

MACGILLIVRAY FREEMAN'S
**DREAM
BIG**
ENGINEERING OUR WORLD

DESIGN CHALLENGE EXHIBIT: **SHAKE TABLE**



INSTRUCTIONS FOR MAKING A MECHANICAL (NONELECTRICAL) SHAKE TABLE

Materials:

- ☐ Wood screws (various sizes)
- ☐ ¼" metal washers
- ☐ Threaded rod 4" long x ⅜" diameter (and nuts)
- ☐ Wooden base: ¾" thick x 11 ½" wide x 19 ½" long
- ☐ Fiskars craft drill (manual hand drill)
- ☐ Wooden shake table top: 12" x 11 ½"
- ☐ 8 spring holders: ⅝" diameter wooden dowels x 1 ½" high
- ☐ 1 connecting rod: ¾" diameter wooden dowel x 11 ¾" long
- ☐ 1" and 1 ¼" split ring tube hangers
- ☐ ⅝" hex bolt
- ☐ 4 compression springs: 4" high x ¾" diameter
- ☐ #33 rubber band(s) ⅛" x 3 ½" (to attach connecting rod to shake table top)
- ☐ Drill base (use a wooden 2 x 4 approximately 3 ½" tall)
- ☐ ½" long screw eyes
- ☐ Metal connecting plate
- ☐ Safety gear, including eye protection

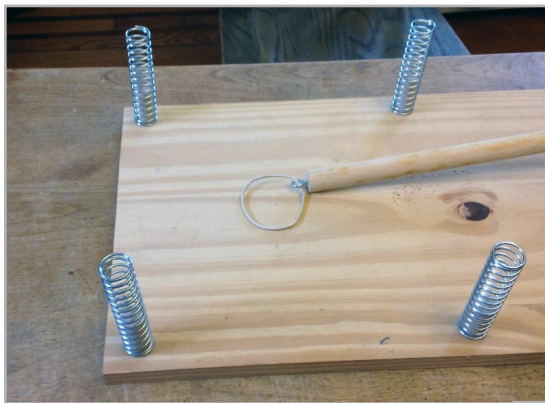


Construction:

Cut the wooden base and the shake table top to size.

Cut dowels for spring holders and connecting rod.

Position a $\frac{5}{8}$ " dowel slightly inside each corner of the shake table top (as shown here) and screw into place

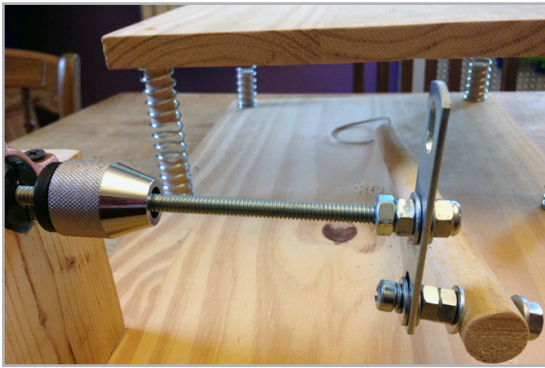


Use the shake table top to mark the position of the four spring holder dowels on the base and screw into place (as shown below.) Place springs onto dowels.

Cut the 2 x 4 drill base to size, and file or drill a semicircular shape (approximately 1 $\frac{1}{4}$ " in diameter) out of the top of the drill base. (See image.) This depression will be used to support the drill. Note: If you are using a different drill than suggested, you may need to adjust the dimensions based on the drill's neck size.



Attach the drill base to the corner of the shake table base by drilling and screwing it in from below (see image that follows). Screw the split tube hangers into the drill base to hold the Fiskars drill in place. Carefully tighten the hex bolt through one of the split tube hangers to provide additional stability for the drill.



Insert the threaded rod into the hand drill and tighten into place. Drill a $\frac{1}{4}$ " hole into the center of the metal connecting plate and attach the end of the threaded rod with nuts and washers as needed—the end of the threaded rod projecting through the plate should be finished with a washer and nylon-insert lock nut. (Refer to the following image.)

