1906 Earthquake Commemoration
3rd Grade Geology Walking Tour

Welcome to Stanford University. This is a walking tour of the Stanford campus discussing the history of the university, what happened on campus during the 1906 earthquake, and some geologic concepts about why earthquakes happen. There are eight stops along the way, with activities and lots of things to talk about.

1. Oval

Why was Stanford University built here?

Leland Stanford came to California in the 1850s as a shopkeeper during the gold rush. He was very successful and eventually participated in a business venture to build a railroad through the Sierras, connecting California to the east coast. If you've ever noticed the train as you drive up to Tahoe along I-80, you're seeing the railroad that Leland Stanford helped build.

The Stanfords mainly lived in San Francisco, but they owned a horse farm in Palo Alto, where their son, Leland Jr., kept dogs and horses and even built a miniature railroad. Unfortunately, he contracted typhoid fever while the family was in Florence, Italy. Just a few months before his 16th birthday, on March 13, 1884, Leland Jr. died.

Figure: The Stanfords

Leland Sr. and his wife Jane were crushed and immediately decided to build a university in memory of their son on the spot where he had loved to ride horses, the horse farm in Palo Alto. That's why Stanford University is here and why the full name of the University is Leland Stanford Junior University.

Why does Stanford look like it does?

The Stanfords hired Frederick Law Olmsted to help them design the new university. He's the same man who designed Central Park in New York City. One of the unique features of the final university design was the long entrance down Palm Drive through groves of trees, known as the arboretum. The arcades (roofed passageways) and columns were also unique architectural elements and were meant to suggest the architecture found in California missions. If anyone has been on campus on a hot summer day, they know how nice it is to walk in the shade of the arcades!

The campus was built around what is known as a quadrangle or rectangle. Today it is just known as "The Quad". The plan was to expand the campus with additional quads at each end. The campus opened in 1891 with the Inner Quad completed. In 1893, Leland Sr. died and his wife Jane was left in charge. She decided to start building things differently than the original plan. She was afraid that if the grand buildings she envisioned weren't built soon, they'd never be built. A massive construction boom began in 1898. Jane oversaw a lot of construction, including the Outer Quad buildings, Memorial Church, the Chemistry building, the Museum, the Gym, and the Library, with several of these being built along Palm Drive instead of on either side of the Main Quad, where they were supposed to have been built. Let's look at the buildings and old pictures to see what's the same and what's different:

Activity
Begin by looking at the first structure. Look for a sign at the entrance to the University telling us that something is very different. Answer: The Memorial Arch sign is still on the left side of the entrance, but there is no longer an arch there

Compare and contrast pictures of the Stanford campus from before the 1906 earthquake. What is different The Memorial Arch is present in the old pictures. After the 1906 earthquake, the Arch top was dismantled and the bases were capped. Another apparent difference is the the church steeple is smaller now.

Figures: Design of Quad; 1891 Quad; buildings along Palm Drive; Gym; Library; Chemistry; Museum; Church; Memorial Arch; Memorial Arch and Outer Quad.

2. Memorial Court

What happened during the earthquake?

At 5:12 a.m. on April 18, 1906, a section of the Earth's crust located about two miles offshore from San Francisco gave way to built-up pressure and slipped with a violent lurch. A series of seismic waves spread out from this point at speeds of up to three miles per second. First people felt a huge jolt, called a foreshock. This initial jolt didn't cause alarm, but then the ground started to shake hard both horizontally and vertically for 45-60 seconds. That's a long time! Has anyone ever felt an earthquake?

Activity
Because few of us have ever felt anything like the 1906 earthquake, we're going to simulate what it might have felt like. First, gently take the hand of your neighbor. We can be lots of short chains. Now we are going to shake, up and down and side to side for 45 seconds; that's how long the 1906 earthquake shook at Stanford. Begin shaking.

After Shaking: What did it feel like? Did it last longer than you expected? How would you have felt if the ground was moving and making you shake rather than shaking on your own? Was anyone able to keep hold of his or her partner's hands?

During the earthquake, the San Andreas fault ruptured the surface of the ground for 290 miles, from San Juan Bautista in Central California to Shelter Cove in Northern California. By comparison, the 1989 Loma Prieta quake only ruptured the ground for about 25 miles. At Point Reyes, an offset of 20 feet was observed, and a recent study has calculated the offset at Shelter Cove to be 28 feet. In the south, the rupture averaged an offset of 8-12 feet.

