How to Build and Teach with QuakeCaster, an Earthquake Demonstration and Exploration Tool

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Contents

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Abstract

QuakeCaster is an interactive, hands-on teaching model that simulates earthquakes and their interactions. QuakeCaster contains the minimum number of physical processes needed to reproduce most observable features of earthquake occurrence: a winch that steadily reels in a line to simulate the steady plate tectonic motions far from the plate boundaries, a granite slider in frictional contact with a porcelain rock-like surface to simulate a fault at a plate boundary, and a rubber band connecting the line and the slider to simulate the elastic character of the earth's crust. By stacking and unstacking sliders and cranking in the winch, one can see the impact of changing the shear and clamping stress on the fault. By placing sliders in series with rubber bands between them, one can simulate the interaction of earthquakes along a fault, such as cascading or toggling shocks. By inserting a load scale into the line, one can measure the stress acting on the fault throughout the earthquake cycle. As observed for real earthquakes, QuakeCaster events are neither periodic, time-, or slip-predictable. They produce rare but unreliable 'foreshocks.' When fault gouge builds up, the friction goes to zero and fault creep is seen without large quakes. QuakeCaster events produce very small amounts of fault gouge that strongly alter its behavior, resulting in smaller, more frequent shocks as the gouge accumulates. QuakeCaster is designed so that students or audience members can operate it and record its output. With a stopwatch and ruler one can measure and plot the results. People of all ages can use this model to explore hypotheses about earthquake occurrence. QuakeCaster takes several days and about $500 to build.

QuakeCaster Design and Purpose

QuakeCaster is composed of a 4-foot long porcelain tile with a fishing reel attached at one end. We used a porcelain faux-rock tile rather than granite due to its high friction, much lighter weight, greater durability, and higher fracture toughness. One to three granite blocks, called "sliders," are placed at the opposite end of the tile. The sliders are joined by a rubber band. The fishing line, made of Spectra is reeled in steadily to the opposite end of the tile and a rubber band joins the line with the first slider. This super-low stretch Spectra line is essentially inelastic at these small loads. The rubber band represents the earth's elasticity. The fishing reel is oriented so that the force acting on the sliders is horizontal, which means that it exerts only shear stress on the slider/fault system. When the reel is cranked at a constant rate, simulating constant tectonic plate velocity, stress will accumulate due to the friction between the sliders and the porcelain tile. This represents the stress buildup on faults.

Students and the audience can be actively involved in the experiments. They are able to measure the time between events, slip distance (a stand-in for earthquake size), force before an event occurs, and force after an event occurs. Despite being a relatively simple model, QuakeCaster is remarkably true to observed earthquake behavior. Thus, students will get a memorable hands-on look at stress and rupture in the laboratory, and they will understand why it is so difficult to predict earthquakes in the real world. The size of earthquakes is measured by the 'seismic moment,' which is the fault contact area (here, the 4 x 4" slider surface), times the elastic stiffness (the stiffness of the rubber band), times the amount of slip (which can be measured in the experiments). Earthquake magnitude is proportional to the logarithm of the seismic moment.

Principles brought to life and hypotheses tested with QuakeCaster

A fundamental riddle of earthquake occurrence is that the tectonic motions at plate interiors are steady, changing only subtly over millions of years. But at plate boundary faults, the plates are stuck for hundreds of years and then suddenly jerk forward in earthquakes. Why does this happen? The answer, as formulated by Harry F. Reid in 1910 (Reid, 1910) is that the earth's crust is elastic—behaving like a very stiff slab of rubber sliding over a substrate of 'honey.' The crust near the fault is deformed by the plate motion until the stress acting on the fault overcomes the frictional resistance and suddenly slips. For the past century, scientists have sought ways to use this knowledge to predict earthquakes. The four leading hypotheses, essentially trending from the most uniform and regular behavior to the most irregular and unpredictable, can all be tested with QuakeCaster:

Hypothesis 1: Earthquakes are periodic (in other words, all slipped the same amount, and all separated by the same amount of time). There is some evidence for this, particularly among very small earthquakes on creeping faults (Schwartz and Coppersmith, 1984). (Figure 1)

Hypothesis 2: Earthquakes are 'time-predictable' (this means that the larger the slip in the last earthquake, the longer the wait until the next one.) (Shimazaki and Nakata, 1980). (Figure 1). Another way of framing this hypothesis is that earthquakes occur when the failure stress is reached. (This means that when a certain amount of stress accumulates, an earthquake will occur.) (Figure 2)

Hypothesis 3: Earthquakes are 'slip-predictable' (this means that the longer the time allowed for stress to accumulate, the greater the earthquake will be.) (Figure 1). Another way of framing this hypothesis is that earthquakes drop their stress to a fixed minimum or background amount (Bufe et al, 1977). (Figure 2)

Hypothesis 4: Earthquakes occur randomly in time and have randomly varying size. (This 'Poisson' hypothesis is also widely used, particularly when little information about a fault and its past earthquakes is available).

