

## Shake Building

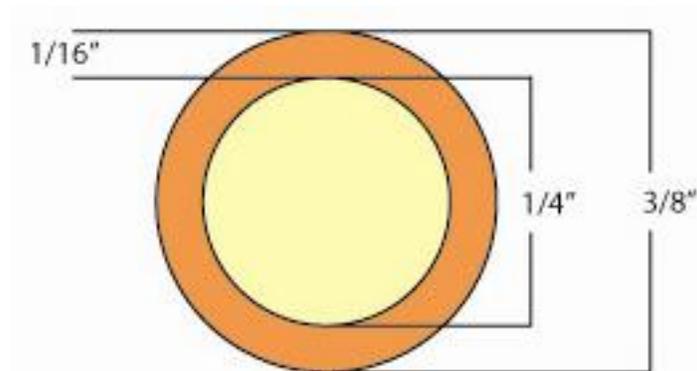
This model was built by Maxwell Willis in conjunction with his advisor Ross Stein, with additional help coming from Volkan Sevilgen.

### 1) Description

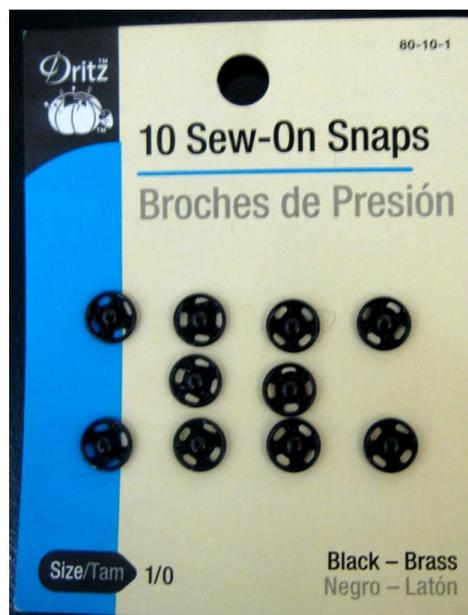
A rudimentary building made from wood dowels and surgical rubber. It is used to show the effects that ground shaking caused by earthquakes will have on man-made structures with different construction techniques and seismic regulations.

### 2) Materials

- Four  $\frac{1}{4}$ " square cross section dowel rods (36" long), purchased from local hardware stores (ACE, Orchard Supply Hardware, etc.)
- $\frac{1}{4}$ " inner diameter,  $\frac{3}{8}$ " outer diameter,  $\frac{1}{16}$ " wall thickness surgical latex tubing (3 feet). Found on internet or at more specialized local pharmacies (ask about catheter supplies) ([http://www.reefscuba.com/surgical\\_tubing.htm](http://www.reefscuba.com/surgical_tubing.htm))



- Sew-on snap buttons size 1/0, found at Joann's Fabrics (8 packs for a total of 80 snaps)



## Teachers and Student's Resources

- Gorilla Super Glue (found at Office Depot)
- X-acto knife
- Drill with 7/64" bit
- Saw (preferably belt saw or coping saw)
- Sandpaper (optional)
- Ruler
- 45° angle
- Pencil

Estimated cost for building materials (surgical tubing, wood, snaps, glue) ≈ \$35-40



### 3) Instructions

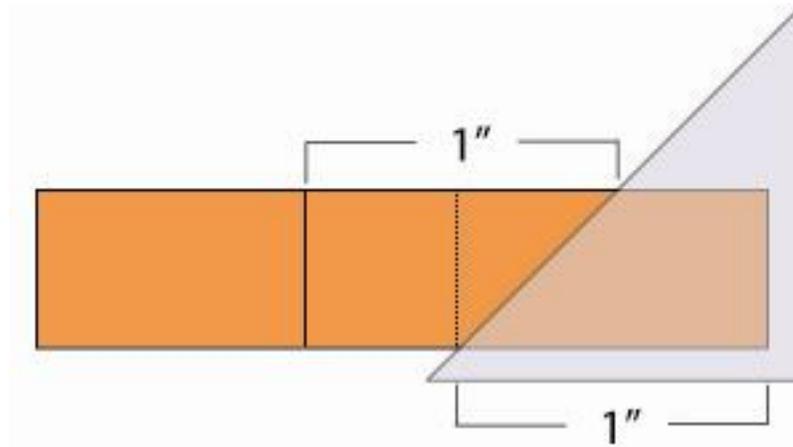
**WARNING:** Construction requires the use of strong superglue and sharp tools. Have good ventilation and preferably a small fan so that fumes are not inhaled. Do not use the saw, sharp X-acto blades, and electric drill without adult supervision.