Figure: Ground rupture and offset fence.

Activity

We just felt the earthquake itself. Now we are going to simulate what happens to the land after the earthquake.

a. *Form into groups of 8-10 students and divide each group in half. One half gets sign* Plate A *and the other half gets sign* Plate B.
b. *Line up A and B students facing each other and explain that each line represents one block of Earth that we call a plate.*
c. *Students should stretch out their arms forward to touch the palms of the student across from them. The line separating the plates is called a fault. Does anyone know the name of the fault here? San Andreas Fault.*
d. *Explain that there can be different types of movement along a fault. One is called creep. Everyone should slowly, smoothly shuffle to his or her right. The two lines will move in opposite directions and the students will slowly change partners.*
e. *Line the groups up as before and have them lock fingers across the fault. Again instruct them to move to the right by slow steps but to keep them moving past the point where they can hold on easily. Just before they have to let go or fall, call out "Earthquake". Ask the student to drop hands and stand up straight. The sudden release of energy should have them to stumble and fall into one another. Explain that they just simulated an earthquake.*
f. *Ask them to compare the difference between the slow creep and sudden movement.*

At Stanford, several of the monumental buildings that had only recently been finished disintegrated. The smokestack of the powerhouse collapsed, killing the Stanford fireman. Chimneys in both Encina (Men's dorm) and Roble (Women's dorm) collapsed and carried floors and students down with them; one student was killed. Aftershocks continued throughout the day and people set up tent cities outside the dorms, fearful of more quakes. The following day, University President Jordan cancelled classes for the remainder of the year. The graduating class was either passed or given special tests to see if they would pass. Do you think that would happen at your school if there were a large earthquake?

Within a month, repair work had begun on campus and it was quickly realized that most of the Inner Quad buildings suffered little damage. Jordan announced in July that Fall classes would continue as planned.

Activity

Compare and contrast pictures of the Stanford campus from before and after the 1906 earthquake.

Figures: Gym, Library, Chemistry, Museum, Church, Memorial Arch

Step back outside the Arch to see the statue to the left. One of the funniest pictures from the 1906 earthquake is from the front buildings of Stanford. The marble statue of naturalist Louis Agassiz fell off the front of Jordan Hall but didn't get smashed. Instead, he broke through the sidewalk head-first and stuck. One of the professors said that Agassiz wasn't so good in the concrete. A student said that Agassiz, who had studied geology, just wanted to stick his head underground to see what was going on. When they pulled him out of the sidewalk, only a piece of his nose was broken and they put him back up from where he had fallen.

Figure: Agassiz before and after

3. Quad

Did all the buildings at Stanford get damaged by the earthquake?

Now we are in the Inner Quad, surrounded by the short building built by Leland Stanford. While almost all the buildings at Stanford had minor damage from the earthquake, like cracked plaster on walls or fallen chimneys, not all of them were as damaged as the ones we just looked at. A group of faculty from Engineering surveyed the damage and they found an interesting pattern. Buildings that were built under Leland Stanford's direction weren't very damaged, while buildings built under Jane Stanford's direction were either destroyed or heavily damaged. Can anyone guess why this was the case?

Activity
Compare/contrast Inner Quad buildings to those built by Jane. Why did some of hers fall down? What would Leland have known that she didn't? Remember his profession was to build the railroad from San Francisco to over the Sierra Mountains. Look at pictures of the Outer Quad and Museum.

Answer: Leland had built the railroad and knew how important strong foundations were. He knew that earthquakes occurred regularly here. He had his builders make the foundations wider and stronger than usual to help lessen damage from earthquakes. Jane just wanted to get buildings built and didn't pay very much attention to foundations. The Inner Quad buildings are also lower(one story rather than 2 or 3) and less heavy than the other buildings.

4. Memorial Church

Why was damage to Memorial Church different than other buildings?