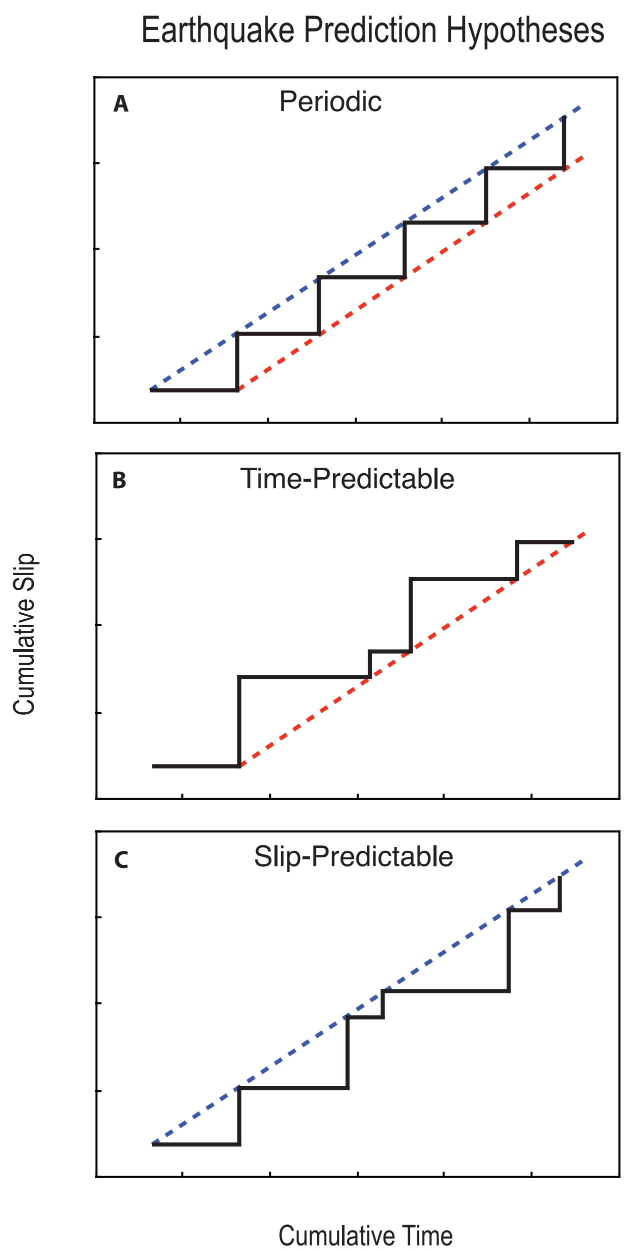

Figure 1. (A) The top chart illustrates what we would expect to see if earthquakes were periodic. (B) The middle chart illustrates what we would expect to see if earthquakes were obeyed the time-predictable hypothesis. (C) The bottom chart illustrates what we would expect to see if earthquakes were consistent with the slip-predictable hypothesis.

