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Model Quake Towers: Construction and demo guidelines

The goal of the *Model Quake Towers* is to help convey how buildings can be easily constructed or retrofitted to resist earthquake shaking. For typical buildings, which are essentially stacks of cubes, regardless of how well secured to the foundation, and regardless of how strong the columns and beams, *the building is only as strong as its corners*. The towers demonstrate that strengthening the corners to add shear and torque resistance dramatically changes their behavior.

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Executive Summary

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 built with different construction techniques and seismic regulations. Building codes across the world vary from extremely strict to non-existent; developed nations tend to have higher standards standard for building construction, especially in areas where seismic hazards exist, while in developing countries, the poor quality of buildings leads to countless unnecessary and avoidable deaths due to earthquakes.

1) Materials

Supplies		
Item	**Store**	**Quantity**
¼” inner diameter, ⅜” outer diameter, 1/16” wall thickness surgical latex tubing	Hardware/Internet	4 feet
Round 5/16” dowel rod	Hardware	20 inches
Square ¼” dowel rod	Hardware	160 inches
Square 3/8” dowel rod	Hardware	6 inches
Sew-on Snaps size 1/0	Fabric	80
Gorilla Super Glue (blue top)	Hardware	15 gram tube
Weldbond Adhesive	Hardware	8 ounces
Sandpaper (220 grit)	Hardware	1 sheet
Dual-lock Velcro	Hardware	1 foot

Estimated total cost for building materials approximately $40.

Figure 1: Buttons required for brace snaps.

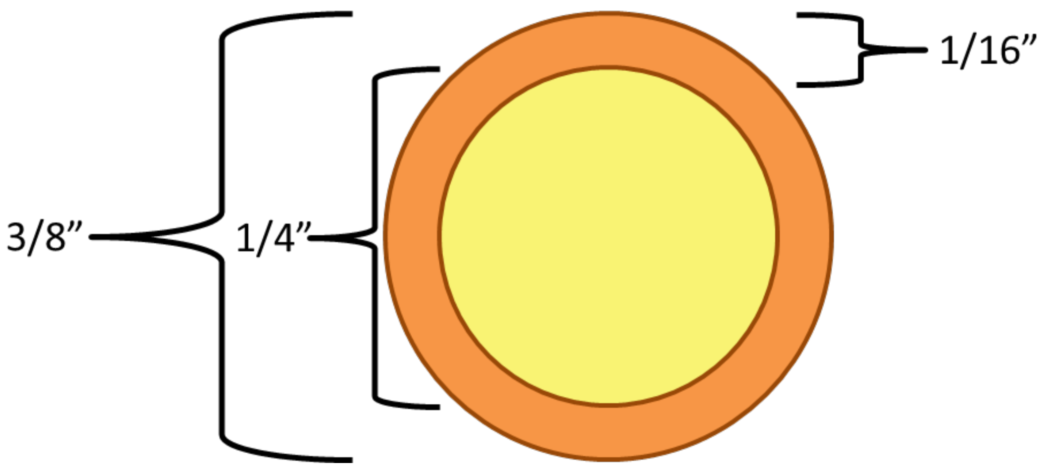


Figure 2: Rubber tubing dimensions.

Tools	
Item	**Store**
X-Acto knife	Hardware
Electric drill with 1/8” bit	Hardware
Saw (preferably belt saw or coping saw)	Hardware
Sandpaper (220 grit)	Hardware
45º Angle	Office Supply
Pencil	Office Supply
Fish scale (optional)	Outdoor

2) 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.

1. Cut twenty 4 inch sections of ¼" square dowel rod.
2. Cut 40 3/8" sections of 5/16" round dowel rod.
    a. Be sure to compensate for width of saw by measuring the pieces to be slightly longer than 3/8" (13/32" may do).
    b. Sand away any loose material due to saw cut.
3. Cut 12 3/8" sections of 3/8" square dowel rod.
    a. Be sure to compensate for width of saw by measuring the pieces to be slightly longer than 3/8" (13/32" may do).
    b. Sand away any loose material due to saw cut.
4. Using Weldbond glue, glue the cut pieces of 5/16" round dowel to a face of the cut 3/8" square dowel rod. Make eight of type A and four of type B.
    a. To do this easiest glue one piece to all 12, then add a second, and then add a third. At this point all of type A are done, so just add one more piece to the four remaining to make type B. Be sure to allow some drying time and hold each piece in place for at least 30 seconds to ensure a good bond.

