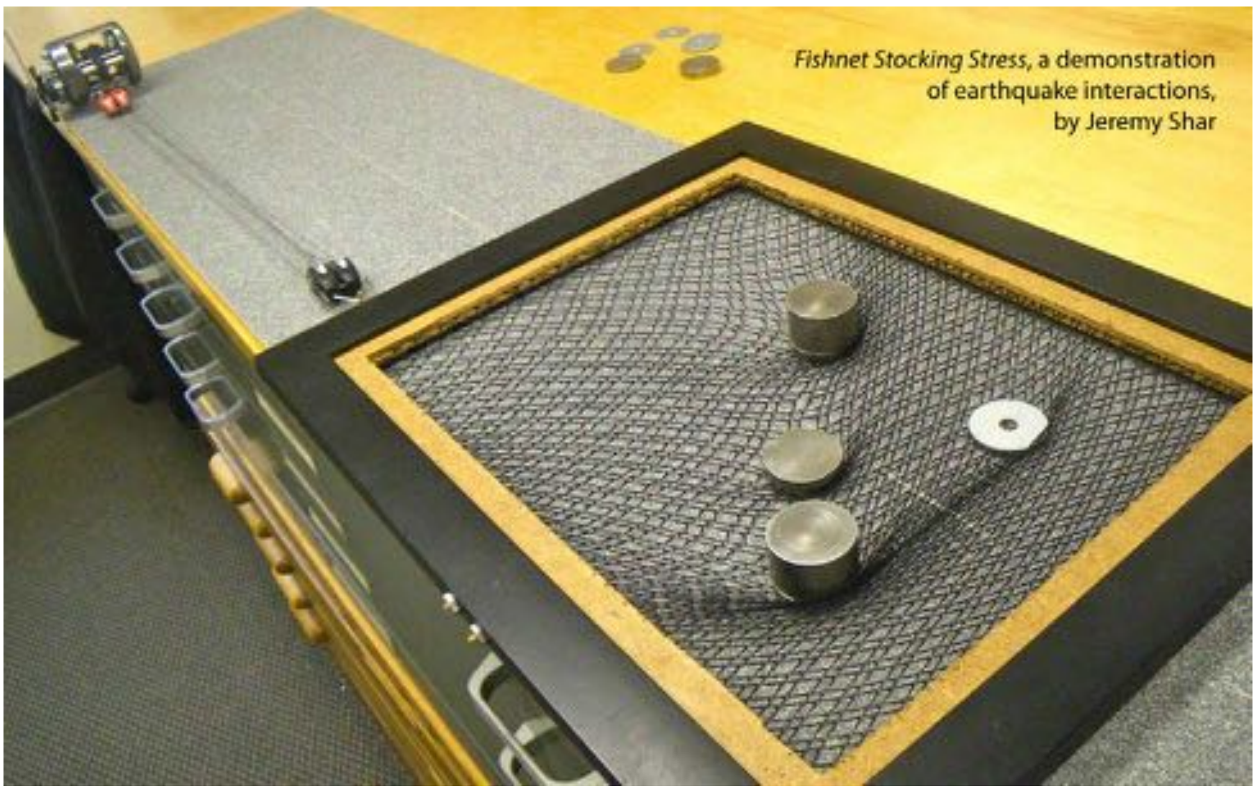
31 March 2014

Fishnet Stocking Stress: An interactive demonstration of earthquake interactions in a 2D elastic crust

By Jeremy Shar (Brown University) and Ross S. Stein (USGS)