Memorial Church didn't always look like it does today. As you saw earlier, there used to be a huge, 80-ft. bell tower that almost doubled the height of the building. Here is what someone wrote about the church after the 1906 earthquake:

> “The dust settled slowly and revealed a terrible sight. The high steeple of the Church had collapsed… The great bells of the tower went through the floor. The works of the clock stood in their house poised on the truncated tower … The concussion of air in the body of the Church burst out the front wall … leaving unharmed the great organ … It is a magnificent wreck, as it was a magnificent structure in life. It is the one thing the earthquake did that we cannot forgive.”
> *Personal letter from President Jordan’s secretary, George A. Clark, April 27, 1906*

Figure: Memorial Church after the earthquake

Look at the damage to the church after the earthquake. Can anyone see anything strange about what happened to the building? Answer: the main part of the damage is where the roofs join the tower. What would cause so much damage to just the roofs of the church where they connected to the tower? Answer: The tower moved independently from the rest of the building. What would allow the tower to move independently from the rest of the building? Answer: The height, along with the material inside of it – steel.

Figure: Memorial church during construction with steel frame sticking out

Steel is more flexible than stone. When Memorial Church was built, steel beams were put inside the tower to hold up a clock and church bells. Since steel is more flexible, it moved differently from the surrounding stone walls when the ground started shaking. You can see in the picture how the moving tower crushed the surrounding roofs.

Because the tower was flexible, everyone thought it didn’t suffer very much damage. When they rebuilt the church, they decided to leave the tower frame.

Figure: Church during reconstruction

The rest of the church was dismantled and each stone catalogued. Then a new building was built around what was left of the tower frame. Architects couldn’t figure out how to rebuild the tower in a safe way, so they decided to leave it off and that’s how it has stayed.

Activity
Students will pretend to be buildings like the Church. Explain that buildings are built to hold up their own weight, just like the bones and muscles in humans can hold up its own weight. The force of weight is downwards. With a partner, one student should push gently down on the other’s shoulders. No one should fall over. Ask what type of motion occurs during the rebound of an earthquake? Side to side movement. Students should gently push forward on the shoulders of their partner to feel the difference of the strength of their bones and muscles.

5. Columns

Did anything happen to the columns and arcades?

Behind the church there used to be a long arcade. We just saw that side-to-side movement makes us unstable, as well as buildings. Since the long arcade wasn't attached to a building, it couldn't stand up to the side-to-side movement and fell. In other parts of the Quad, the weight of the moving buildings caused columns to break and keystones (the wedge-shaped stones in the middle of the arches) slipped down in archways.

Figure: Arcade before and after quake

The columns in Stanford's arcades, though, tell us something about the geology of California. There's a fossil in one of the Engineering buildings – can anyone find it?

Activity
Walk up the hill to building 550 and locate the fossil in the NW corner of the building. Location: 3rd course of stones near drainpipe.

What does the fossil look like? It's a cast of a shell fossil, from a type of snail that used to live on the seafloor. Scientists call it a turritellid gastropod. Let's think about this a little bit. How did a shell from the seafloor get into the wall of a Stanford Engineering building?

Activity
Step through questions and answers about how the fossil got to Stanford. Where did the stone come from? It was mined from a quarry in the hills south of San Jose. Why would a sea creature fossil be in the hills south of San Jose? The creature was covered in mud and sediment on the seafloor, where it fossilized. Then all that stone was uplifted.

Now we need to talk about plate tectonics. The outer crust of Earth is broken into pieces we call plates. These plates move slowly over time, some growing and some getting smaller. The edges of plates are where lots of the geological action is. As you modeled before as plate A and plate B, you were two plates sliding by each other. The evidence here with the uplifted ocean floor shows where one plate is pushed under another plate.

Activity
With this cream filled cookie (Oreo or equivalent), the hard cookie will represent the plates and the cream represents the mud and sediments on the ocean floor. 1. Remove the top of cookie and leave the bottom one with cream. The top cookie is the continental plate. The bottom is the oceanic plate. 2. Push the bottom plate under the top plate and the cream will get pushed up and accumulate at the edge between the two plates. 3. This is showing how the oceanic sediments, including the fossil in the building, was uplifted due to the movement of the plates.

Besides this gastropod, there were more fossils found in this area. Has anyone heard of the Stanford Linear Accelerator? It's close to I-280 and Sand Hill Road. When they were digging the trench for SLAC, they found fossilized shark teeth, oysters, some bones from a porpoise, some bones from a whale, more snails, and a complete skeleton of Paleoparadoxia – an ancient sea manatee.