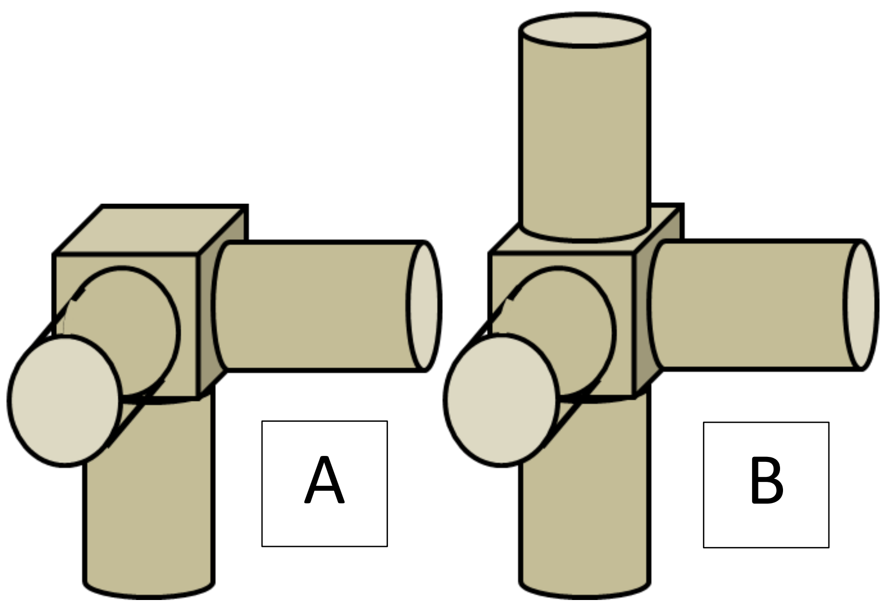


Figure 3: 3-corner and 4-corner assemblies.

5. Cut 40 2 1/16" sections of ¼" square dowel rod.
    a. Measure 2 1/16" along a dowel rod.
    b. Draw 45° from end points to form a trapezoid with long side being X" long

c. From end of short side, measure another 1 9/16" down, drawing another 45° line. The wood dowel should look like the picture below before cutting.

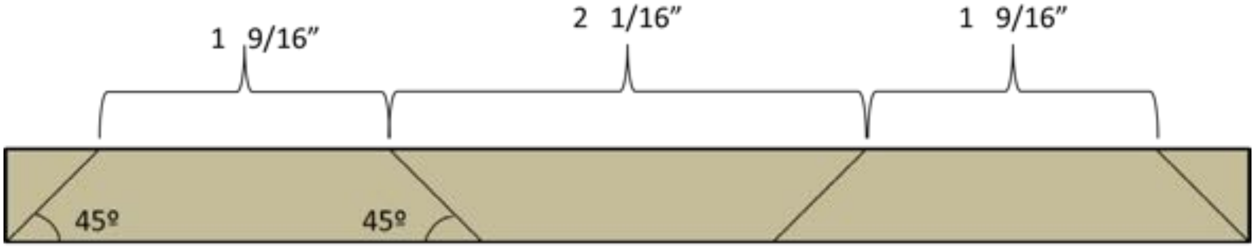


Figure 4: How to measure for the trapezoid shear braces.

d. Sand away any loose material due to saw cut.

6. On each slanted face of trapezoid pieces, drill a small hole with a 1/8" drill bit, deep enough so that the "pimple-out" side of the snap can fit into it. Glue the button heads (pimple-out) side into these holes, one on each side, with Gorilla glue.
   a. Measure 5/32" from the short end and mark with a pencil and drill the hole there.

Figure 5: How to measure where to drill the guide hole.

Figure 6: Drilling the guide hole in one of the shear braces.

b. Make sure to take the snaps apart before gluing them to the brace as the two pieces may become stuck together by glue otherwise (use Gorilla glue).