Executive Summary

Fishnet Stocking Stress, like its predecessor QuakeCaster, is an interactive teaching and demonstration tool that simulates earthquake behavior. Where QuakeCaster was able to mimic the transfer of stress in a one-dimensional system, Fishnet Stocking Stress is a two-dimensional model that allows dynamic lateral transfer of stress. A fishnet stocking acts as an elastic membrane and simulates the elasticity of the earth's crust. Weights are magnetically attached to this membrane and are dragged along a rough sandpaper surface by a fishing reel. Static friction prevents the weights from gliding easily across the surface, causing stress to build up in the membrane. These stress effects are clearly visible as both a compressional buildup behind each

weight and a tensional stress shadow in front of each weight. Fishnet Stocking Stress can be used to demonstrate both simple and complex earthquake and fault interaction phenomena in a pleasing visual format. It is ideally suited to consider asperity interaction on a megathrust surface, but also illustrates the potential interaction of earthquakes on the sub-parallel strike slip faults across the San Francisco Bay area, or normal-faulting earthquakes in the U.S. Basin and Range or western Turkey.

Motivation for Demo

The original QuakeCaster was a fantastic tool for demonstrating one dimensional stress transfer in a fault-like system. In order to achieve its goals, it was necessarily designed as a long narrow device. In order to transform the bones of QuakeCaster to accommodate two dimensional demonstrations, extra width had to be added. This was simply accomplished by adding a second long tile to the apparatus, placed alongside the first one. However, the original ceramic tiles proved too heavy for practical and easy transport, so lightweight plastic planks covered in self-adhesive non-skid (to mimic the rough surface of the ceramic) were substituted.

