intend to use for the demonstration with newspapers. Create a data table to record the results of your experiment runs (an example has been provided at the end of the lesson in Table 1). Encourage students to add new columns or to experiment with other materials that are not mentioned above, or to make remarks about behavior of the system that does not fit neatly into any of the categories.

2. Assigning duties: assign one student to be in charge of lifting one side of the cookie pan to create an incline as in Figure 3, telling the student to lift it slowly and smoothly, without shaking the pan or stopping, until the material on the pan begins to slide down. Assign another student to be in charge of measuring the angle that the cookie pan is at using the protractor. This student should call out the angle in increments of 5° when the material is not moving, and should call out the angle when the material moves (example:

the material does not move until it reaches 23° where it begins to crack, then at 27° it collapses: the student would read out “5 degrees…10 degrees…15 degrees…20 degrees…cracking at 23 degrees [as it begins to crack], 25 degrees, collapse at 27 degrees [as it collapses]). This student should be concentrating on reading out the angle when significant events occur, while the remaining students make specific notes that describe what is happening.

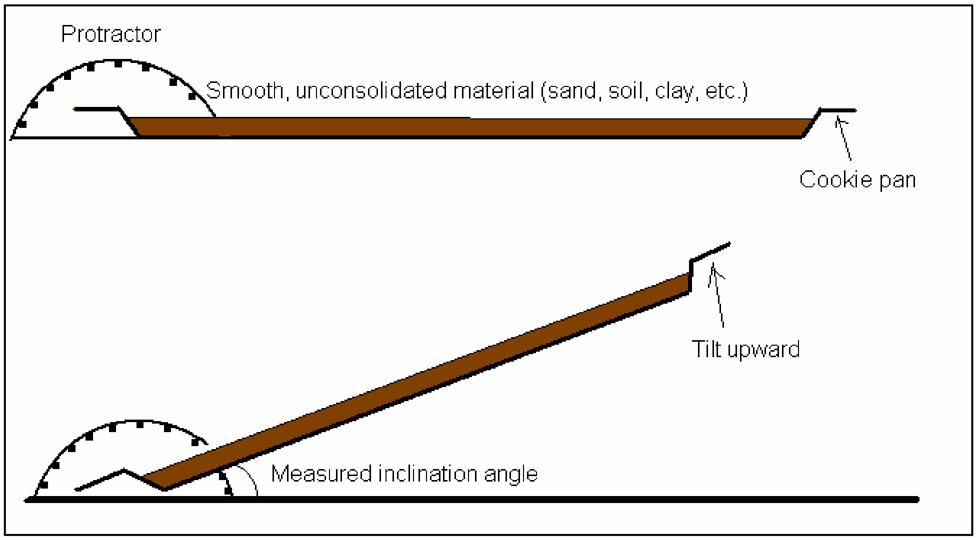

Figure 3. Side view of the cookie pan setup, protractor, and tilting orientation to produce a simulated landslide.

3. Start the experiment with the dry materials first, in order of those that are easiest to clean up (example: flat rocks, then gravel, then sand, then soil). Have the students complete the entries in the table that describe how the landslide simulation occurred. Have the students record details of the experimental setup before tilting the pan, such as what material was used, the dimensions of the pan, how deep the material sat in the pan. As the material begins to move when the pan is tilted, encourage the students to describe and note what happens in the data table at different angles, as provided in Table 1 below. After the materials have collapsed, have the students make note of *how* the material collapsed- did the material flow like a fluid, or did it travel in discrete blocks or slabs? Did it come to rest as a smooth pile of material, or were there small bumps or cracks in the collapsed material?

Complete the first run with all of the materials and discuss. If time permits, do more than one experiment for each material. When changing materials, use the cloths or paper towels to wipe off the cookie pan to make the conditions of the different experiments as similar as possible.

Note! The key to any scientific experiment is reproducibility. If the surface of the cookie pan is not regularly cleaned between different experiments, then the results might vary because of debris left on the surface from the previous experiments.

Discuss what happened with the students and encourage them to derive new questions about the setup. Were there any patterns? Which materials collapsed at the smallest and largest angles? Which materials collapsed quickly and which collapsed slowly? Were the materials that were used similar to materials that make up the mountains or hills around their region, why or why not? Could the students identify movements or behaviors in the materials that collapsed that corresponded to the warning signs that the three friends observed in the Tabletop Exercise scenario around their city?

4. Ask the students to predict what will happen if they repeat the experiments again, with the same materials, except that this time the pan will be tapped or gently shaken while it is being titled. Then repeat the steps above exactly as before for all of the same materials, but this time ask the student assigned to tilt the cookie pan to gently shake or tap the cookie pan as it is being lifted. Instruct the student to make sure that the rate at which the cookie pan is lifted is about the same as before. Instruct the student to keep the shaking motion about the same (in magnitude of motion and frequency) while tilting for all materials. Record any differences the students observe about the angles at which the materials collapse, how fast they collapse, the ways in which the materials collapsed, etc.

The overall result should be that the angle of collapse should be lower when the pan is shaken. Ask the students to describe why this should be the case, based on their knowledge of the weight, direction of gravity, friction, and angle of inclination angle. One answer is that materials like sand, when you view them very closely, are comprised of tiny little specks, each of which can be thought of as a tiny stone resting on many other tiny stones, surrounded by pockets of air called pore spaces (recall the liquefaction exercise in Lesson 7). When the students shake the cookie pan with pebbles on the slope, they tend to either roll down the slope, or to be pushed out directly away from the face of the incline, which causes it to 'jump' down the slope. When you add up the contributions from countless little stones that are all bouncing off one another, the net effect is that the entire mass of material is pushing itself down the slope as every little stone hops a tiny distance down the slope.

