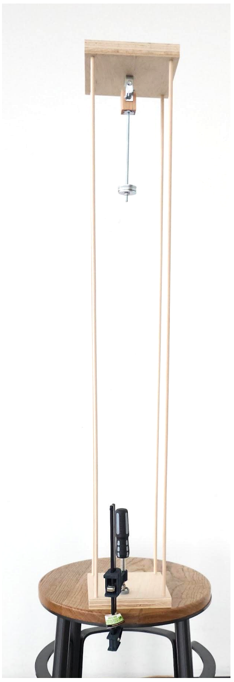


Tuned Mass Damper

Swaying buildings can cause more than an upset stomach.

[Based on a design by Grady Hillhouse from Practical Engineering]

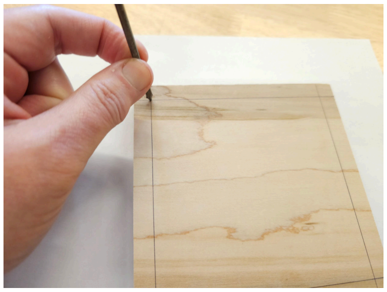
To quickly stop a building set swaying by wind or earthquake, you want an internal oscillator with the same frequency of the building to steal the energy away and then a way to transfer the energy safely to something besides a swaying building.

Materials

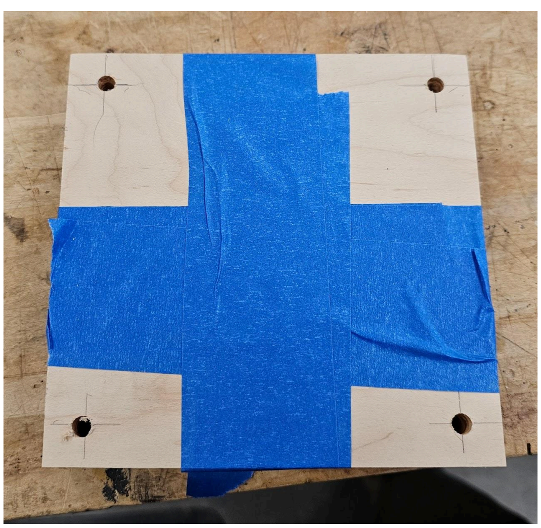
- 2 6-inch by 6-inch square by ¾ inch thick pieces of plywood
- 4 ¼-inch by 36-inch (or longer) wooden dowels
- 1 right angle L (corner) bracket 1 ½ in
- 1 wood screw, usually included with the L bracket
- 1 #8-2 inch panhead machine screw (see note)
- 2 #8 wingnuts (see note)
- 2 #8 washers (see note)
- 1 #10-24 x 6 inch (or longer) threaded rod
- 1 #10-24 T-nut
- 3 #10-24 nuts
- 6 1-¼ inch diameter fender washers (or similar)
- 1 piece of wood 1 in x 1 in x 2 inch square wood dowel
- Wood Clamp (not shown)
- Ruler
- Small nail
- Hammer
- Electric drill and appropriate bits
- Drillblock drill guide or drill press

Note: #8 is kind of an arbitrary size. #6 and #10 would work equally well. Use what's cheaply available. The #8 washers are optional.

Construction

1. Mark a hole ½ inch from each edge in each corner of the piece of plywood. Use a nail and a hammer to make a small dent in the wood. This hole will help guide your drill bit go where you want it to.


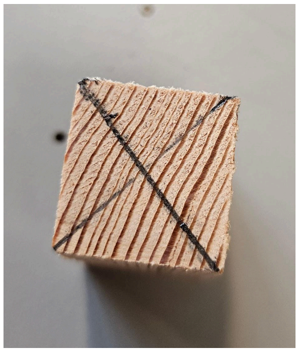
2. In a scrap piece of wood drill a hole the size of the dowels you purchased. Check to see if the dowels actually fit snugly. Many dowels are actually 1/64 or more smaller than their nominal size. So pick a drill bit that fits tightly. Alternatively, if the hole is too big, wrap a small piece of tape around the dowel to make it wider.
3. Attach the appropriate drill bit to your drill and use the drill guide to drill straight down. Alternatively you can use a drill press. It is important that the drill holes be perpendicular to the face of the plywood. Repeat for all four corners.


4. Tape the second block to the first block. Use the first block as a guide to drilling the holes in the second block.


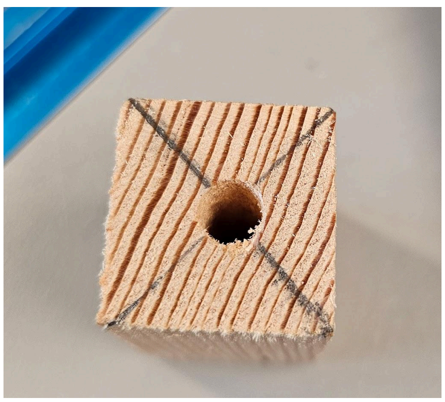
5. On one plywood piece attach the L bracket. You will only need one screw to hold it in place.