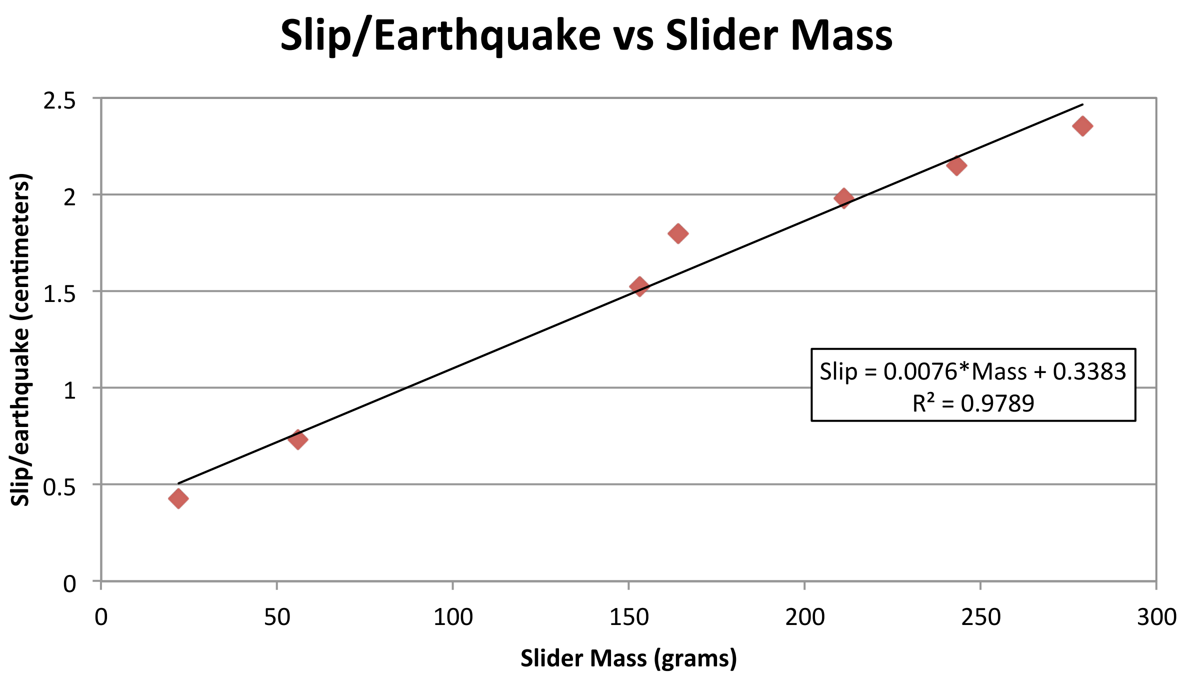
Design and Purpose

Fishnet Stocking Stress was designed primarily to demonstrate the concepts behind two dimensional stress transfer in fault systems in a simple visual format that is easy to understand even for those unfamiliar with the field in general. The basic setup is a frame pulled by a fishing reel along a stationary roughened substrate: the relative motion of the frame and substrate represents the relative plate motion that causes earthquakes. A fishnet stocking stretched across the frame was chosen to represent the Earth's crust and mimic its elastic behavior. An advantage of this approach is that stress concentrations are automatically rendered visible to viewers by the expansion and contraction of the weave of the stocking's fabric: a tight weave indicates compression and a loose weave indicates tension. These visual cues allow viewers to more clearly understand how faults and asperities interact with one another at a distance with the crust as a buffer medium. Metal sliders are used to represent either individual asperities or entire faults, and act as areas of high friction between the two moving plates. The sliders have a rough sandpaper base that is in contact with the equally rough substrate, and are directly attached to the crustal membrane using magnets. These sliders can be freely placed within the frame, allowing the demonstrator to concoct whatever scenario or arrangement of asperities they choose. This freedom of experimental design also allows for audience participation — the ability to experiment and try out different setups makes the demo interactive and thereby engaging.

As the frame is pulled by the fishing reel, it glides freely on Teflon rails. The sliders however are in contact with the rough substrate so they stick in place, much like asperities in a real fault. As the frame moves inexorably along its rails, stress builds up in the stocking membrane at the asperities, which is visualized in the weave of the membrane. When the stresses eventually become too great, the sliders lurch forward in miniature earthquakes, suddenly altering the state of stress for the other sliders attached to the membrane. These dynamic changes can either provoke or inhibit earthquakes in other sliders, all of which can be seen in the membrane in real time.

Relationship between slider mass and earthquake size

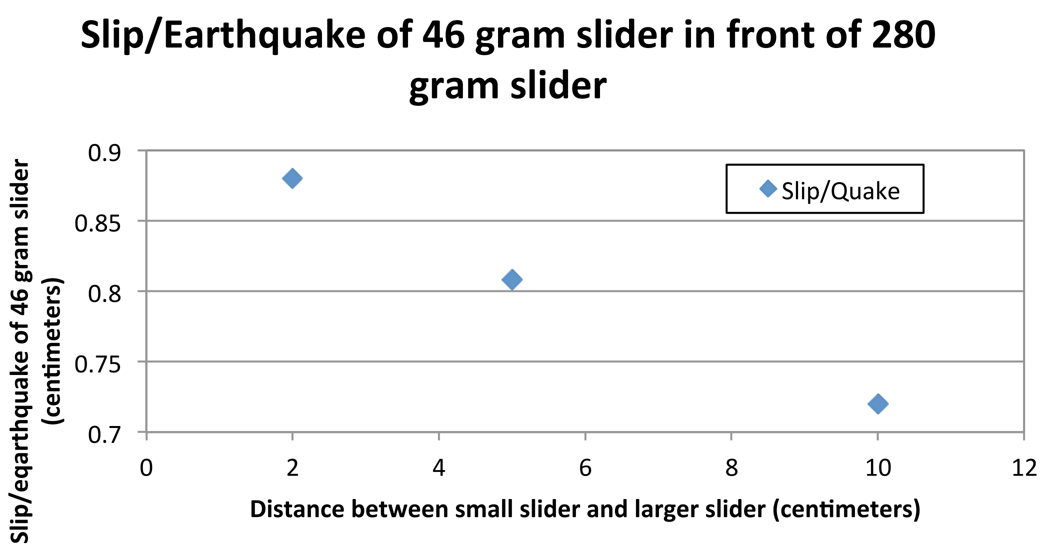
Much like real earthquake systems, Fishnet Stocking Stress demonstrates predictable behavior in simple setups averaged over large numbers of trials, but individual trials and more complex interactions are highly unpredictable. The most fundamental behavioral property of the Fishnet Stocking Stress system is the correlation between slider mass (grams) and earthquake size (centimeters/earthquake).

