Revisiting the BOSS Model to Explore Building Resonance Phenomena with Students

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While the Federal Emergency Management Agency's publication Seismic Sleuths: Earthquakes: A Teacher's Package on Earthquakes for Grades 7-12 (1995), is currently out of print, many of the activities contained within it are well worth revisiting for both interest in use and the opportunity to enhance established curricula. This is especially the case since the entire document is now freely available online as pdf files (www.fema.gov/hazards/earthquakes/nehrp/fema-253.shtm). One activity from the curriculum, the Building Oscillation Seismic Simulation (BOSS) model, provides an opportunity to engage students through the use of discrepant event demonstrations, and allows them to experience the process of science as they explore the interaction between buildings and shaking of the ground as a result of an earthquake.

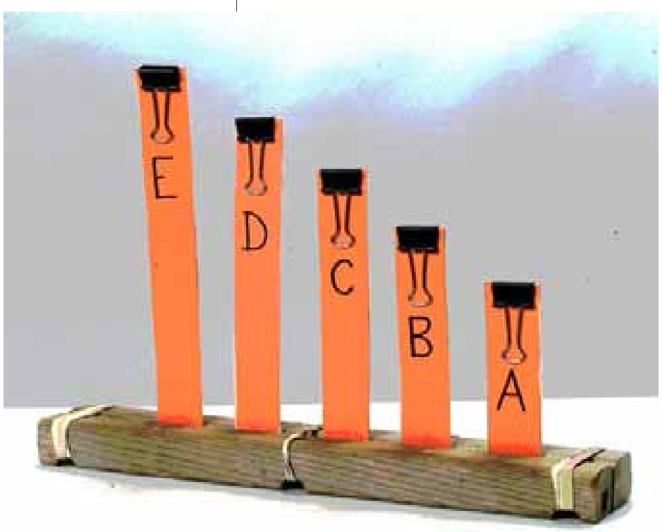

Figure. 1. The simplified BOSS Model is constructed almost entirely from materials found in your desk! Photo Credit: David Tuttle.

The construction of the original BOSS model was achievable by most classroom teachers, however it did require the purchase of some specialize materials; threaded rods, t-nuts, machine bolts, wood, and the use of a saw, drill, hacksaw, and hammer. With a bit of improvisation an equally effective model can almost entirely be constructed with materials found in your desk! The modified design of the BOSS model (Fig. 1) combined with both the detailed description of the pedagogical content knowledge for introducing your students to the model as a discrepant event and the discussion of the science behind the model found in this article can greatly reduce the barriers to implementing this lab with your students.

Constructing the simplified BOSS model

Materials

1 – Heavy manila file folder

5 – Small binder clips

2 – Blocks of wood .5in wide x .5in high x 10in long

1 – Roll of Duct tape or 3 strong rubber bands

Tools: Ruler, scissors, pencil

Assembly

A. Create "buildings" from the manila file folder. Measure and cut the following lengths of 1in wide strips

(2) 4 inches long

(2) 5 inches long

(2) 6 inches long

(2) 7 inches long

(2) 8 inches long

B. Place the two equal length strips together and clip at one end with the binder clips.

C. Label each building A thru E as shown

D. Place all five "buildings" equally spaced, between the two wood blocks.

E. Use the Duct Tape to tightly bind the two blocks together; securing the "buildings" in a stable vertical position.

Investigating the discrepant event sequence in-depth

When building a house of cards, one quickly realizes that only one or two floors creates a relatively sturdy structure. However, if the building reaches three, four or more floors, the slightest bump of the table easily sends a tall house of cards tumbling down. The lesson many people learn from this experience is that this sturdiness of a house of cards quickly decays as the number of floors in the card house increases. Many people extrapolate the lesson they learned from simplistic building experiences and attempt to apply these to reality. This often results in a naïve mental conception that taller buildings are "less safe" or "more likely to collapse" during shaking resulting from an earthquake.

Realizing the role that simple experiences like these play in the development of our understanding of the world is crucial to providing effective science instruction. In the late 1800's Johann Herbart laid the groundwork for this concept; recognizing that previously existing knowledge served as the starting point for the development of new concepts (DeBoer, 1991). My personal experience teaching this subject matter and using this model with many classes of students and many workshops of in-service educators has provided me with significant anecdotal evidence to support the presence of the naïve misconception described above. Unfortunately due to the relatively thin research base exploring learner conceptions of geophysics content, this claim cannot be further substantiated. Building on the role of pre-existing knowledge; discrepant event demonstrations, such as the BOSS activity, seek to challenge existing knowledge and motivate students to seek and formulate new explanations for the observed phenomenon (Chiappetta & Koballa, 2002).