6. Push one dowel into each one of the holes. They are much less likely to buckle or break if you hold the dowel very close to the end. Repeat for the other four dowels.
 
7. Place the other block on top. Gently wiggle the dowels into the hole. Gently tap with the hammer if necessary to seat the dowels. This may take a bit to get everything to work. You may need to untwist the blocks when you are done.


8. Place the 1 x 1 square wood block into a wood clamp so that the short side is facing up. Find the center of the face by drawing two lines that connect the corners. Use a nail to make a dent at the center.



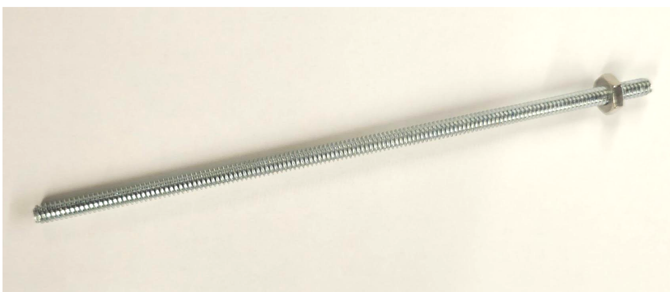

9. Hold the block with the wood clamp. Drill a small ⅛ inch hole about 1 inch deep in the block using the drill guide or drill press. Then expand the hole using a 15/64 inch bit (or ¼ inch) in the end of the block. The two-step process makes it easier to drill straight and through the center.

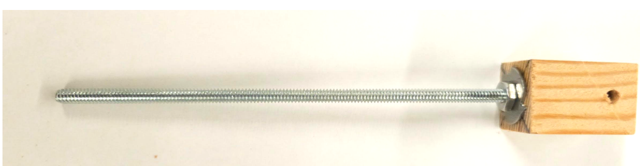


10. Turn the block sideways and drill a 7/32 inch hole on the side of the block so that the #8 screw can fit through.

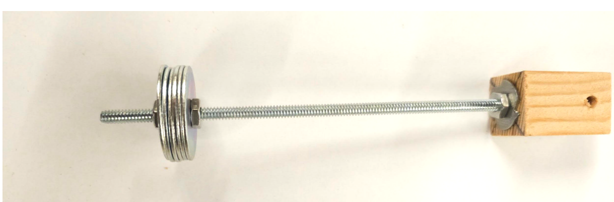
11. Hammer the T-nut into the hole and flat against the face.

12. Twist a nut onto a threaded rod, and then twist it onto the T-nut inserted into the block.





13. Add nuts and fender washers to the other end.



14. Clamp the bottom plywood square to a table.

Note: It is possible to make many parts as 3D prints. For example, here is a file to make the wooden hanger and L bracket. Fusion 360 and STL

To Do and Notice

Make sure that the bottom block is firmly clamped to the table top. Pull the top block straight backward, approximately 1 inch and let go.

Look at the motion of the “building”. How long does the building vibrate back and forth? What do you think that a graph of the motion would look like?

While an earthquake is the obvious first thought for people in California that a building could start swaying, wind is an even more common occurrence. Buildings present large areas to the wind. A gust can flex a building, and then when the wind subsides, the building would move back and start to sway.

You can graph the motion of the building using your smartphone and one of a variety of apps. We like phyphox and Physics Toolbox Suite; both are free and without advertisements or tracking. Download them from the appropriate App Store. In phyphox, select “Acceleration with g”. Use the play button to start recording data and set your phone–with the long axis of your phone pointing in the direction of motion of the building–on top of the building and pull the building back. Let the building swing for 10 to 20 seconds, and then press the pause icon. You can zoom in on the data by double tapping on the y-axis information. You can zoom in and out with your fingers.

Consider how long the building vibrates for. If you were an occupant in the building how would this make you feel? Could this threaten the structure of a real building?

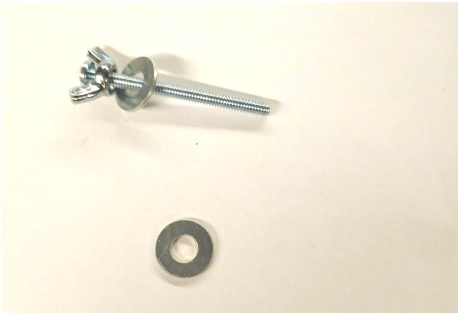
So you might want to stop a building from swaying for such a long period of time, but how to do that?

It’s helpful to think about the sway of building in terms of conservation of energy. When the building is pulled out of its original position, we’ve added elastic energy to the building. When it sways back, the elastic energy becomes kinetic energy which swings the building back past its rest position and converts energy back into elastic energy.