Drill another $\frac{1}{4}$ " hole toward one end of the connecting plate. Drill a $\frac{1}{4}$ " hole completely through the wooden dowel connecting rod about $\frac{1}{2}$ " from one end. Use a bolt, nuts, and washers to attach the end of the wooden connecting rod to the connecting plate. NOTE: You may need to use additional nuts as spacers (as shown) so that the end of the metal threaded rod doesn't bump into the wooden dowel.



Use one screw eye and insert it completely into the center end of the wooden connecting rod (as shown in the following image). Use a screwdriver or pliers to slightly open the screw eye at the end of the connecting rod so that you can slip a rubber band inside the screw eye.



Position the other screw eye into the underside of the shake table top, centered along the same axis as the wooden connecting rod, approximately 1 inch from the edge, and toward the center of the shake table top. (See image following.)

Use a screwdriver or pliers to slightly open this second screw eye so that you can slip a rubber band inside the screw eye. Lastly, connect the rubber band to each screw eye and lower the shake table top onto the four springs so that the wooden spring holder dowels are captured on both top and bottom.



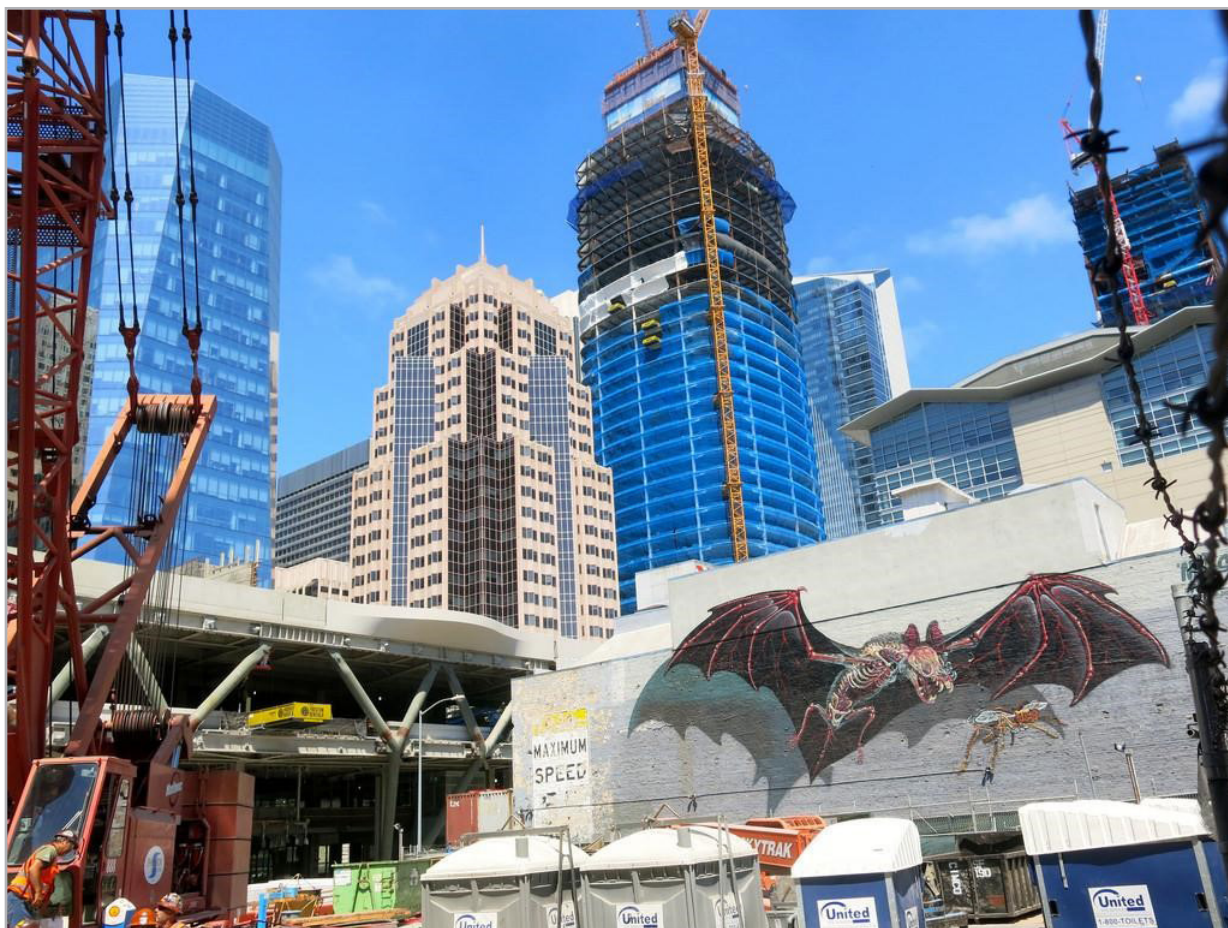
Now if you turn the drill handle, the shake table should wiggle and oscillate back and forth. (You may need to tighten or adjust the nuts or other pieces slightly to get everything moving properly.)