**Step 1:**

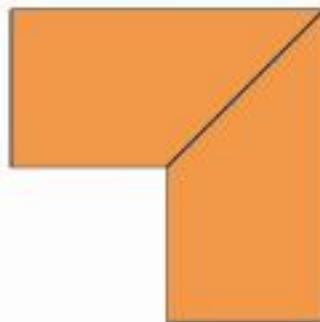
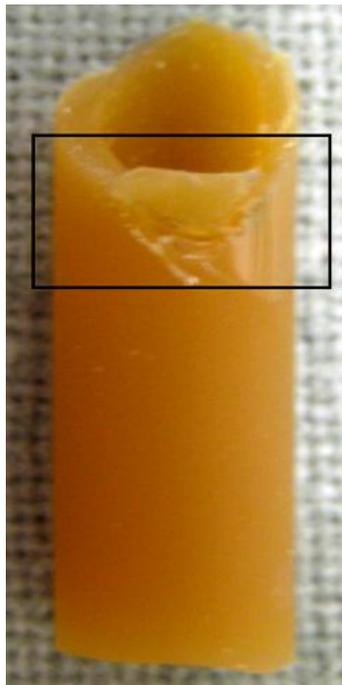
- Purchase Materials

**Step 2:**

- Measure 1 inch of surgical rubber
  - i. Lay down the 45° so that it intersects with the 1 inch line, push down on the 45° and cut the tubing with an X-acto knife along the edge of the 45°



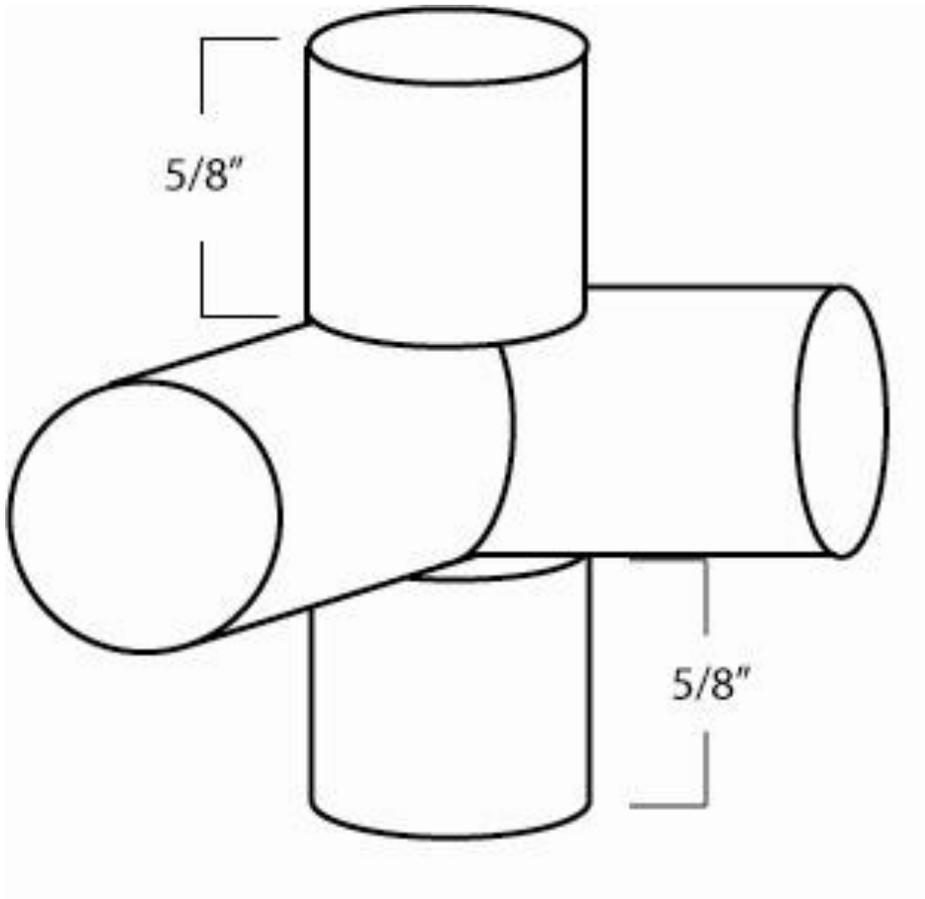
- ii. From the pointy end of the remaining tube, measure 1" and cut a straight line (you now should have two identical pieces)
  - iii. Cut 24 pieces total
- Glue the two angle-cut pieces together so that they form a right angle as shown