Figure: Skeleton and reconstruction of paleoparadoxia

There's another way we can test the sandstone to see if it is from the bottom of the sea. One characteristic of marine sandstone is that a mineral called calcite holds it together. Calcite is fairly soft and it dissolves in acid, so if we put something acidic on the stone and there is a reaction, we'll know that it has calcite in it.

Activity
Put some vinegar on pieces of sandstone to see whether there is a reaction.

You can probably guess that this doesn't make the best kind of stone to build with. After the 1989 earthquake, it was decided to replace damage columns with seismically safer look-alikes made out of concrete. Let's see if anyone can tell which columns are concrete and which ones are sandstone.

Activity
Go down to arcade along Geocorner. Most freestanding columns are concrete while those still attached to buildings are sandstone. On the inner side of the arcade at the archway between Geocorner (bldg 360) and Building 310. there is a sandstone column attached to the building under the arcade and a concrete column next to it, but more out in the open. A seam can be seen on most concrete columns.

It's really hard to tell the sandstone apart from the concrete, but one way of doing it is to look closely at the rock. Concrete has a regular mixture of larger, black grains sitting in brown stuff while sandstone is just small sand particles. The concrete columns sometimes have a seam that you can see, where the two sides of the mold fit together. You can also tell by the bases of the columns. Remember how vinegar, an acid, dissolved the calcite? Rainwater is very slightly acidic, like vinegar, so over time it dissolves the calcite, making the columns crumble.

6. Geocorner

Had earthquakes been studied before 1906?

Stanford has a long history of geological study. The first professor ever hired at Stanford was a geologist, John Casper Branner, but not that much was known about earthquakes. After the 1906 earthquake, a professor at Berkeley, named Andrew Lawson, got together a group of scientists to study this huge earthquake as soon as possible in order to learn more about why earthquakes happen. This group of scientists included Stanford's J.C.

Branner, who had his office in this building. The scientists realized that they didn't know enough about earthquakes so they first set off to record as many details as possible. They took pictures, interviewed local residents, measured ground offset, and many other things all along the almost 300 mile ground rupture. Today, people call the report that these scientists published the birth of modern seismology, which is the study of earthquakes.

What did they learn?

One of the most valuable things the report did was to gather as many observations as possible. This means that scientists today can still go back and find meaningful information in what was collected by Lawson, Branner, and the others. They also came up with several theories that are really important.

Activity

Learning about the Lawson Report Theories

1. Elastic Rebound. One of the most famous theories is called "Elastic Rebound". Let's decipher these words. Elastic – who knows something that is elastic? How does it respond when pulled? Rebound - What does that mean? How does the elastic rubber band or band on your underwear respond? How does it feel on your skin? Theory – that is what scientists call something when they have lots of evidence that explains what is going on. The Elastic Rebound theory says that faults can be locked (remember holding hands), storing up energy as land slowly bends (your arms were bending) until the friction is overcome and the strain energy released (When you almost fell, that was the stored energy being released). The blocks of earth then slip and the earth "rebounds", releasing the stored energy as seismic waves. You can think of it like breaking a stick. As you bend the stick, the stick deforms until the force becomes too great and it snaps. While Elastic Rebound theory provided an explanation for how strain energy is released as an earthquake, the driving mechanism of the strain was not at all clear; that explanation had to wait until fairly recently.

   ACTIVITY: Hand out a chopstick to every student. Explain that the rebound of the blocks of earth is like what happens when bending a chopstick. As you bend the stick, the stick deforms until the force becomes too great and it snaps.

2. San Andreas Fault System. The area between two plates is not a simple line as the word fault may imply. Actually it is a set of faults that are the define the boundary between plates. A way to visualize this is the look at a deck of card, on edge. Hold the cards tight in between your hands, palms on the top and bottom. Shift the left had forward and right hand backwards. The center cards will shift and show the fault system.

3. Soil types affect damage. Another important result of the report is the understanding of how soil types affect damage. Some soils are very compacted, hard and dry. Other soils which are much more hazardous in earthquakes are soils full of water.

Sandy and unconsolidated soils are saturated with water. The shaking of the soil during an earthquake causes the soil to act like a liquid. We call this process liquefaction. The ground may sink or even pull apart. This can be a significant threat to pipelines, roadways including airport runways, and harbors.