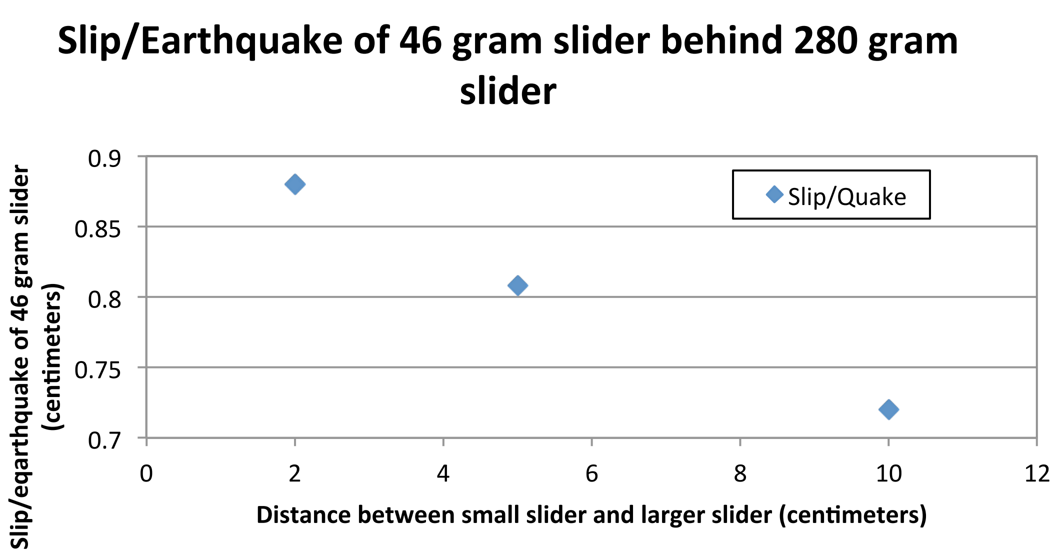


These data were produced by observing 100 successive earthquakes for a slider of each mass and dividing the total measured distance the slider travelled by 100. The data show an unequivocal linear trend, with an r^2 value of 0.97 correlating greater mass with larger earthquakes. While we have not directly measured the tension in the elastic strands of the stocking, it seems clear that the stress in the fabric at which earthquake failure occurs is also positively correlated with slider mass. This hypothesis is borne out visually by the size and intensity of the stress shadow produced by the sliders, with more massive sliders producing larger stress shadows and more bunching of the stocking fabric behind the slider, as well as greater extension and enlargement of the weave in front of the slider.

The ability of a large slider to capture, or change the behavior of, a small one nearby

One of the simplest experiments that can be performed using Fishnet Stocking Stress is the interaction between two sliders of disparate size initially placed at various distances from each other. The most noticeable feature of such a setup is the effect of distance on the earthquake size of the smaller slider.





The closer it is initially placed to the larger slider, the more its behavior mimics the larger slider, exhibiting larger and less frequent earthquakes regardless of the relative arrangement of the two sliders (e.g. there is little difference between the smaller slider in front of the larger slider and the smaller slider behind the larger slider). This experiment demonstrates the "capture" effect, wherein a larger fault can influence or even control the intensity and frequency of earthquakes on neighboring faults entirely through dynamically altering the state of stress in crust.