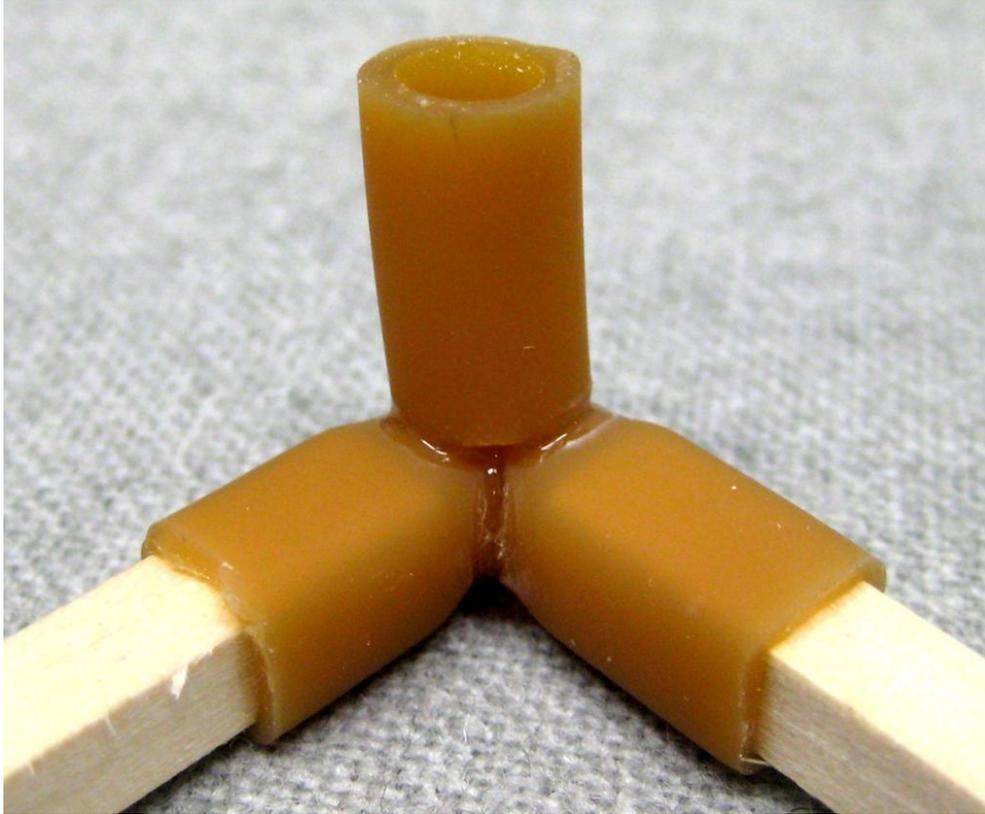


- i. Be sure to place glue around the entire contact and hold together for at least 3-5 minutes so that the hold is strong. A trick involves gluing a small piece of excess surgical tubing (size of a pen head) into the nook at the bottom of one half of the joint (outlined region of picture on left, which is a front on view of a fresh cut 45°). This makes the area of glue contact larger hence strengthening the corner