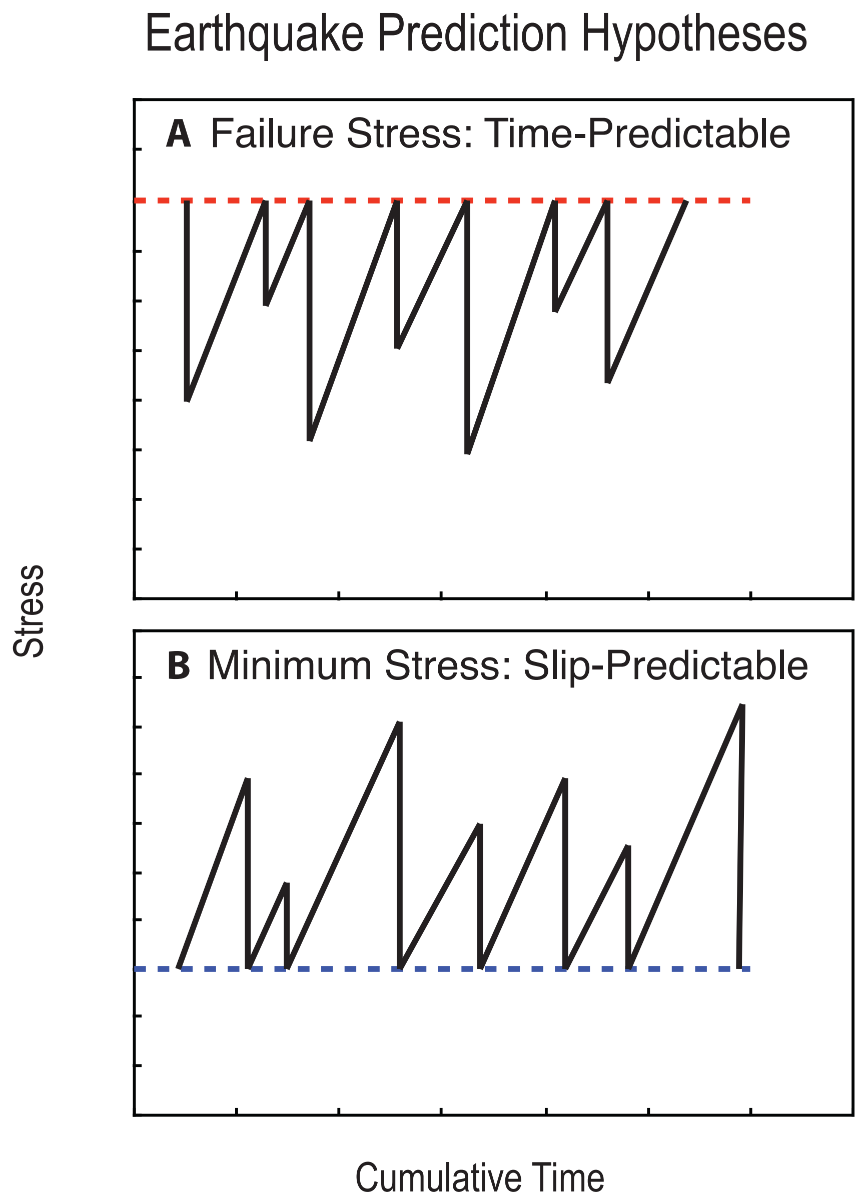

Figure 2. These hypotheses are variations of the slip-predictable and time-predictable hypotheses, but in terms of fault stress rather than slip. The slope of the diagonal lines is the fault stressing rate; these lines are imperfectly parallel because hand-cranking results in slight variations in loading rate. (A) A result similar to this record would indicate that there is a fixed failure stress but a variable post-earthquake minimum stress. (B) Results similar to this record would suggest that the minimum stress is the best indicator of earthquakes because failure stress is too variable.

Coulomb failure, stress triggering, and earthquake interaction

QuakeCaster can demonstrate Coulomb failure criteria, which holds that when a fault is close to failure, either increasing the shear stress (by reeling in a bit more line) or decreasing friction by reducing fault clamping (often termed 'normal') stress will promote failure. To do this stack two sliders, and reel in the line until the slider is on the verge of slipping. Now crank a bit more and it will trigger an earthquake. Reel in the line again until the slider is on the verge of slipping, and lift the top slider. Again it will trigger a quake. If the static friction coefficient of the fault is about 0.5, then increasing the shear stress will have twice the impact as unclamping the fault in triggering an earthquake. The Coulomb hypothesis and the concept of stress triggering of earthquakes is explained in Stein (2003).

QuakeCaster can also demonstrate how earthquakes converse with each other by the transfer of stress. When we normally speak about stress, it is defined as the force divided by the surface area. In QuakeCaster, when the force builds up to 1000 grams, one 4" x 4" slider has a shear stress of roughly 0.96 kPa.With this model, since the area is constant, we can look at force alone. One QuakeCaster experiment involves adding a second slider behind the first. The sliders are joined by a rubber band. When stress overcomes the frictional resistance on the fault, the first slider moves forward, which increases the stress on the second slider. Eventually, the second slider slips, and this reduces the restraining force on the first slider, and the first slider slips again. We ask the audience to 'wager' on which slider will rupture first, second, third, and fourth. They are almost always surprised by the outcome (which changes somewhat from one trial to the next). By making a prediction of their own, they become invested in the outcome and more curious about its behavior.