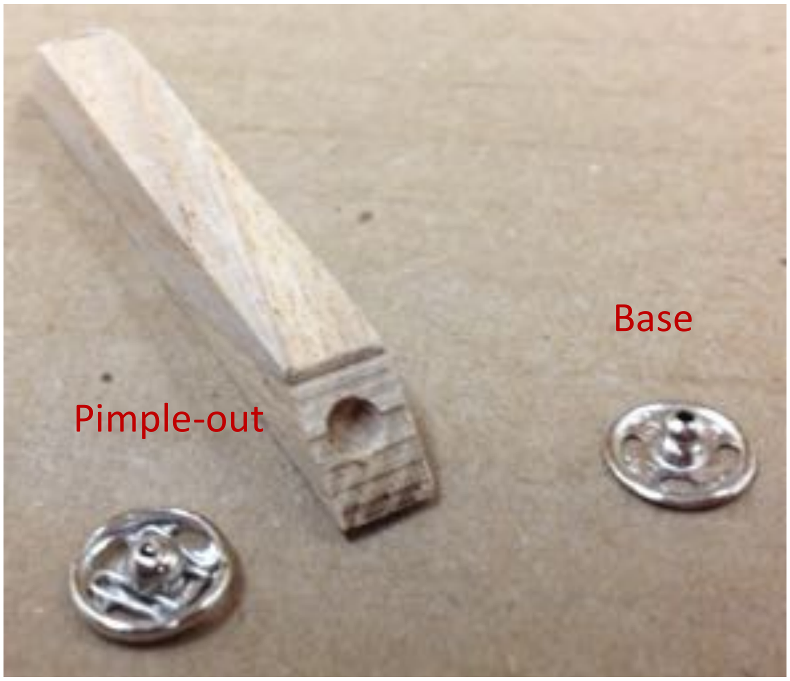


Figure 7: Shear brace with guide hole drilled and button parts.

c. The finished trapezoid brace should look as below

Figure 8: Trapezoid brace with snap glued in place.

7. Cut 40 pieces of surgical tubing 17/16" in length. Use the X-acto knife for this.
    a. Slide the pieces of rubber over the round dowels of the corner pieces so that the fit is snug.
        i. Make sure that you have given the corner pieces sufficient time to dry.

Figure 9: Example of a 4-corner type B corner (from Figure 3) with and without rubber sleeves attached.

8. Assemble the building by placing the 4" square dowel rods into the corner pieces. Try to make the gap between the corner nub and the dowel beam equal for all connections.

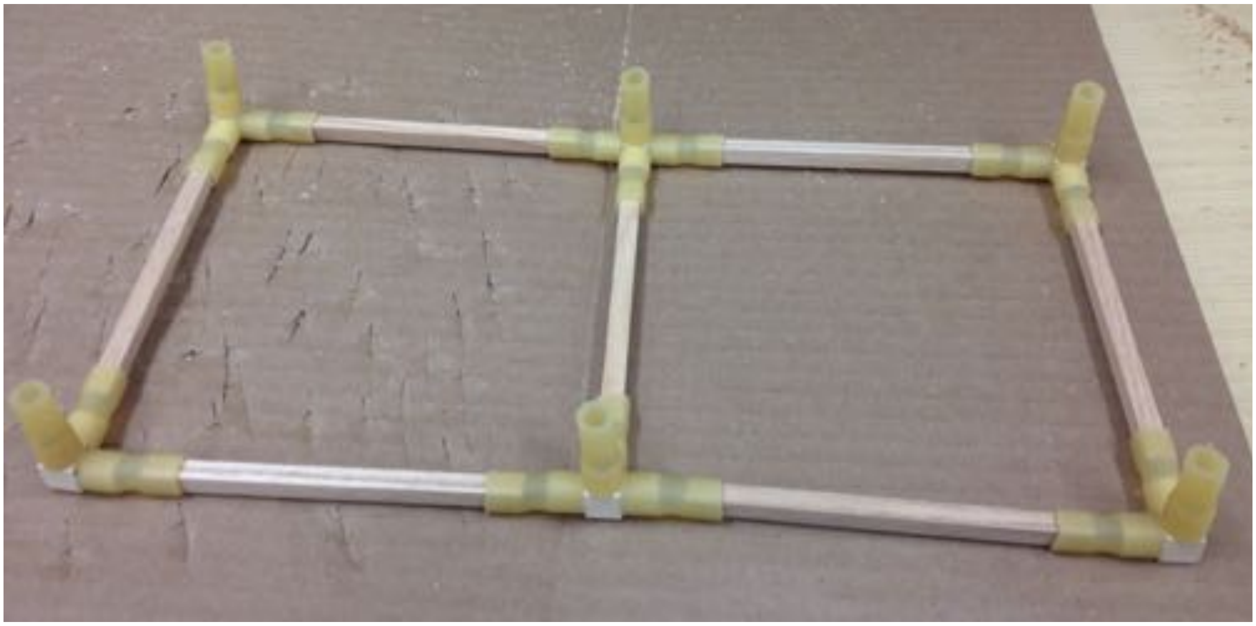


Figure 10: Half assembled building.