**Step 3:**

- Cut 16 pieces of surgical tubing of length  $\frac{5}{8}$ "
  - i. Glue piece on top of corners created in step 2 so that the corner now looks like an 3-way junction shown below
  - ii. Do this for all 12 corners made. In addition, for 4 of these corners, also glue a  $\frac{5}{8}$ " piece to the underside as well (these will be the junctions between floors). Hold these connections while glue dries for 3-5 minutes and allow at least 1-2 hours for drying time as these need to be strong



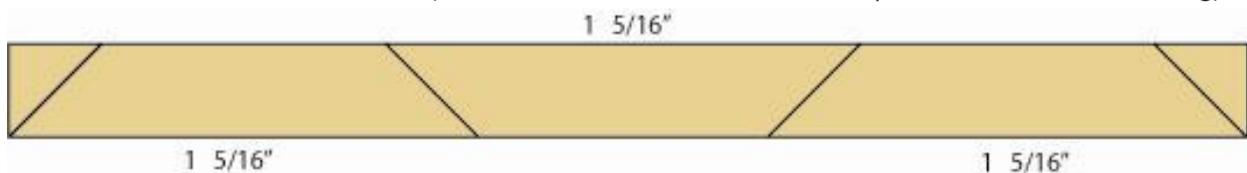


**Step 4:**

- Cut twenty 4" sections of  $\frac{1}{4}$ " square dowel rod
  - i. Optional: Sand ends of 8 beams into the look of a half-sharpened pencil (helps with inserting vertical columns for easier assembly and disassembly)

**Step 5:**

- Mark off  $1 \frac{5}{16}$ " on unused dowel rod
  - i. Draw  $45^\circ$  from end points to form a trapezoid with long side being  $1 \frac{5}{16}$ " long
  - ii. From end of short side, measure another  $1 \frac{5}{16}$ " down, drawing another  $45^\circ$  line. Cut 40 sections (the wood dowel should look like the picture below before cutting)



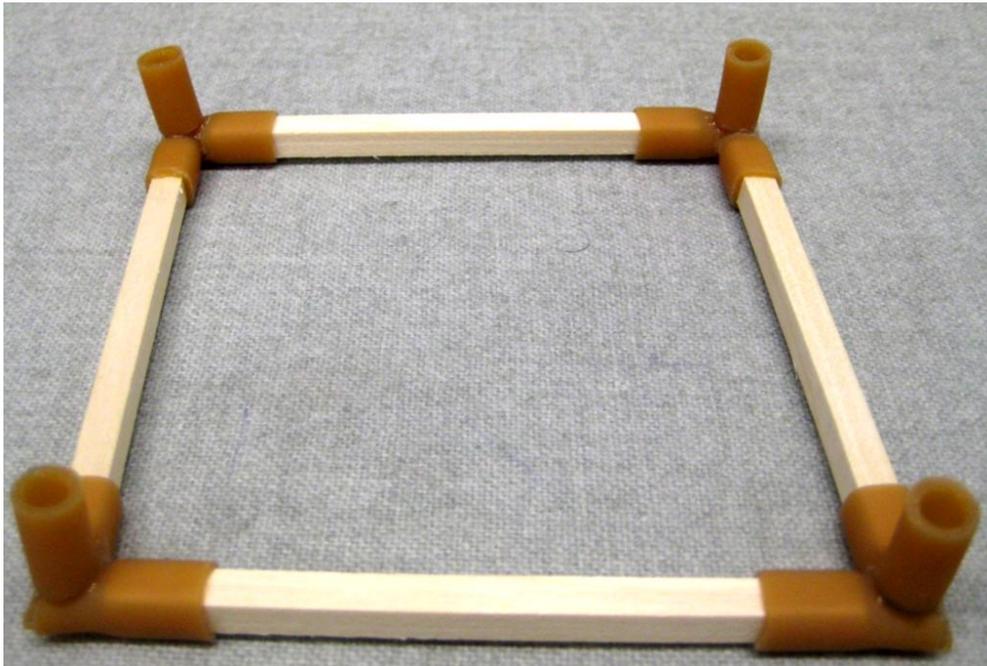
**Steps 6 & 7:**

- On each slanted face of trapezoid pieces, drill a small hole with  $7/64$ " drill bit, deep enough so that the "pimple-out" side of the snap can fit into it. Glue button heads into these holes, one on each face, for a total of 80 snaps, 2 on each trapezoid
  - i. Make sure to take the snaps apart before gluing them to the brace as the two pieces may become stuck together by glue otherwise