Additional accessories can be used to enhance the audience's understanding of earthquake behavior. A ruler can be used to measure the slip during earthquakes, a lap-timer stopwatch can measure the time between earthquakes, and a fish-scale (a small dial scale) can be used as a force (stress) gauge.

Examples of QuakeCaster experiments

We ran experiments using QuakeCaster to test the four earthquake hypotheses. First, we performed three trials to measure the time between events and the slip distance. This required a minimum of three people. We placed a piece of white electrical tape along the side of the porcelain tile. Then, one person reeled at a constant rate (which simulates constant plate motion). One person used a Sharpie pen to mark the slip distance after each earthquake. Another person held the stopwatch and recorded the time (one needs to measure in tenths of seconds) of each event. After one trial, we measured the distance (cm) between events. We repeated this two more times. The results are shown in Figure 3.

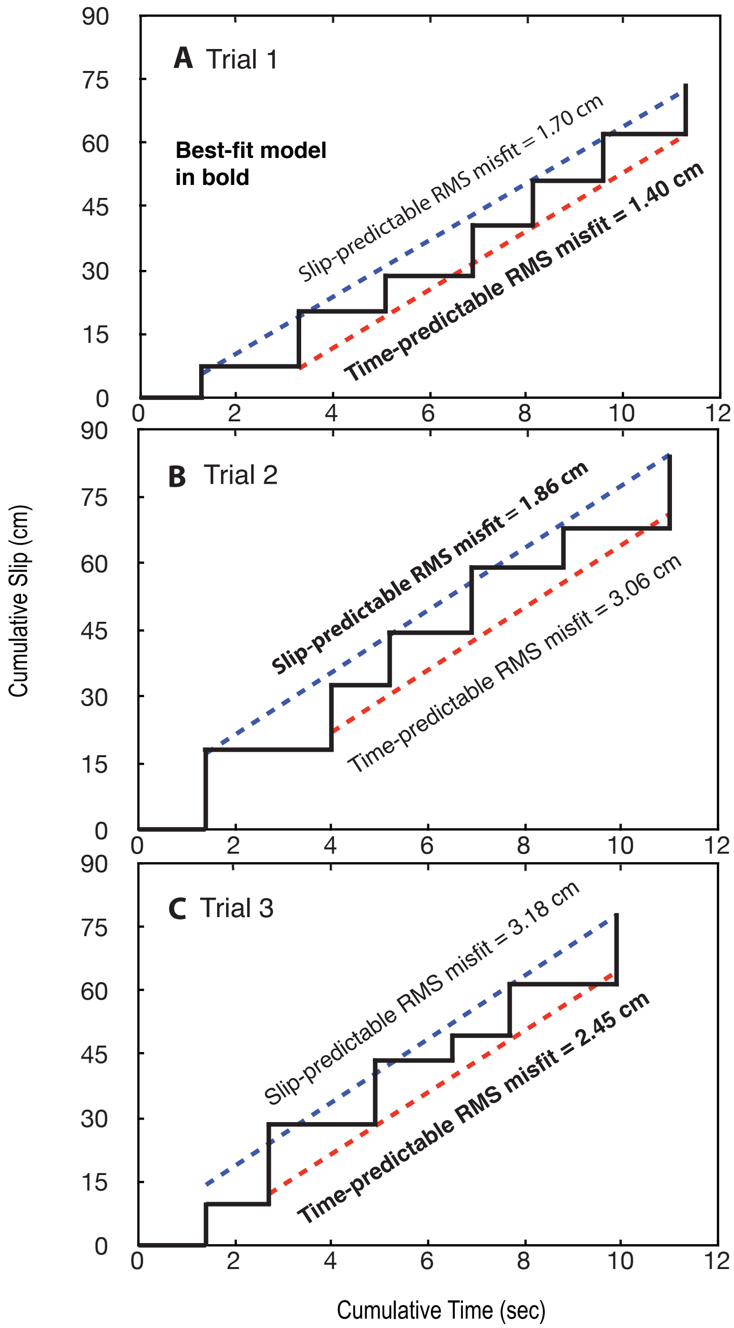

Figure 3. The hypothesis in bold indicates better agreement with the observations in a given trial. We do not count the time to the first earthquake because the spring starts fully unloaded. (A) Trial 1 suggests that the time-predictable hypothesis is a better predictor of earthquakes than the slip-predictable hypothesis. (B) Trial 2 suggests that the slip-predictable hypothesis is a more reliable predictor. (C) Trial 3 also favors the time-predictable hypothesis. The same slider and the same rubber band were used in each trial. The same person attempted to crank at a constant speed in each trial, while another person marked the slip distance and one recorded the times. Any gouge we could see was brushed off after each trial.