Materials and Sourcing

- Plastic base tiles
  - Two pieces of 5 3/4" x 47" x 1/8" Foamed PVC from TAP Plastics: http://www.tapplastics.com/product/plastics/cut_to_size_plastic/foamed_pvc_sheets/342
  - But any stiff, lightweight plank is acceptable.
- Acrylic strips
  - Four pieces of 1 ½" x 14" x 1/16" acrylic
  - Four pieces of 1 ½" x 8" x 1/16" acrylic (purchased from TAP Plastics)
- Self-adhesive non-skid
  - One 6" x 30' roll of Abrasive Anti-slip Tape (Sand/amber color) from McMaster-Carr [Product number 6970T261]
- Adhesive spray
  - 3M Super 77 Multipurpose Spray (available at most hardware stores)
- Strong glue
  - 5 minute 2-part epoxy
- Cork
  - 1/16" thick cork sheeting, preferably in pieces at least 4' long (available at most hardware stores)
- Slider cylinders
  - Various lengths (1/8" – 1 ½" long) 1 ¼" diameter non-stainless steel or iron cylinders (purchased from Alan Steel in Redwood City, CA, but should be available at any good metal supplier)
- Neodymium magnets
  - ¼" x .06" Ultra-High-Pull Neodymium-Iron-Boron Magnets from McMaster-Carr [Product number 5862K48]
- Washers
  - Plain Steel General Purpose Washers ½" ID, 1 ¼" OD from McMaster-Carr [Product number 91071A032]
- Teflon rails
  - Two Teflon PTFE 90º Angles ½" x ½" x 1/16" from McMaster-Carr [Product number 8604K11]
- Picture frame
  - 11" x 14" picture frame, with picture secured by metal tabs (purchased from University Art in Palo Alto, CA but available wherever frames are sold, such as Aaron Brothers)

- Fishnet stockings
  - Merona Collection Fishnet Stockings (by far the best stockings we've found, and available only at Target. One wants the most stretchy stockings possible.)
- Kite blocks
  - Four Ronstan Series 16 & 19 Kite Blocks [Ronstan Item# RF13101-2] (They come in packs of two. We purchased ours from West Marine, SKU #3734134)
- Fishing reel
  - Corvalus 300 fishing reel (purchased from West Marine)
- Binder clips, steel wire, and miscellaneous screws

Estimated total cost for the building materials approximately $300

Figure 1: Ross Stein demoing Fishnet Stocking Stress at the EUCENTRE in Pavia, Italy. From the article, "Quake Catcher," by Joanne Baker, *Nature* **498,** 290–292 (20 June 2013). Photo by James Brown.

Building Instructions

1. **To assemble the base tiles:**

    a. Detailed instructions for building the base tiles have been published in USGS Open File Report 2011-1158 (see http://pubs.usgs.gov/of/2011/1158/). In the Appendix, steps 1, 2, and 4-8 detail how to fully assemble the base tiles including the attachment of the fishing reel and pulley system. To build the second base tile, simply follow the instruction in step 2 to make a single tile with only sandpaper on the surface, and then add cork to the bottom of the board as described in step 8.

2. **To assemble the frame apparatus:**

    a. Using short screws, attach the Teflon rails to the underside of the frame, making sure that their spacing is exactly equal to the width of the two plastic tiles side-by-side. It helps to hold the rails in place with tape while fine-tuning the fit before more permanently screwing them in.

Figure 2: Teflon rails attached to the picture frame. The other side of the frame has a mirror image of this.

b. Glue the narrow acrylic strips together edge to edge into two frames, using acrylic glue. Make sure that the frames fit into the picture frame without too much wiggle room (see Figure 4).
c. Using sharp scissors, cut a leg off of a pair of stockings, and remove the foot. Cut along the length of the leg to open the fabric into a rough rectangle (bunching up the leg helps here).

Figure 3: Fishnet stockings. Larger sizes are better.

d. Stretch the stocking evenly across the large open frame, holding it in place with binder clips to keep it taut. Don’t worry if the edges are stretched unevenly, but make sure that there is a uniformly stretched area of stocking the size of the picture frame.
e. Invert the picture frame and place one of the acrylic frames into the picture frame’s opening. Adhere strips of double-sided tape around the entire acrylic frame, and then position the large open frame above the picture frame so that a uniformly stretched area of stocking is directly above the picture frame’s window.

f. Adhere strips of double sided tape to the second acrylic frame and press it, tape facing down, into the first one, trapping the stocking between the two frames and securing it in place with pre-adhered tape. Secure the acrylic frame sandwich in place in the picture frame using the metal tabs.