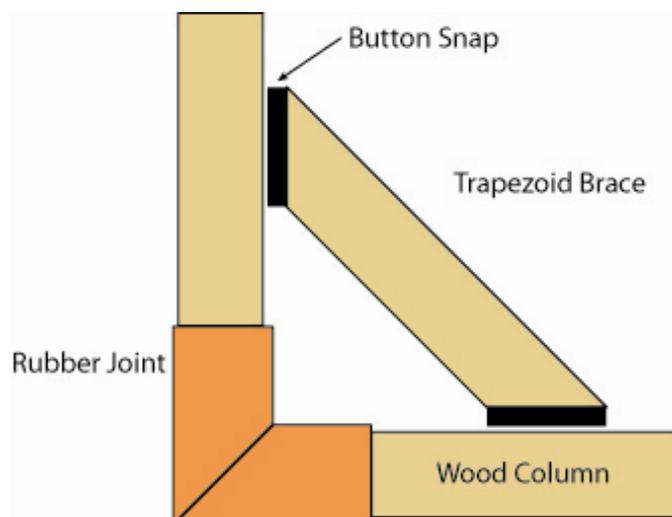
**Step 8:**

- Once everything has dried and looks ready for assembly, put straight ended columns from step 4 into the corners made in step 3, forming 3 squares. Then place sanded columns into the uprights assembled in step 3 from the 5/8" length tubing. Columns should be inserted as deep as possible into connections



**Step 9:**

- Using a trapezoid from step 7, put complete snap set on one (including base). Use this to mark off with a pencil where the centers of the base of the snap attachment will be glued to the column. Do this for all column-beam intersections.