For each trial, we calculated the RMS (root mean square) misfit value for each hypothesis (slip- and time- predictable) in order to see how the data compared to the hypotheses. As shown in Figure 1, Trial 1 suggests that earthquakes are best predicted by the time-predictable hypothesis. At first glance, the earthquakes in Trial 1 appear to fit the periodic hypothesis. However, the RMS misfit values suggest differently. The RMS misfit value for the slip-predictable hypothesis is 1.70 cm, but the RMS misfit value for the time-predictable hypothesis is 1.40 cm. In contrast, Trial 2 suggests that earthquakes are best predicted by the slip-predictable hypothesis. The RMS misfit for the slip-predictable hypothesis is 1.86 cm and for the time-predictable hypothesis the RMS misfit value is 3.06 cm. Trial 3 suggests, like Trial 1, that earthquakes are best predicted by the time-predictable hypothesis. The RMS misfit value for the slip-predictable hypothesis is 3.18 cm and for the time-predictable hypothesis the RMS misfit value is 2.45 cm. Thus, none of these trials perfectly match the slip-predictable, the time-predictable, or the periodic hypotheses. These tests show how difficult it is to accurately predict earthquakes: even when we grossly simplify the likely complexity and variability in the earth, we still do not get regular, predictable earthquakes.

After testing slip- and time-predictability, we performed another experiment to test whether failure stress is an accurate predictor of earthquakes. We measured the force with the dial scale just before an earthquake occurred (failure stress) and the force just after an earthquake occurred (minimum stress). This required four people in order to ensure the most accurate data possible. One person reeled at a constant rate, one held the stopwatch and recorded the time of each event, one recorded the force just before an event, and one recorded the force immediately after an event. We performed three trials, and the results are shown in Figure 4.