5. Finally, for each material, select an angle lying directly between the angle of collapse for shaking and the angle of collapse for the non-shaking case (example: the sand collapses at 15^{o} when shaking, 25^{o} when not shaking, so you should select the angle of 20^{o} for this case). Prepare each material in the pan and lift to the selected angle for that material. Ask the students what they believe will happen if the pan is shaken and why- the answer should be that it will collapse, because we are moving the material from a stable case to an unstable case by changing its environment. This is analogous to an earthquake-induced landslide.

Have the student shake the pan exactly as before, and have the students note the results.

Warning! The actual results may vary, but this is also part of the exercise. In some cases, the material will collapse as predicted, and in others, it may not. There are a tremendous variety of factors that dictate when, how, and why a landslide will occur, such as how compact the material sitting in the pan is, random variations in shaking the pan as it is tilted, and the random arrangement of sand grains at the contacts with the cookie pan, to name a few.

6. Summarize all of the observations made. Encourage the students to discuss the limitations of this setup when relating it to a natural environment, and have them identify some of the challenges earth scientists may face when trying to prevent landslides from affecting human communities. There are many possible answers: natural materials are not homogeneous, but a mix of different materials and consistencies. Natural slopes are uneven and irregular, with complex surfaces, cracks, and forces. The presence of water is also a complicating factor: for some materials observed with this type of setup, the water may increase cohesion and raise the angle of collapse. But in the real world, too much water tends to lower the angle of collapse due to the increase in pore pressure.

7. Encourage students to use their imaginations and the materials at hand with the sand, gravel, and soil materials to stabilize the surface. Some ideas include simply placing a wet paper towel over the surface. This functions very similar to surface netting and is a very effective, but somewhat expensive, way of stabilizing real surface cuts next to roads and buildings. Other ideas include building retaining walls using the flat rocks, or pebbles from the gravel, to hold back the material. Have the students experiment with different stacking arrangements and shapes at the base of the cookie pan as they tilt it upward, to see who can build the structure that best prevents landslides. Encourage students to find other materials around the classroom such as sticks, string, or pencils that may be incorporated into landslide barriers.

(Optional): Time permitting, have the students experiment with wetted materials. Have the students completely soak some of the materials in water for a few minutes (the longer the better). Have them load the cookie pan as before and note the results of raising the cookie pan. The results should be highly unpredictable. In some cases, the material will collapse at a shallower angle. In others, the material will collapse at a higher angle but the result will be much more catastrophic and sudden. The students can simulate rain water infiltration by *very slowly* pouring water onto the material at the top of the cookie pan as it is lifted. The students can also experiment with inducing an earthquake at various angles with wet materials.

Other optional activities include simulating the surface effects of creep by placing toothpicks, driven vertically into the sand, soil, or gravel materials, and slowly lifting up the cookie sheet as in previous steps. For some materials, very small movements of the material are reflected in the movement of the toothpicks readily before the slope collapses.

USEFUL INTERNET RESOURCES

Engineering for the World:
http://www.engineering4theworld.org/

REFERENCE

Much of the material used to derive the Tabletop Exercise and Tabletop Experiment can be found in the following web directory:
http://www.bechberger.com/Mel/Landslide_Activity/

2005 Kashmir Earthquakes: Landslides (all photographs taken by S. Mohadjer):

Landslide 1

Landslide 2

Landslide 3

Landslide 4

Landslide 5

MATERIAL	INITIAL CONDITIONS	ANGLES	FAILURE AND TRANSPORT MODES (% MATERIAL REMAINING)	GRADUALLY, RAPIDLY, OR SLOWLY?	FLUID OR CLUMP DEPOSITION	NOTES ON COLLAPSE
Rocks						
Gravel						
Sand	1) 20 CM X 40 CM X 4 CM 2) DRY 3) CONSISTENT DEPTH 4) NO CLUMPS	15 DEG. 18 DEG. 22 DEG. 25 DEG.	SMALL SAND DEBRIS FLOW (99%) SMALL DEBRIS FLOW (90%) SMALL DEBRIS FLOW (50%) SAND COLLAPSE, DEBRIS FLOW (5% REMAINING)	SLOWLY & GRADUALLY SLOWLY & GRADUALLY GRADUALLY RAPIDLY	FLUID FLUID FLUID FLUID	SAND GRADUALLY RELEASED UNTIL COLLAPSE AT 25 DEG.
Soil	1) 20 CM X 40 CM X 4 CM 2) DRY 3) CONSISTENT DEPTH 4) SOME CLUMPING	26 DEG. 30 DEG. 38 DEG.	CRACKS FORM NEAR TOP OF MATERIAL, SLAB OF SOIL SLIDES (100%) CRACKS GET LONGER, SOME BUNCHING AT BASE OF MATERIAL (95%) CATASTROPHIC COLLAPSE, LAND AND DEBRIS FLOW (10%)	GRADUALLY RAPIDLY RAPIDLY	CLUMPS (1-5 CM) MOSTLY CLUMPS, SOME FLUID CLUMPS BECAME FLUID AFTER MOVEMENT	EXCEPT FOR CLUMPS AT TOP, SOIL SLAB WAS NEARLY CONTIGUOUS UNTIL COLLAPSE.

Table 1. A sample data table to record the initial slope failure, transport, and final debris deposition modes of the landslide simulator. This table was adapted from the description of the ‘Landslides to Seafloors’ activity found in the web folder referenced above.