Have fun learning how to build earthquake-resistant structures on top of your shake table!

CHALLENGE OPERATIONS

Overview:

The Salesforce Tower (formerly called the Transbay Tower) is expected to be completed in 2018, as part of the redevelopment of the Transbay area of San Francisco. At 1,070 feet tall, the tower will be the second tallest in the western United States. Rather than enforcing traditional building code, San Francisco has recently implemented performance-based design, which allows architecture firms to use computer modeling to test the ways that buildings perform in an earthquake. One example of performance-based design is the One Rincon towers property in San Francisco's Rincon Hill, where 50,000 gallon water tanks are used to add weight to the structure, and rebar strengthens the middle floors (models show the structure had more of a whip-like movement in quakes, with stress at the middle).



Salesforce Tower under construction. Photo courtesy Flickr: torbakhopper / [flickr.com/photos/gazeronly/29178016171](https://www.flickr.com/photos/gazeronly/29178016171)

In this activity, participants will be able to build and test models, just like architectural engineers who use performance-based design, to see how those models act in an earthquake. Based on how the models perform, participants can adjust their designs to see if they can make improvements.

Program Goals:

- Demonstrate the action of an earthquake
- Encourage participants to investigate building techniques
- Help participants to discuss shapes and structures used in architectural engineering
- Demonstrate how modeling impacts the engineering design process
- Provide opportunities for collaborative and intergenerational learning

Materials Needed:

- ☐ Blocks (Kapla blocks were used in trials, but various types and sizes could add different challenges or advantages)
- ☐ A “frame,” if desired, to act as a foundation for construction

Demonstrate the Force

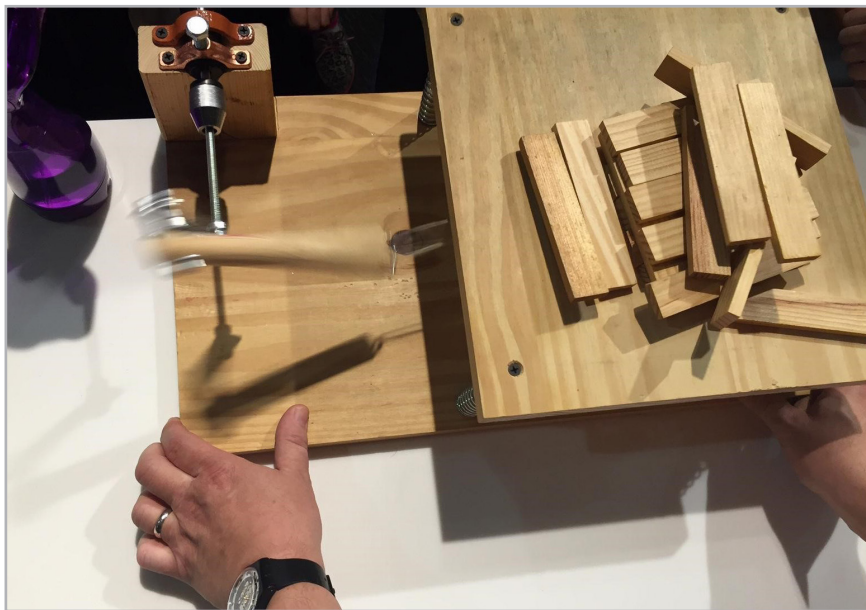
Encourage participants to first turn the hand crank to see what happens to the table.