In the BOSS demonstration the instructor presents five cardboard "buildings," of varying heights to the students. Since middle and high school aged students often think of physical models as copies of reality rather than representations the instructor should lead an explicit discussion of how the model is both like and unlike reality (Grosslight et al., 1991). In this case the cardboard strips represent the elastic nature of buildings; when a great enough force is applied to the buildings, they deform and return to their original position. The binder clips represent features of real buildings like air handling systems or pools that can add large amounts of weight to the top of a building. The model is unlike reality in that it is an extreme over simplification of the system we are modeling. In this case, the cardboard buildings are 2-dimensional and not scaled, they are more elastic than actual buildings, and the binder clips add proportionally too much weight to the top when compared to reality. Even though not exactly like reality, it is important to note to students that models are useful for exploring this phenomenon in real structures that would otherwise be prohibited due to costs and hazards.

Once the students and instructor have positioned the model in reality, the instructor asks the students to choose the building they would prefer to be in during an earthquake. Using a Think-Write-Pair-Share strategy students develop both a building choice and simultaneously develop a reason for their choice. As a result of student's naïve preconception discussed above, most students will select the shortest building to be safest. Following the student sharing of predictions and associated reasoning, begin to create an "earthquake" by oscillating the base of the model at a low frequency, or back and forth at about once per second. At low frequencies the tallest building will respond with an amplified displacement of the top of the building. Now alter your "earthquake" by oscillating* the base of the building through a range of frequencies from low to high. As you do, the tall building no longer responds. Instead progressively smaller and smaller buildings do! With a bit of practice, you can develop enough "touch" to allow you to shake each building individually and "walk" the shaking up and down the various height buildings in the model.

*NOTE: It is important that the amplitude of the oscillations be as consistent as possible for all frequencies. If you do not, students will attribute the discrepant behavior of the buildings to the distance you displace the buildings' bases rather than the rate at which they were displaced.

Engaged through the discrepancy between their own personal experience and the behavior of the model, students are primed for learning to occur as they search for a plausible explanation (Piaget, 1971). Exploring the demonstration with students should emphasize the importance of careful observations in science; what did you observed during the demo? Unless your students are already practiced at making careful observations, creating a list of evidence/observations can be more challenging exercises than you might. In fact, you should repeat the demonstration at least once, but are likely to have to repeat it a third or fourth time, while teasing out details with questions like: what was the cause of the shaking of the buildings, was the cause constant, how did it change?

Armed with a list of careful and detailed observations, the class is now prepared to develop a logical argument that accommodates the discrepant behavior of the model. Research on the effective use of discrepant events suggests that teacher should neither confirm nor deny students' tentative explanation of the event, but instead should provide guidance and cues so they can make explanations on their own (Cawelti, 1999). Sequences of questioning can help students develop their own reasoning; how did the actual demonstration compare to your prediction, what appeared to be the variable controlling which building shook, and ultimately... based on our observations can anyone propose a relationship between frequency or rate of shaking and building height? Once students have reached this point and have formulated a stated relationship between the frequency of shaking and building height, questioning should be pushed to the synthesis level; devise a simple experiment that would test such a statement. Given the relatively simple nature of the problem and model the entire sequence described above can be completed in about 10 minutes. Thus, it is worth spending the next 5 minutes encouraging students to write out the steps, in sufficient detail, to "test" the statement of relationship of the model.

If you do not plan to use the full lab contained within Seismic Sleuths (Ireton et al, 1995) follow a student's design and test the relationship they developed as a demonstration. Not only will this provide an opportunity to explore the phenomena, but it also accommodates a class discussion regarding the level of detail and process required for experimental design. If you do plan to use the Seismic Sleuths, allow enough time for students to follow the steps they have developed to test the conclusion and reflect on the process in the journals. Either way, a homework assignment that asks students to explain their results from the experimentation should be given. Thus, through either a 15 - 20 minute discrepant event demo or a the demo connected to a lab, students have been cognitively engaged in the lesson and have participated in the process of science. That is, they have had the opportunity to collect empirical data through observation, develop a logical argument as a class through the linking of observations to reach a stated relationship and finally to undergo skeptical review as they detail their "findings" in their homework assignments.