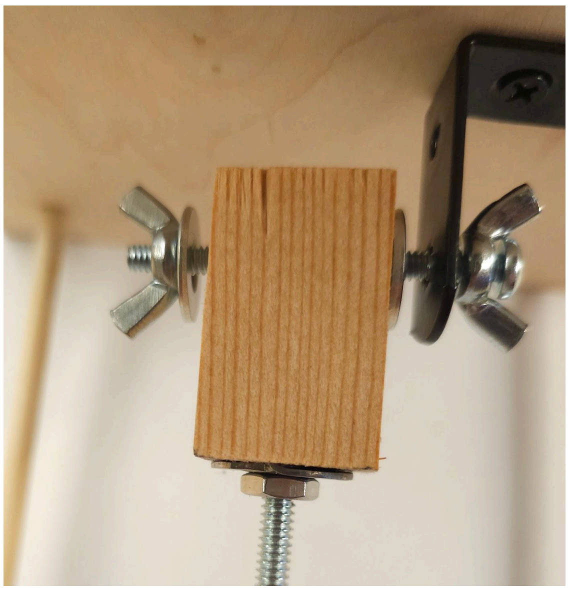
Some energy is lost in each swing to deformation of the structure and wind resistance, but the amount lost is smallish compared to the size of the building, meaning that the building can swing for a long time before slowing enough to be tolerable.

To reduce the total number of cycles, we need to steal some of that stored energy away. A common way is with a mass damper.

To attach the damper pendulum, Screw one wingnuts onto the #8 screw along with a washer.



Insert the screw into the block. Add the other washer and put it into L-bracket. Add the other wingnut. Tighten so that nothing moves.



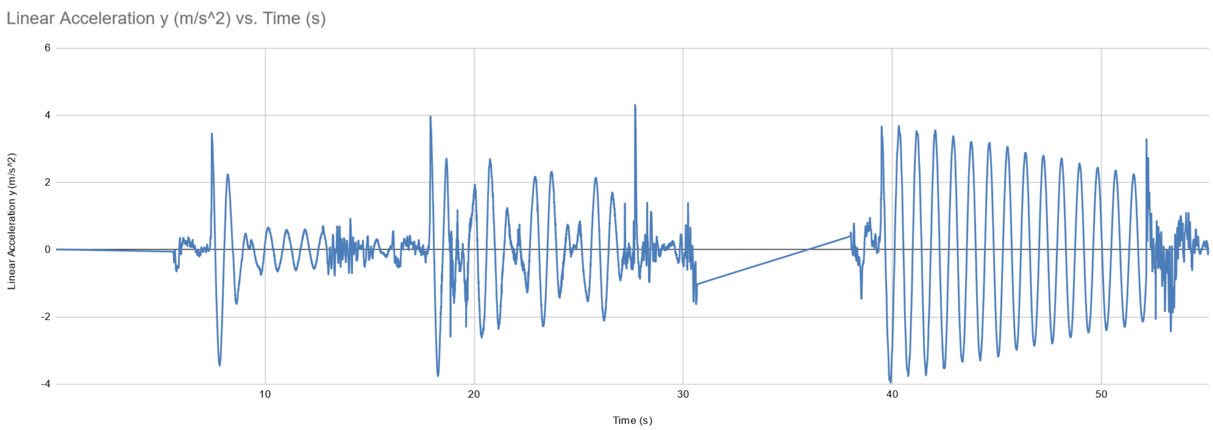
Pull the building back and let it swing again. You may notice that the period of the building is different now. The extra mass of the pendulum makes the building harder to move and so each swing takes longer. You can collect this data with a phyphox and the like.

Loosen the wingnuts so that the pendulum can swing freely. Release the building again. You'll notice that the building now swings in a herky-jerky fashion. The energy goes into the pendulum but then comes back out moving the building. You may notice that the building swings for a shorter time, but it looks even less comfortable.

We don't want the energy to just end up in the pendulum, we want the energy to be converted into something besides elastic and kinetic energy. We actually want a pendulum with friction. The energy lost to friction will decrease the total energy, decreasing the number of swings.

You increase the friction by tightening the wingnuts. Too tight, and the pendulum won't swing. Too loose, and little energy is lost. You'll have to play around to find the right amount.

Can you tell in the following graph where the pendulum was locked down, where the pendulum was swinging freely, and where the friction was just right?



Tuning the mass dampener

You can get an even better dampening if the period of the pendulum is close to the period of the building. Each swing will then be timed to so that more energy will be transferred.

First, you need to find the period of the building. You can use a stopwatch or you can look at the graph in phyphox. Measure the time from one crest to another.

While this pendulum isn't a simple pendulum, the simple pendulum equation will work well enough.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Where T is period, L is the length of the pendulum, and g is the strength of gravity (usually 9.8 N/kg).

Solving for L we get

$$\frac{T}{2\pi} = \sqrt{\frac{L}{g}}$$

$$\left(\frac{T}{2\pi}\right)^2 = \frac{L}{g}$$

$$g\left(\frac{T}{2\pi}\right)^2 = L$$

Measuring from the screw, move the nuts on the pendulum so that the center of the bob is the computed distance down.

http://tinyurl.com/tuned-mass-dampener