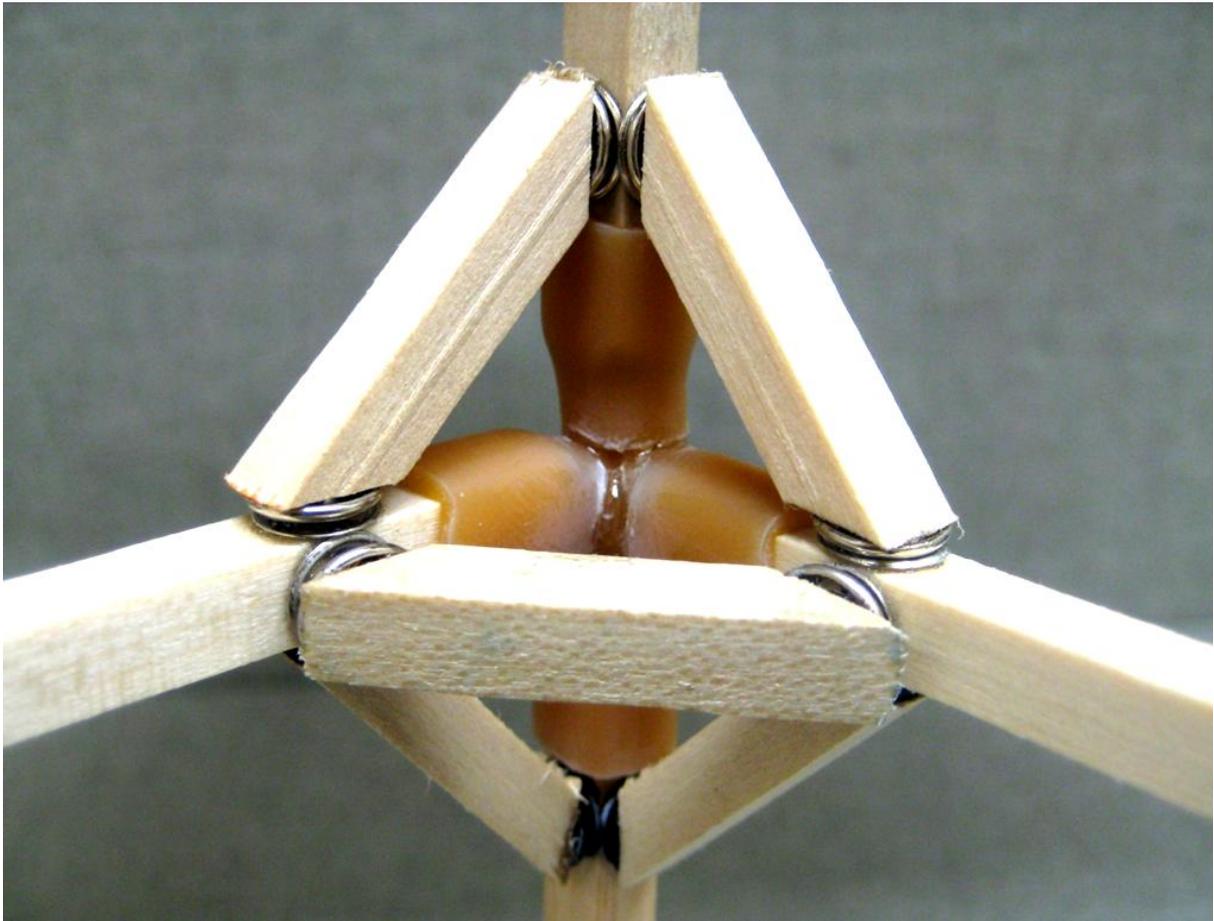


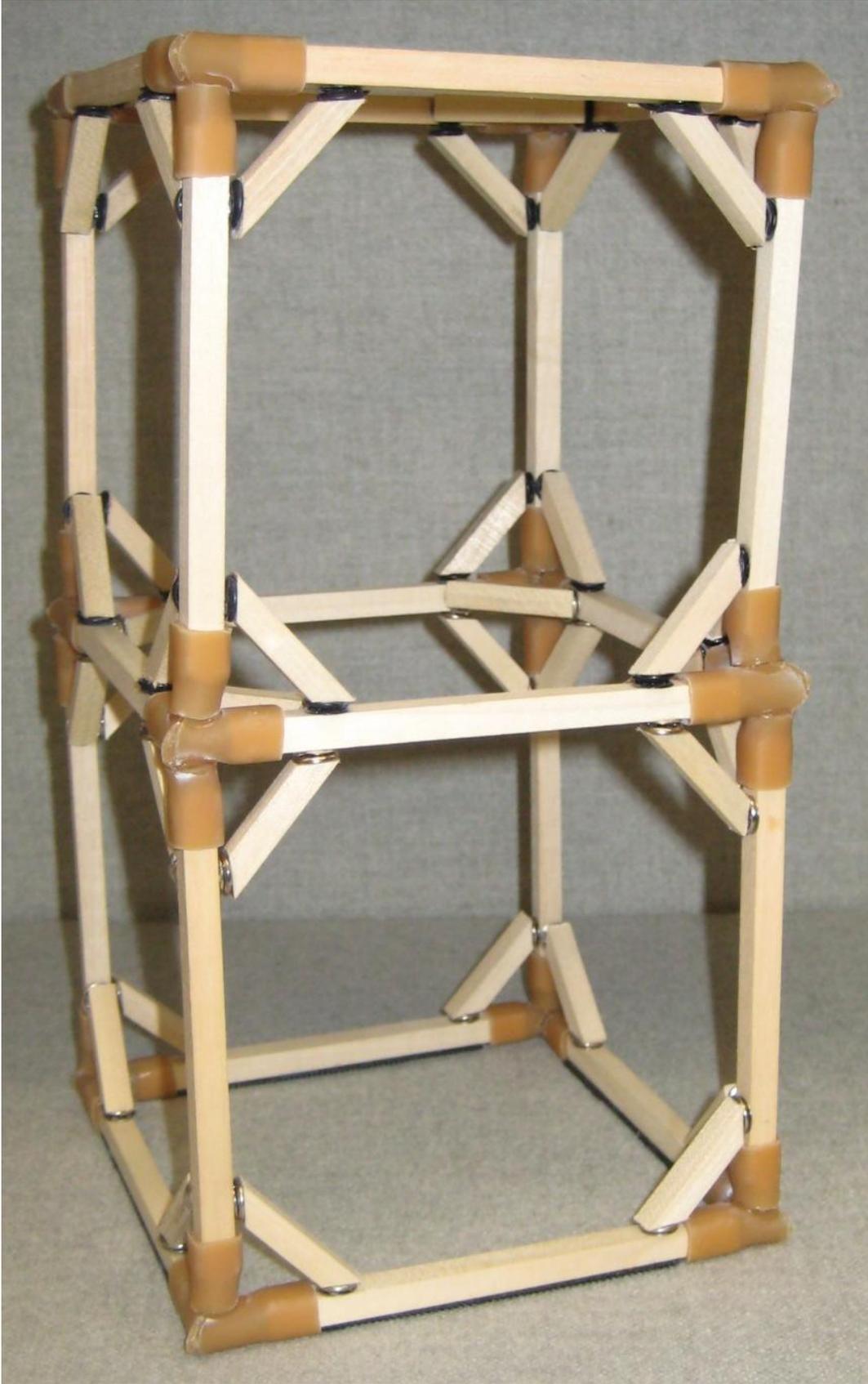
**Step 10:**

- Glue all snap bases to where they should be as marked on the columns. Allow drying time

**Step 11:**

- Insert braces, final corner should resemble the one shown below (this is the joint between floors hence its 4-way connection)





#### 4) Usage

The model demonstrates the susceptibility of different building construction styles to the ground motion produced during an earthquake. By adding or subtracting supports and mass in different key locations and applying different shaking styles, one can see the reaction that a building has to different earthquake scenarios based on construction style. The building also represents basic structural engineering by distributing load through the use of triangular elements.

Place the model on a flat mobile surface (top from a plastic storage bin usually suffices), and firmly attach the base using tape or, for more elegant designs, industrial strength Velcro. This base acts as a rudimentary earth to which you can apply different styles of ground motion to. Try shaking it fast and then slow (frequency), try smaller versus larger shakes (amplitude) and see how the building responds to each of these in its different modes (soft, soft first story, rigid).

#### 5) Interpretation

The building can be used to examine several aspects of seismic and structural engineering used in modern structures. By comparing how much the building sways under different conditions we can see how well the building would hold up to an earthquake:

- Soft Corners: Remove all of the trapezoid braces from the building. Shake the building at different frequencies and different amplitudes to see how the building reacts. Does the building do better against large motions or small motions? High frequency or low frequency shaking? What happens when weight is added to only one of the top corners of the building? How does this affect the way that the building sways?