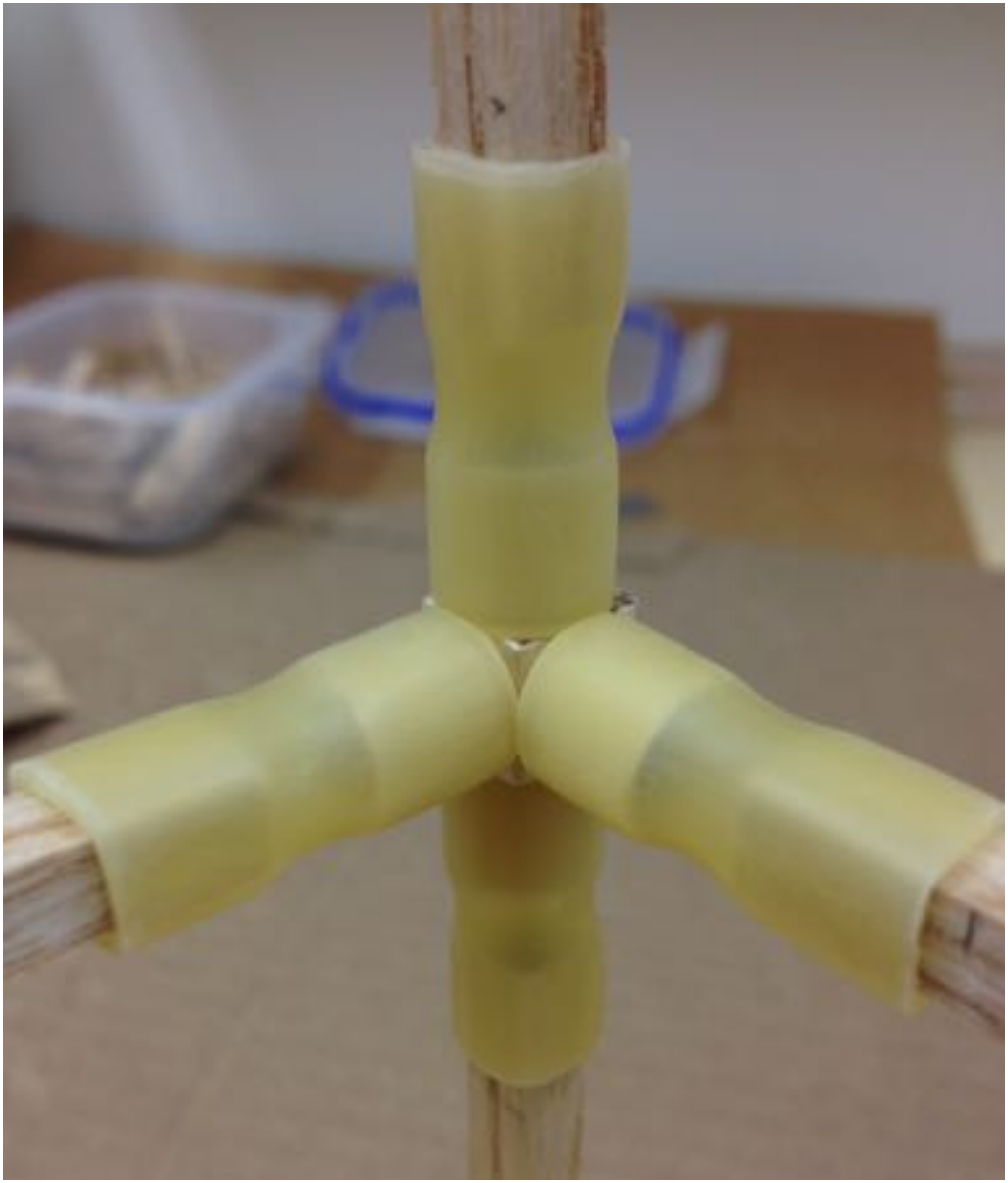


Figure 11: Fully assembled 4-corner piece (type B from Figure 3).

Figure 12: Fully assembled building without snaps.

9. Once the building has been fully assembled, take one of the brace pieces and snap in the base of the snap (make sure the glue has dried sufficiently or the base may get stuck).

Figure 13: Place the snap base in (foreground) in order to use the diagonal brace for measurement of where to glue the bases.

   a. Use this piece to measure the appropriate distance at each corner for gluing the snap bases to the beams.