Why does this Discrepant Behavior Occur?

All buildings have a natural resonance, or motion at which the addition or superposition of energy at the same frequency amplifies that motion. For example, when a child is being pushed on a swing, if pushing is applied at random times, the likely result is that swing will slow and stop. However, if the push to the swing is applied at the "right time" or the peak of swing (at the correct frequency) during each swing, the swinging will increase dramatically. Therefore, if seismic waves accelerate the base of a building at a frequency close to the resonance frequency of the building, the resulting amplification of energy can result in an increased and eventually unsafe displacement of the top of the building. While specific building geometries and materials control the resonance of a building, resonance frequency is largely a factor of building height. A buildings resonance frequency can be roughly estimated by using a simple formula; 10Hz divided by the number of floors ~ Natural Resonance (Pratt). Thus, tall buildings have a low natural resonance, and respond to low frequencies; a 30-floor building would have an estimated resonance period of 3.33 seconds and would be most effected by ground shaking at a frequency of 0.3Hz. In contrast, short buildings have high natural resonance and respond to higher frequencies; a five-story building would be most affected by ground shaking at a frequency of 2Hz (Pratt). While building height is a major factor controlling the natural resonance of the building, the distance the building is from the hypocenter influences the frequency of the seismic waves that reach it.

When an earthquake occurs, seismic waves with a fairly broad range of frequencies are released.

As these seismic waves propagate away from the earthquake source, their amplitude becomes smaller and their frequency tends to decrease with distance. Earth materials, while elastic enough to deform and store the potential energy that is released as an earthquake are also

anelastic, or deviate from elastic response. This means that as seismic waves travel through the Earth, kinetic energy is converted to heat as the material is permanently deformed, which in turn reduces the frequency of seismic waves. Researchers Stein and Wysession (2004) note in their global seismology textbook, that without anelasticity… "seismic waves from every earthquake that ever occurred would still be reverberating until the accumulated reverberations shattered the earth."

As the waves travel out from the source, geometric spreading decreases the amount of energy per unit area of the expanding wave. This is analogous to a pebble tossed into the pond. Since the pebble released a limited amount of energy and the resulting wave spreads out from the source, the conservation of energy requires that the amount of energy per unit area must also decrease. The wave becomes smaller with increasing distance from the source.

In a simplistic summary, taller, more flexible, buildings are susceptible to the smaller, low frequency oscillations of distant earthquakes, while shorter and stiffer buildings are more susceptible to the larger, high frequency shaking of nearby earthquakes.

Real-world Applications to Reinforce the cCncepts

Selective building response to shaking such as demonstrated by shaking only one or two buildings of the BOSS model has direct applications in real life. A classic example of this can been seen in the damage resulting from the September 19th, 1985 Mexico City earthquake. While the majority of damage resulting of the quake can be attributed to construction techniques that lacked appropriate earthquake reinforcements not all buildings of similar construction were equally damage. The USGS reports that broad survey of damaged buildings across the city revealed that a disproportionate number of intermediate height buildings, 8-18 stories were damaged, when compared to shorter buildings and skyscrapers. This effect was most pronounced in the area of the city that was situated on an ancient lakebed. Why did this selective damage occur? Think back to our model and the description of the phenomenon above.

Intermediate story buildings were at greater risk due to geologic setting of Mexico City. The soft clay sediments deposited by the ancient lake preferentially amplified the seismic waves, resulting in surface waves with approximately a 2 second period, or 0.5Hz. Using our rule of thumb estimation for building response described above, structures of intermediate height, with an estimated resonance frequency of 1.25Hz to 0.55Hz, were most susceptible to these damaging waves. Studying this event with your students can further reinforce students' new, more complex cognitive framework regarding earthquake effects on buildings of various heights. Below are several resources that can help your explore the Mexico City event with your students:

Mexico City Event (USGS) http://neic.usgs.gov/neis/eq_depot/world/1985_09_19.html

A 2001 newspaper report revisiting the event
http://www.chron.com/disp/story.mpl/first100/1068709.html

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