Figure 4: The two assembled acrylic frames held together by double sided tape and paper clips. The stocking has been removed from this example.

g. Using sharp scissors cut off the excess stocking spilling out from the edges of the frame.

Figure 5: Frame holding the stocking (now shown in brown made from wood) emplaced in the picture frame using the metal tabs. The hook is also shown which is used to pull the frame along the track.

3. To assemble the sliders:

a. Using a heavy hammer, smash the inside lip of several washers so that the opening on one side is slightly smaller than on the other. Be careful not to press the lip downward into the hole – instead, try to keep it flat and level with the face of the washer.

Figure 6: Metal washer and neodymium magnet.

b. Put a neodymium magnet into each washer. Attach half of the washers to each other using the epoxy and allowing the magnets to pull them together so that they are doubly thick (see Figure 8). The washers should be oriented so that the smashed side faces outward, preventing the magnet from being pulled out.

Figure 7: Neodymium magnet placed in the washer. The opposite side has been hammered in to prevent the magnet from falling out.

c. Cut circles of adhesive-backed non-skid slightly smaller than the washers, and glue them to the non-smashed side of the remaining washers, trapping the neodymium magnet inside each one. To ensure that the magnet does not fall out, place duct tape over the opposite side.

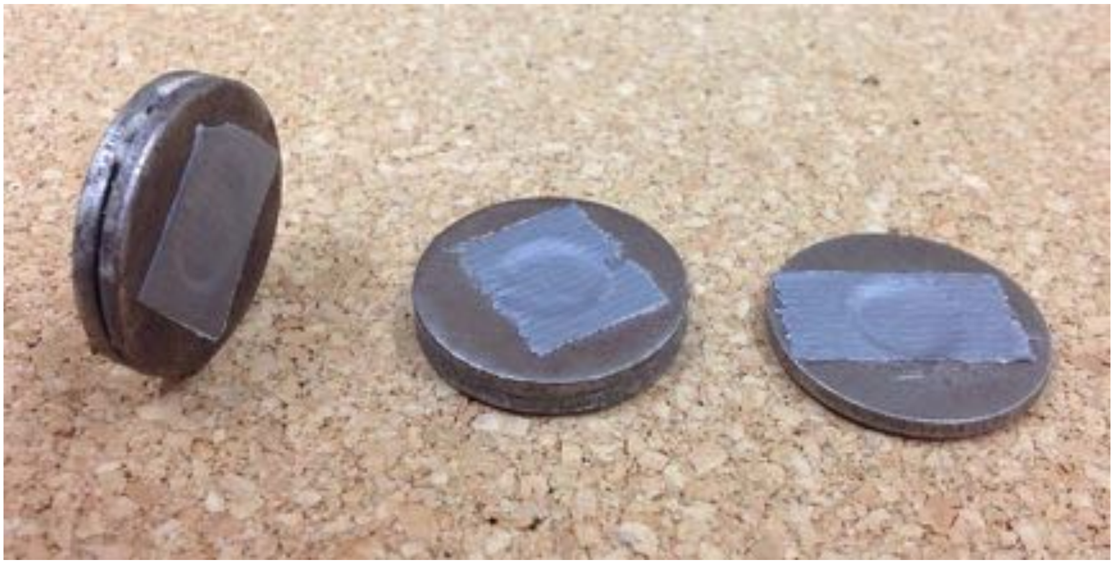


Figure 8: The different washer and magnet combinations. The two on the left are the double thick versions while the one on the right is the single washer with non-skid attached to the side facing down.

Figure 9: Single washer with non-skid attached to one side. The opposite side has duct tape ensuring the magnet will not fall out.

d. Each double-washer/non-skid-washer pair is one slider. The double-washer is placed above the stocking and the non-skid half is placed below the stocking, non-skid side down. To add further weight, the steel cylinders can be magnetically attached to the tops of the double sided washers.