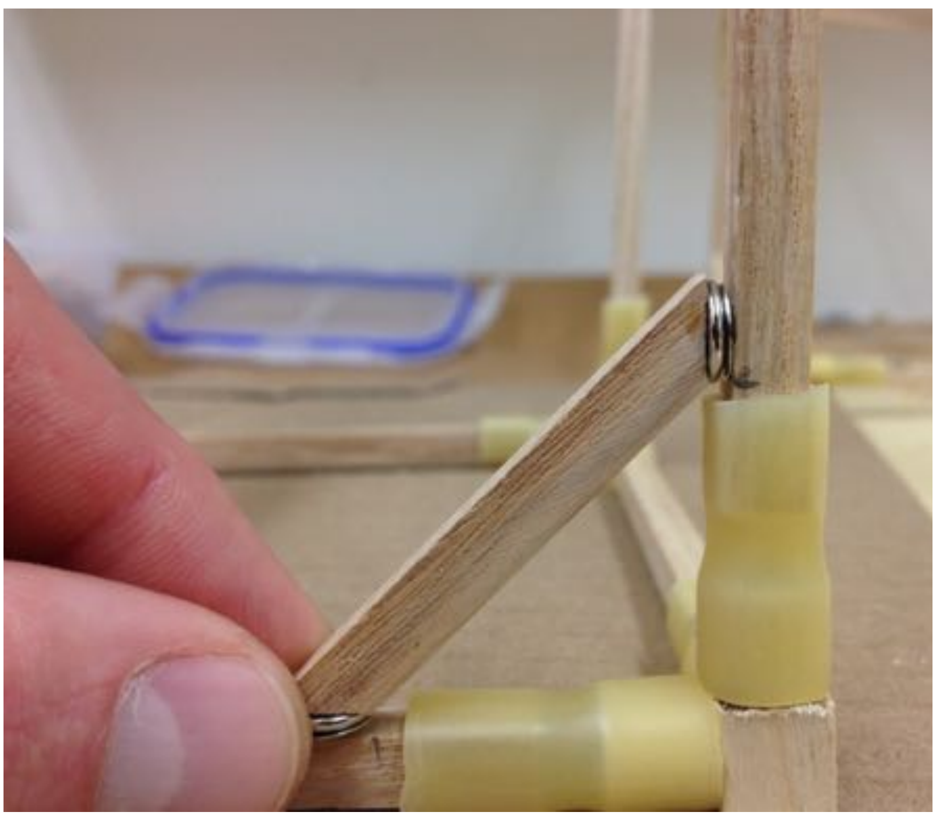


Figure 14: Measuring of glue spots for snap bases (notice the pencil marks).

10. Once all of the distances have been marked, glue down all of the snap bases using the Gorilla glue. Make sure that sufficient time is allowed for the bases to dry before snapping the corner braces in (overnight will suffice).

