Structures Shaking During Earthquakes

Utah SEEd Standard 7.2.3: Ask questions to identify constraints of specific geologic hazards and evaluate competing design solutions for maintaining the stability of human-engineered structures, such as homes, roads, and bridges. Examples of geologic hazards could include earthquakes, landslides, or floods. (ESS2.A, ESS2.C, ETS1.A, ETS1.B, ETS1.C)

Summary: Students will explore some basics of how and why structures behave in different types of earthquakes.

Background:
Along the Wasatch Front, the effects from possible earthquakes have to be considered when designing and building safe structures. Many things, of course, determine how a structure will respond in a given earthquake, but here we focus on resonance. Earthquakes produce energy across a broad spectrum of frequencies, and all structures are constantly vibrating at their own natural frequencies. If the frequency of shaking from the earthquake coincides with one of the natural frequencies of a structure, that structure will resonate, shaking at greater amplitudes than in non-earthquake conditions.

Activity Details:
With this activity, students learn about the natural frequencies of objects, beginning with strings. They explore how different material properties affect the natural frequency at which a string vibrates, including length, diameter, and tension. This works best when each group can have their own stringed instrument, but working through this as a whole class using just one instrument is fine as well. If there is no access to instruments, an online guitar can work, either on tablets or projected for the whole class. Many objects vibrate at multiple natural frequencies, where the predominant one is usually the "fundamental frequency" and higher ones are called "overtones." Here, however, students don't explore these higher frequencies and the natural frequency referred to in the activity is the fundamental one.

Students then explore vibration recordings of different natural arches and bridges (see https://geohazards.earth.utah.edu/bear/). These are constructed naturally through forces of nature, but behave similarly to human-made structures. There are pictures, 3D interactive models, animations, and vibration recordings of arches in southern Utah for students to explore. Seismometers, sophisticated tools used to record ground and structure motion, recorded the natural vibrations of the arches. These vibrations aren't observable to the human eye, but once they are sped up, the frequency of vibration enters the audible range and the motion is then heard as sound to the human ear.

Next, the concept of resonance is introduced to students, using an example of pushing a swing to describe it. If students are struggling to think of different examples of resonance, there are many videos available on YouTube with different demonstrations (see https://www.youtube.com/watch?v=BE827gwnnk4 for a great slow-motion example of a tone from a speaker matching the natural frequency of a glass and causing it to shatter). Some other examples are singing in the shower, something in your car excessively vibrating as you drive on a washboard road, radios, tuning forks, or soldiers breaking cadence on a bridge.

The final task for students is to construct different towers out of marshmallows and toothpicks (see diagram). They hypothesize which tower vibrates at a lower natural frequency and which vibrates at a higher natural frequency. Students then test this by securing their towers to a moveable foundation (like a Styrofoam, a box, or cardboard), and try to cause the towers to resonate by shaking the foundation back and forth at a low and high frequency. If students are struggling with the idea of low- and high-frequency shaking, explain that moving the foundation back and forth once per second is low-frequency shaking relative to shaking the foundation back and forth five times per second, which would be high-frequency shaking. After reporting their results, students imagine they are engineers responsible for designing buildings that can withstand shaking from earthquakes. Based on their previous knowledge and what they learned about resonance, students are asked what considerations they should have while constructing such buildings. You can share with them that one of the tools engineers use to counteract sky-scraper resonance during earthquakes is employing dampers. These can look like massive pendulums that are specially tuned to move opposite to the building's natural frequency, thereby reducing the amplification of the building's vibrations. The same applies for some pedestrian bridges. See the links for helpful videos and explanations:

Taipei 101 (skyscraper in Taiwan)
https://www.youtube.com/watch?v=NYSgd1XSZXc damper movement to counteract shaking from an earthquake becomes more obvious around 0:35
https://www.atlasobscura.com/places/tuned-mass-damper-of-taipei-101

London's Millennium Bridge: human-caused resonance
https://www.youtube.com/watch?v=gQK21572oSU
https://www.youtube.com/watch?v=SQEAj29IkNU

Vocabulary:
Frequency: How often something repeats in a certain amount of time
Natural frequency: how often an object vibrates back and forth each second, measured in Hz. In music, this is called the "tone."
Resonance: when the amplitude of an object's natural vibrations increase when the frequency of an applied force matches the object's natural frequency

Materials:
Stringed instruments, preferable (ukulele, guitar, violin, etc.)
    There are also online guitars that can work (see https://www.musicca.com/guitar), but you may have to adjust the student's worksheet a little
Tablets, preferable
    The class can also go through the activity together with a computer projecting for everyone
Toothpicks, ~50/group
Mini marshmallows, ~24/group
Moveable base to attach toothpick-marshmallow structures to
    Styrofoam blocks work, or boxes/cardboard with some putty to attach the toothpicks

Diagram:

Two different marshmallow-toothpick towers. Because the materials used to construct the towers and the widths/diameters are (for all intents and purposes) identical, the height should be the main controlling factor for determining each tower's natural frequency. The smaller tower should resonate with higher-frequency shaking and the taller tower should resonate with lower-frequency shaking.