- Rigid Corners: Put all of the braces in. Now shake the building in the same manner as before and compare. Does the building sway? What does addition of weight to a top corner do? Weigh the building with all of the braces. Remove them and weigh the building without the braces. Compare these two numbers as an analogue for how much more material must be used to make the building rigid, and therefore roughly how much more it should cost to build the building in this manner.
- Soft First Story: Remove the braces from the first floor (leave the horizontal braces on the middle floor). Shake again. How does this compare to the soft construction? How does a weight in the top corner affect the buildings motion? Does the strength of the upper floors affect the overall strength of the building? This is how many buildings are designed in poorer countries where the bottom floor is used for retail shops as well as today in tuck-under parking apartment buildings and narrow first story buildings across the developed world. These lower levels contain little if any structural reinforcement.

## Teachers and Student's Resources

While actual buildings do not necessarily have visible bracing elements as in the model, the methods of construction yield the same results through use of triangular weight redistribution and shear bracing. The rubber joints represent simple concrete connections with no reinforcing through steel rebar. The addition of the braces is symbolic of reinforced concrete or bolted I-beam joints which have the same qualities as triangular elements. The building shown below also shows the use of diagonal shear braces, which are much larger versions of the bracing elements used in the model. The I-beams used for the second floor are also resistant to vertical shearing due to the large area of their bolt connections which act like triangular elements.