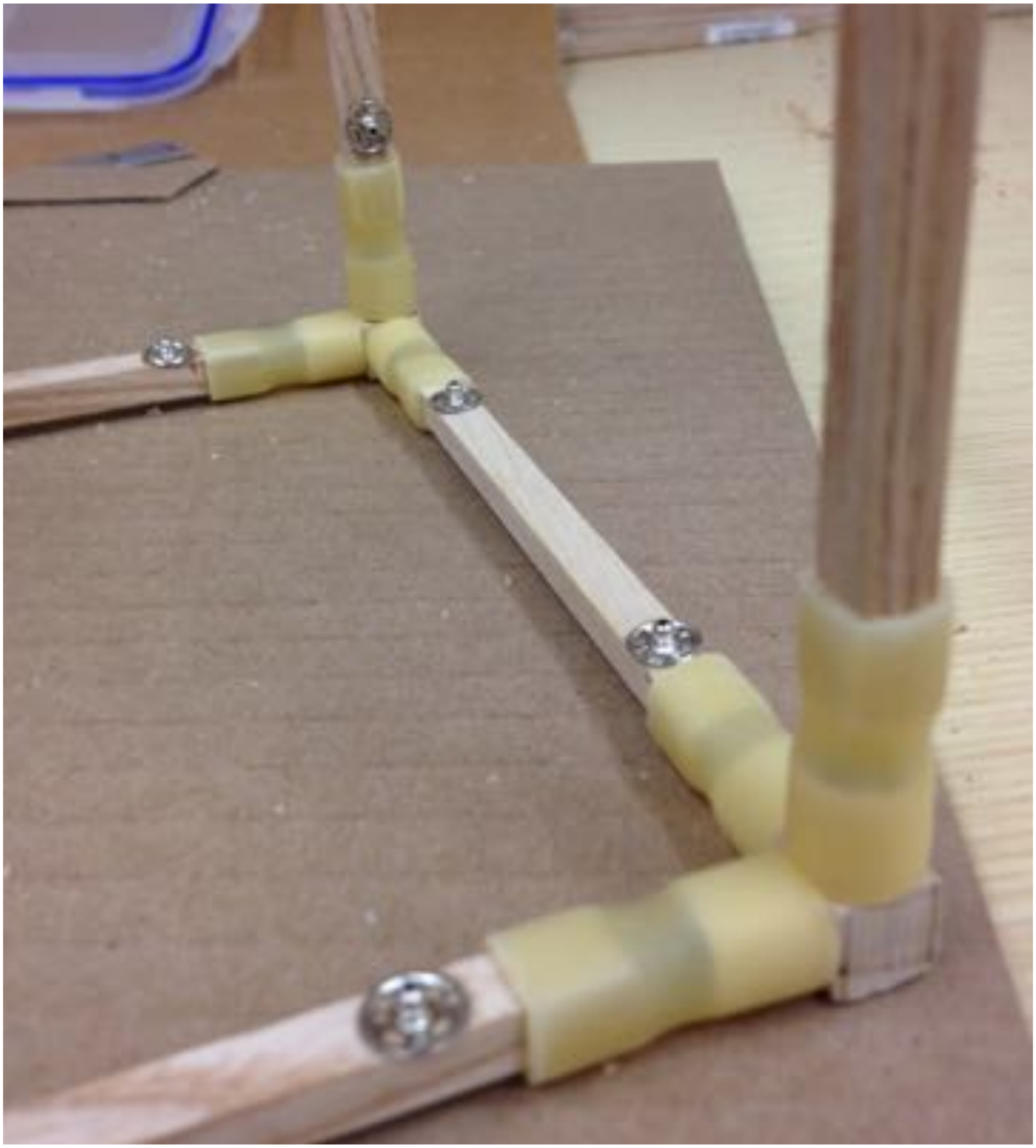


Figure 15: Building with some snap bases glued into place.

11. Cut pieces of Dual-Lock velcro which can be adhered to the bottom of the four corners. Cut larger pieces which can be adhered to the base. The base can be any flat surface that can be carried easily (plastic cutting boards work well).

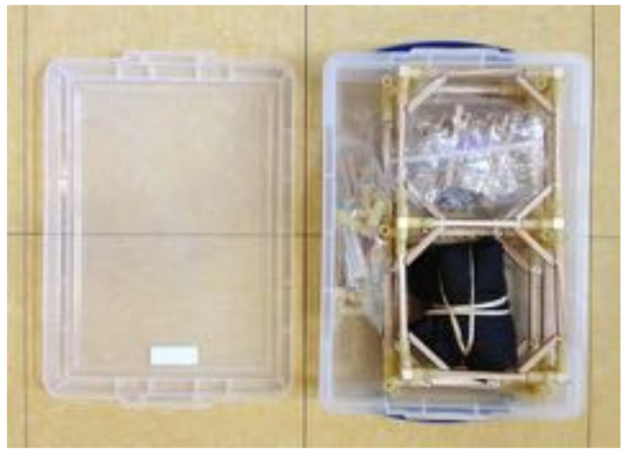
a. Be sure that the base pieces lineup with the bottom corners of the building when they are placed on the base

Figure 16: Completed building on its stand.

Storage

For the fully assembled towers and bases, we use a large plastic carrying case (Really Useful Box, 25 L). For more compact storage that fits in a computer rucksack as part of carry-on baggage, we partially disassemble them, and put the towers and bases into a 'Really Useful Box 4 L' case. Both cases are strong and light. We include a repair kit, with extra snaps, corner braces, dual-lock Velcro, and Gorilla Glue, in both cases. We use a soft cloth bag (black, below right in the small case) to transport them when reassembled, so one does not have to assemble them (10-15 min) on site.

Large 25 L case for fully assembled towers



Small 4 L case for partially disassembled towers

3) 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).

Using these simple techniques, this model has been used in presentations to a multitude of groups in countries across the globe, including; The Global Earthquake Model (GEM), TEDx Bermuda, The Discovery Channel, large corporations and insurance companies, academic institutions, national governments, and more.

Figure 17: Ross Stein demoing the Model Quake Towers to David Burger, Deputy Chief of Mission to the US Embassy in Slovenia.

4) Interpretation

The *Model Quake Towers* 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.

- Tuck Under Parking: Remove the braces from one face at the base of the building. This is similar to how small apartment complexes will have parking on the bottom floor. How does the building react to shaking? Remove braces from two adjacent sides. How does it behave now?
- Shearing Strength: Remove the supports from the building as shown in the picture below. If the building is pushed to the right, the supports are only resisting in compression. If pushed to the left, they are resisting in tension. Using a fish scale, apply the same force to the building in both directions, and measure the deflection for each (distance that the top of the building is displaced when forced). Compare this deflection to that of the building with no supports in place. Which way deflects more? What does this say about the strength of the supports in compression versus in tension?