7. Mitchell Building/Stock Farm Monocline

Why is there a hill between Mitchell and Geocorner?

Mitchell sits quite a bit higher than the Quad, but if you look down Escondido Mall towards the clock tower, you'll notice the hill tapers off. This hill is actually a clue to the geology that Stanford sits on. It's known as the Stock Farm Monocline and it's what we call a surface expression, meaning we can see it on the surface, of a fold in the rock.

This fold and others in the Santa Clara valley run parallel to the San Andreas Fault, which is roughly followed by I-280 west of campus. The San Andreas Fault is the boundary between the North American Continental Plate and the Pacific Plate. Since the monocline and other folds are parallel to the San Andreas Fault, we can guess that they are related, but the folds are the result of a different process than the fault. Remember how we looked at the deck of cards and saw how the San Andreas is a system of faults rather than just one crack in the ground? Well, the two sides of the fault also don't slide smoothly alongside each other.

Can anyone think of what kinds of features are on either side of the freeway near Stanford? Hills. While the Pacific Plate is moving north relative to the North American Plate, just like you were moving as groups called Plate A and Plate B earlier, the plates don't move exactly parallel to each other. They also move slightly towards each other and over time this causes the land to bend and fold and uplift the hills, even the ocean floor with fossils buried in the mud. The Stock Farm monocline is one of those folds. It runs through campus and all the way past Page Mill – has anyone driven to 280 from El Camino? The big hill you go up is the Stock Farm monocline. No movement was recorded on the monocline during the 1906 or the 1989 earthquake.

Do modern buildings need to be retrofitted?

Even modern buildings sometimes need to be retrofitted like the old buildings. The Mitchell building is a good example. After the 1989 earthquake, engineers assessed the building and decided that it needed some changes to make the building safer. Can you find anything that lets us know something was changed to make the building safer?

Activity
Look at the building and the different materials. Try to figure out what material was added or changed from the original. Answer: Concrete was poured between the eight corner columns creating shear walls. The concrete was obviously added at a different time than when the columns were built. The concrete in the columns has large stones in

the mixture while the shear wall addition between the columns is much more fine grained.

The concrete that was poured between the corner posts on Mitchell created what is called a shear wall. Do you remember when you acted like the church and either pressed down or were pressed from the side? Sideways force is called shear force, and shear walls are meant to give a building greater ability to withstand side-to-side movements.

Inside Mitchell is the Geophysics Department of Stanford Earth Sciences. This is where the study of earthquakes is carried out. In the past, people used to study things that they thought could predict when earthquakes would occur, even looking at things like how animals behaved, weather patterns, and electrical pulses in the ground. None of this proved to be very useful. Studying how the ground moves, though, is extremely useful. Today we saw different ways the ground moves during an earthquake and we saw how the Mitchell building was retrofitted to anticipate that kind of movement. Remember the big buildings that Jane Stanford had built? They weren't able to withstand that kind of movement because scientists didn't understand ground movement very well. Without a good understanding of ground movement, architects and engineers didn't see a reason to change the way they built buildings. Remember the buildings that Leland Stanford had built in the Inner Quad? He had built a railroad through wetlands of the Bay Delta and the Sierra Mountains and knew the importance of understanding the environment where a building was built. He used really strong foundations in the Inner Quad as a way to anticipate earthquake shaking. Even though he wasn't a scientist, his hunch turned out to be a pretty good one.

8. Stone River

As a final/optional stop on the way back to your car, this stop is across from the Cantor Art Center.

Stanford's earthquake history has inspired more than just architecture. In 2001, environmental artist Andy Goldsworthy was commissioned to create an outdoor sculpture in honor of President Gerhard Casper. He wandered the campus "boneyard" where he discovered original sandstone blocks from buildings damaged in both earthquakes. From this he decided to create a 320-foot long serpentine wall emerging from a depression hidden amongst the trees in front of the recently reinvented museum. Goldsworthy named the project Stone River. "The idea of stone that was once a building returned to the ground, back into the earth, for a work that is about flow, movement and change, it was perfect. It was really perfect," he said.

Suggested Supplies

Sandstone	Playing cards
Vinegar	Chopsticks
Oreo cookies	Signs A and B