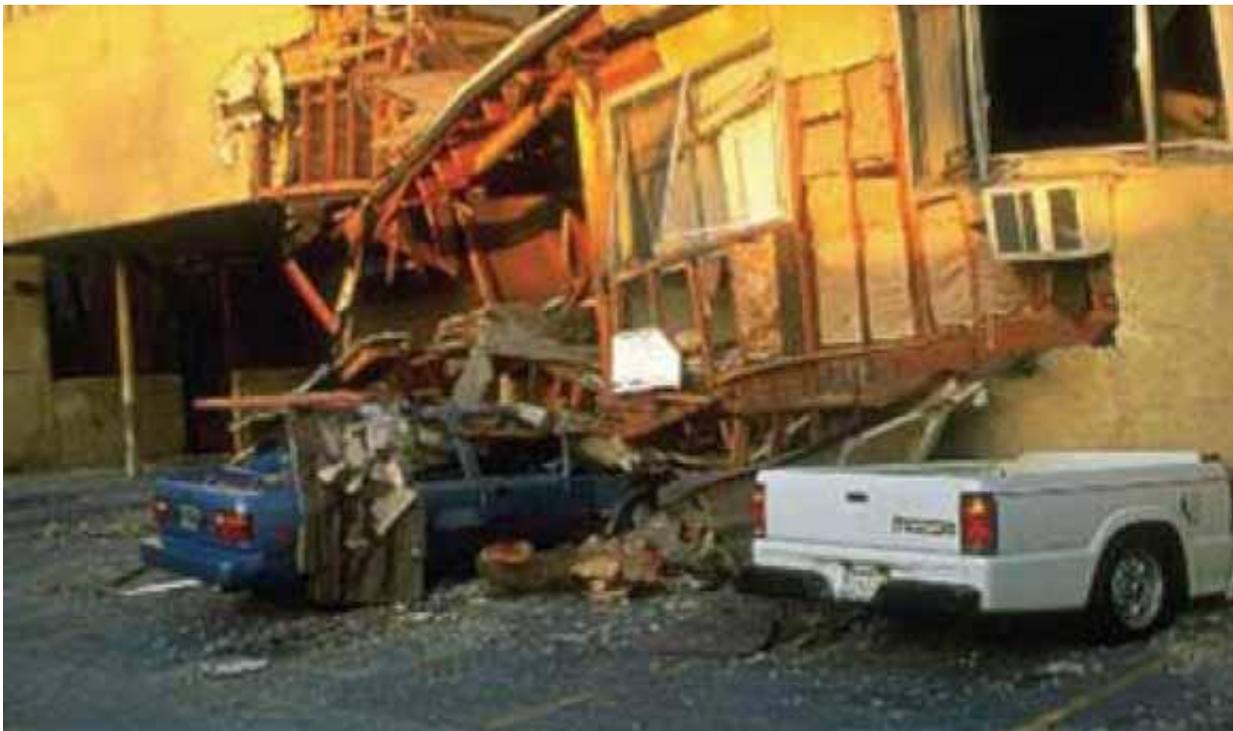


The triangular members in the model act the same as the larger shear bracing seen here on this school under construction, Menlo Park CA. Notice that not every wall has the shear supports, hence the thicker shear braces



*The 1971 San Fernando, California, earthquake (magnitude 6.7) severely damaged the recently built Olive View Hospital. This building was not instrumented with seismic sensors. Accordingly, no data were obtained to understand how the damage initiated and progressed during the intense shaking. The building was razed and replaced with a stronger structure that survived the 1994 Northridge earthquake (see back page).*

Example of soft first story construction in public hospital: USGS Fact Sheet 068-03



Tuck under parking and effects caused by Northridge earthquake: USGS General Information Product 15

## Teachers and Student's Resources

For further information contact Ross Stein at [rstein@usgs.gov](mailto:rstein@usgs.gov)

The USGS library maintains a wonderful teacher resource facility with materials any teacher can check out. Tel 1-650 329 5026 or 5028, USGS Library on Survey lane off 345 Middlefield Road, Menlo Park (map <http://online.wr.usgs.gov/kiosk/mparea3.html>)