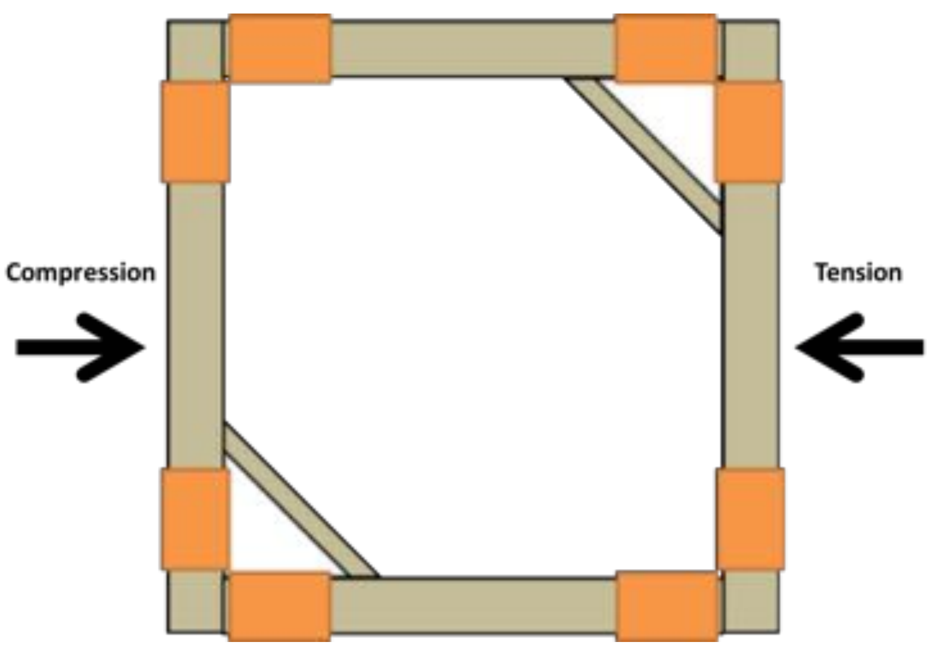


Figure 18: Support layout for determining strength of the supports in compression and tension.

- Torsional Strength: Tie a string or rubber band to opposite corners on the roof of the building with no supports in place. Pull in opposite directions (but not parallel to the beams, 45° from them) so that the building rotates. This happens in earthquakes and can cause buildings to fail. Fix one end and measure the force on the other using the fish scale. Apply the same force as during the support experiment, and examine the angle of rotation and the amount that the corner offsets from its original position. Is this more or less deflection than seen when the building was sheared without supports?

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 flood are also resistant to vertical shearing due to the large area of their bolt connections which act like triangular elements.