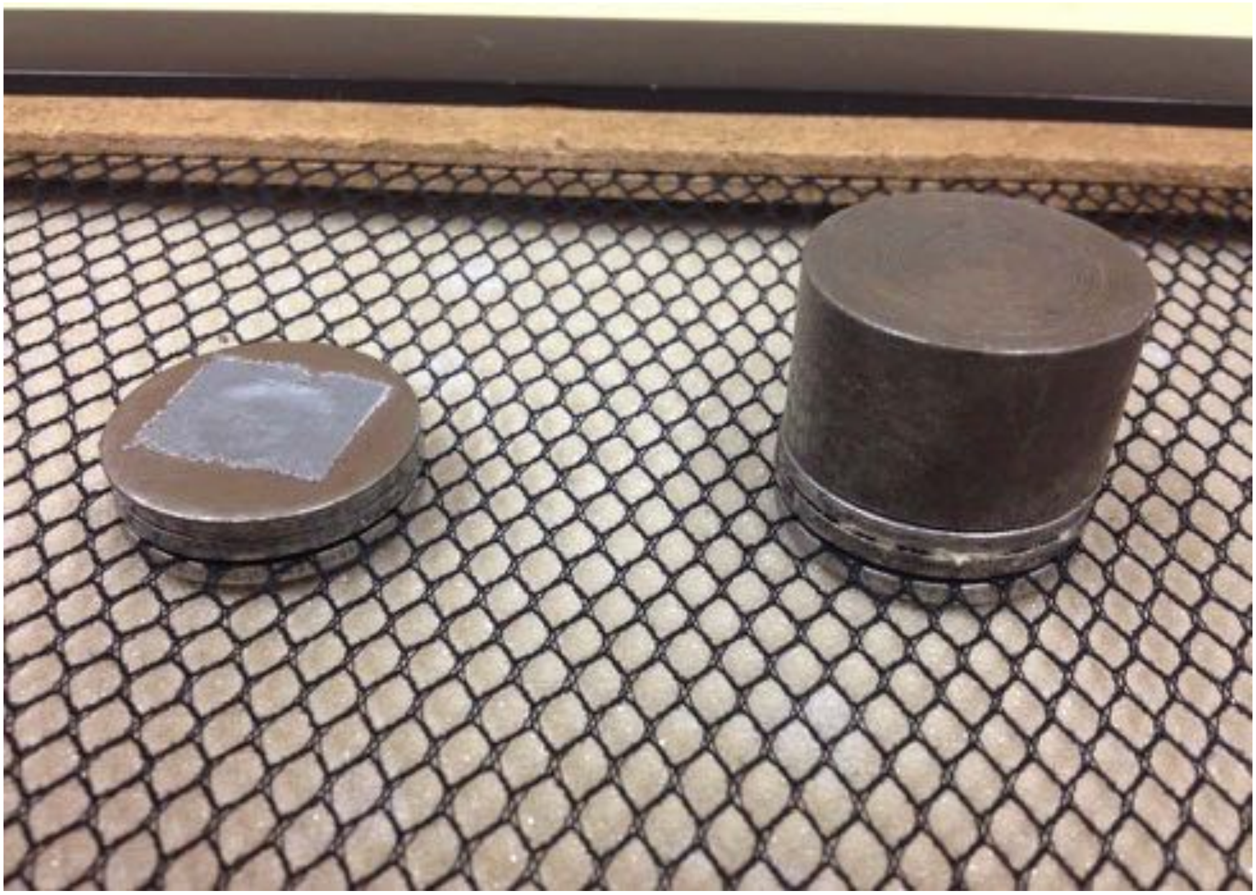


Figure 10: The non-skid faces of the single washers are beneath the stocking in direct contact with the sandpaper track. The double-washers are magnetically attached to the single washers. The slider on the right has a large steel weight attached to the double-slider.

We thank Max Willis for editing and photography, and Volkan Sevilgen for advice and suggestions.