Earthquakes can accurately be described as the shaking of the ground due to seismic forces (and therefore can be caused by all nature of things, including human activity and volcanic activity).

Earthquakes are usually caused by geological faults and the movements of tectonic plates against one another.

Movements could be accelerated by the types of soil underneath a building. Soft soils tend to amplify the shaking. This model represents a sturdy soil (like bedrock), or in the case of the Salesforce Tower, the poured concrete foundation (14' thick, and 1 acre in breadth).

Earthquakes generate forces within the building itself: back-and-forth motion in the body of the building, and a force called “hinge,” in which the top of the building goes too far off center, and the bottom of the building starts to lift up.



Challenge:

- Let participants know that engineers and architects use shake tables themselves to test the strength and earthquake-resistance of their models before building.
- Explain that the activity is an investigation of forces that act on buildings (referencing *Dream Big* or not). Buildings have to be able to stand up to earthquakes, both strong and weak.
- Encourage participants to build a structure and then test it by making the table shake. (Tasks could be divided between two participants: one as the builder and one as the “quake-maker.” Roles could then be reversed if needed.)
- Discussion:
 - ☐ What happened when the table started to shake?
 - ☐ Which parts of the building are stable? Which are unstable?
 - ☐ Are there opportunities to make the structure more stable? Where? How?
- Give participants an opportunity to improve the design of their structure based on how it performed in the previous test. Note the changes that are made, and if the structure becomes more stable.
- Introduce a “frame” for the base of the building (this could very simply be clipped onto the shake table surface with binder clips, depending on its thickness). This frame mimics the Salesforce Tower’s foundation, which adds stability to the building. Though bedrock is 245' below this foundation, the 14' thick, acre-in-breadth foundation keeps the building from moving.



Extension Activities:

The Salesforce Tower has stability at its core, rather than at the edges (note the glass windows). Is it possible for participants to model this idea? Encourage participants to build a “core” with the blocks, and see if that performs better or worse than more open design.

Vary the springs or the rubber band to show possible differences in the shake table “design” and how that can affect its flexibility for movement. For example, use a very taut rubber band vs. a very loose one, or very tight springs vs. very open ones. You could equate differences to varying earthquake magnitudes.

Educational Resources:

PBS’s *Building Big* lessons “Skyscrapers” and “Loads”:

pbs.org/wgbh/buildingbig/skyscraper/index.html

pbs.org/wgbh/buildingbig/lab/loads.html

Historical lessons and document-based inquiries from the Skyscraper Museum:

skyscraper.org/EDUCATION/lesson_plans.htm

Exploratorium’s Faultline website:

exploratorium.edu/faultline/damage/building.html

Earthquake-proof engineering activity from *Scientific American*’s Science Buddies:

scientificamerican.com/article/bring-science-home-earthquake-proof-engineering/

Content Resources:

USGS on the 1906 San Francisco Earthquake: earthquake.usgs.gov/regional/nca/1906/18april/

FEMA: “Earthquake Effects on Buildings”:

fema.gov/media-library-data/20130726-1556-20490-0102/fema454_chapter4.pdf

Pelli Clarke Pelli on the Salesforce Tower: pcparch.com/project/transbay-tower/detail

About the pouring of the Salesforce Tower’s foundation:

wired.com/2015/11/it-took-18-hours-to-pour-san-franciscos-biggest-ever-concrete-foundation/

Salesforce Tower website and Construction Camera: salesforcetower.com/cam

ACKNOWLEDGMENTS

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