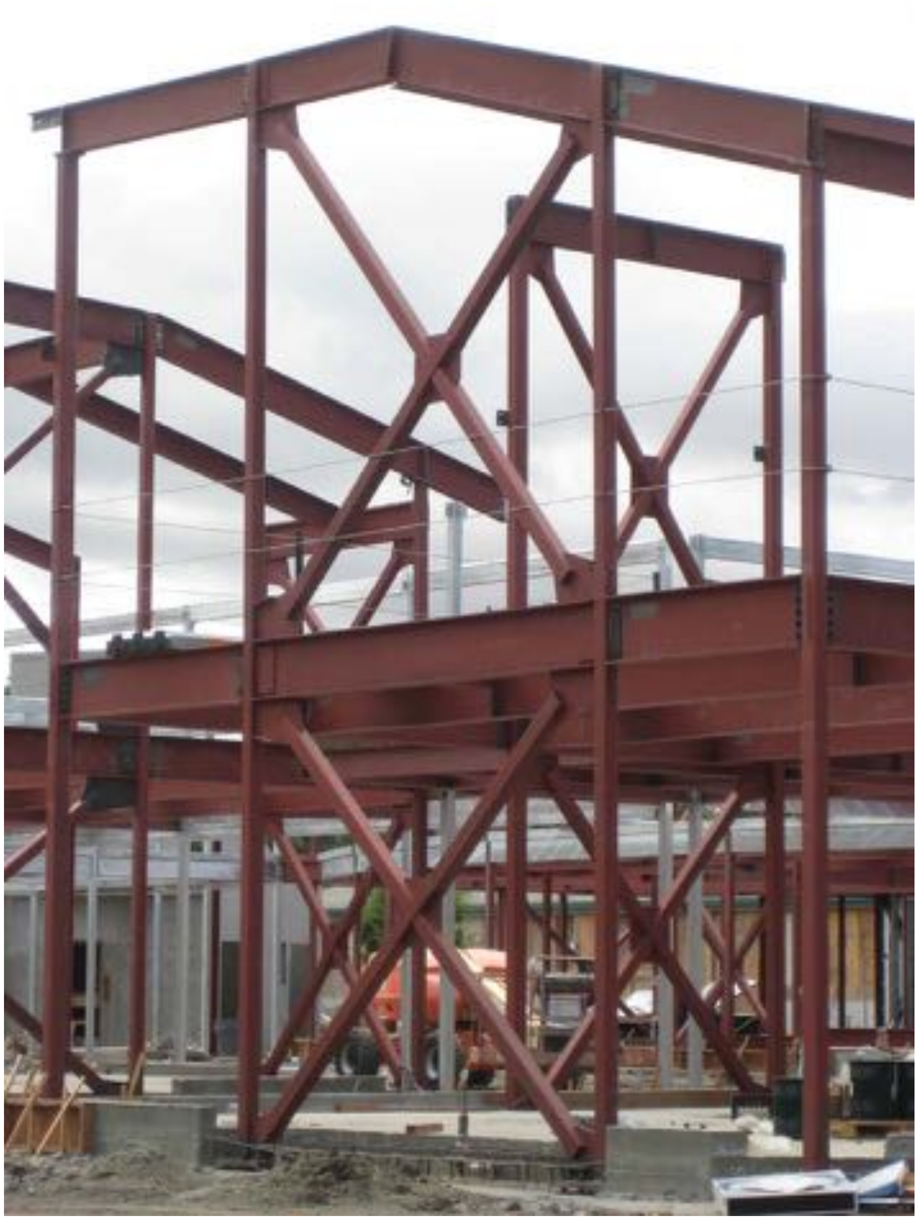


Figure 19: The triangular members in the model act the same as the larger shear bracing seen here on this school under construction, Menlo Park CA. Notice that not every wall has the shear supports, hence the thicker shear braces.

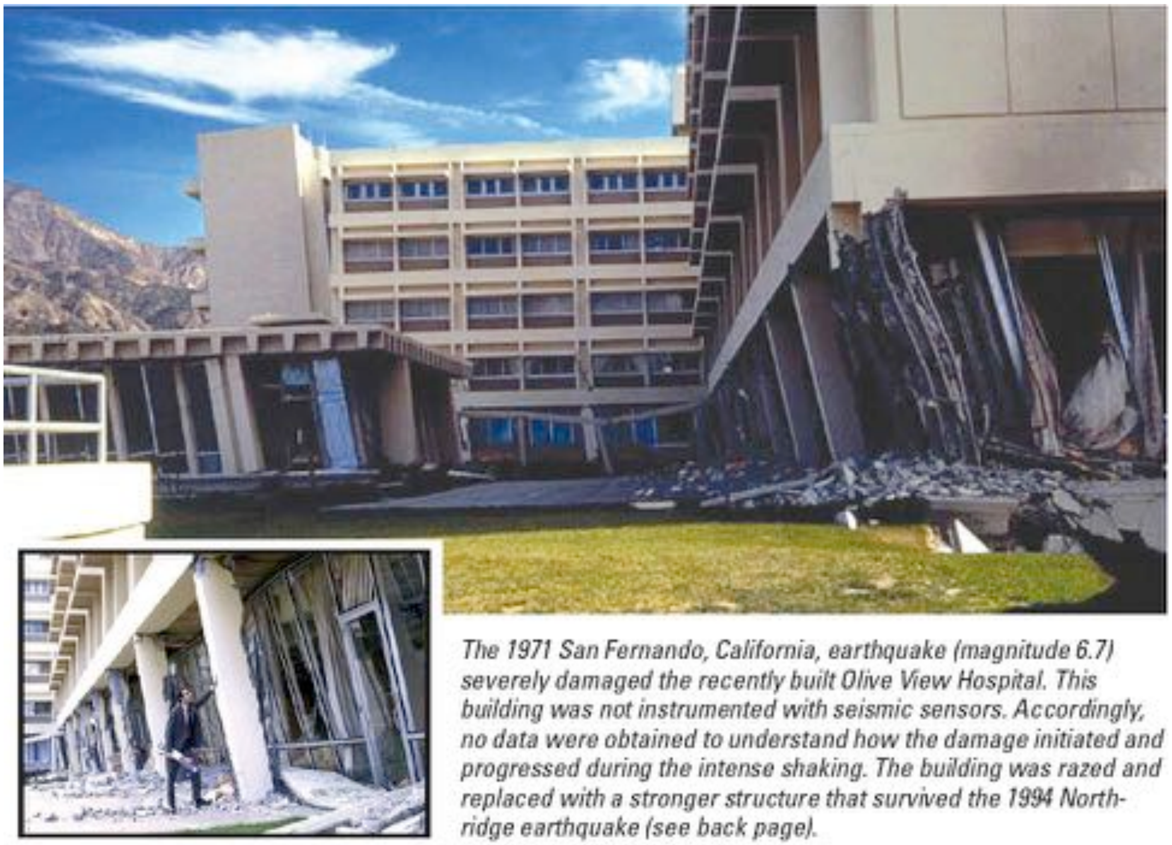


Figure 20: Example of soft first story construction in public hospital (see USGS Fact Sheet 068-03).

Figure 21: Tuck under parking and effects caused by Northridge earthquake (see USGS General Information Product 15).

For further information contact Ross Stein at rstein@usgs.gov or visit his USGS professional page https://profile.usgs.gov/rstein.

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)