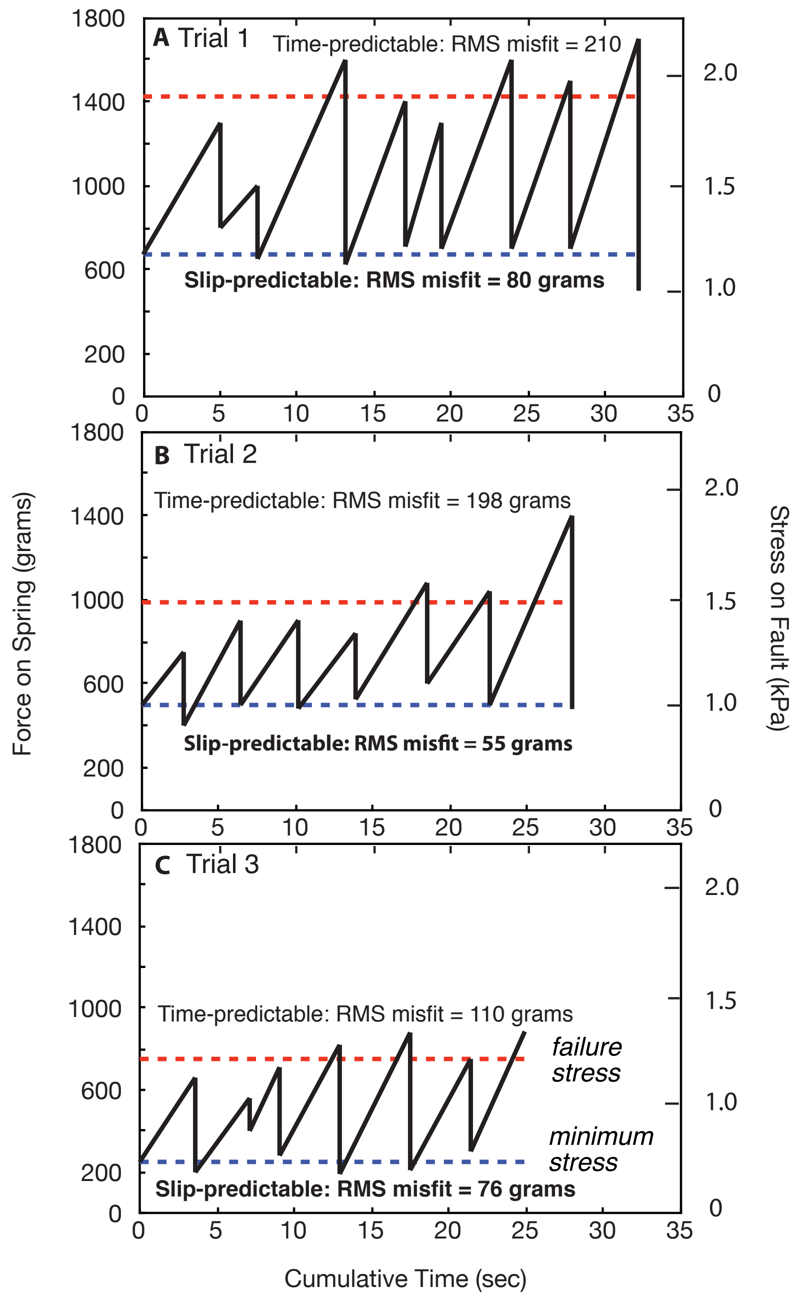

Figure 4. The hypothesis in bold indicates better agreement with the observations in a given trial. (A) Trial 1 suggests that minimum stress is a better earthquake predictor than failure stress is. (B) Trial 2 also suggests that minimum stress is a better predictor. (C) In contrast, Trial 3 suggests that failure stress is a more reliable predictor. The same slider and the same rubber band were used in each trial. The same person attempted to crank at a constant speed in each trial, while one person recorded the force before an event, one recorded the force after, and one recorded the time.

For each trial, we calculated the RMS misfit value for each hypothesis (slip- and time-predictable) in order to see how the data compared to having a constant failure stress (equivalent to time-predictable) or to having constant minimum (equivalent to slip-predictable). Figure 4 suggests that there is no identifiable failure stress; in all three trials earthquakes did not occur at the same level of stress. Surprisingly, the trials indicate that the minimum stress is a better predictor of earthquakes than the failure stress. In Trial 1, the force-after RMS misfit value is 80 grams whereas the force-before value is 210 grams. Again in Trial 2, the RMS misfit value is lower for the force after an earthquake. The RMS misfit value is 55 grams and the force-before value is 128 grams. In Trial 3, the force-after RMS misfit value is 76 grams and the force-before value is 110 grams. However, none of these trials perfectly fit either failure stress hypothesis. It is also surprising that the size of the shocks, as well as the failure and minimum stress, decreased markedly form trial 1 to 3. We have no good explanation for this, with the possible exception of minute quantities of naturally occurring fault gouge (granite powder) than one can see form on the sliding surface asperities (local high spots), which may alter the frictional properties.

QuakeCaster relates to the Parkfield section of the San Andreas Fault

The Parkfield section of the San Andreas fault is the best documented and the most periodic earthquake sequence known on the planet, but its event sequence is neither time- nor slip-predictable. The Parkfield fault section, at first glance, appears to be roughly periodic, with magnitude 6 earthquakes roughly every 20-30 years. Christopher Scholz (2002) assessed Parkfield data from an earlier time period, 1850-1988. However, Scholz points out that the 1934 Parkfield earthquake occurred roughly a decade earlier than the average interval, and since his work, we now know that the 2004 Parkfield earthquake struck about 1-2 decades late. This data emphasizes the fact that even the most predictable earthquakes deviate from slip- or time-dependent hypotheses. Also, Murray and Segall (2002) found that the Parkield magnitude 6 earthquake is not time-predictable. The most recent earthquake after 1966 should have occurred sometime between 1973 and 1987, but it didn't. If this model doesn't fit a simple, seemingly periodic fault, then how can it apply to a larger and more complex fault?

Even though it turns out that the M= 6 Parkfield shocks are neither periodic nor the same size and location from one to the next, there is a class of very small shocks (M=1-3) that are exact repeats of each other. Are these periodic, time-predictable, or slip-predictable? Rubinstein et al. (2011) shows that they are neither time- nor slip-predictable. Rubinstein et al. showed the time history for Parkfield repeating earthquake sequence #1 (Figure 5). Rubinstein found that these earthquakes failed both the time- and slip- predictable hypotheses, even though they are roughly periodic. It's worth noting that the magnitude of QuakeCaster earthquakes are closer in magnitude to the Parkfield repeaters than the repeaters are to the Parkfield magnitude 6 shocks.

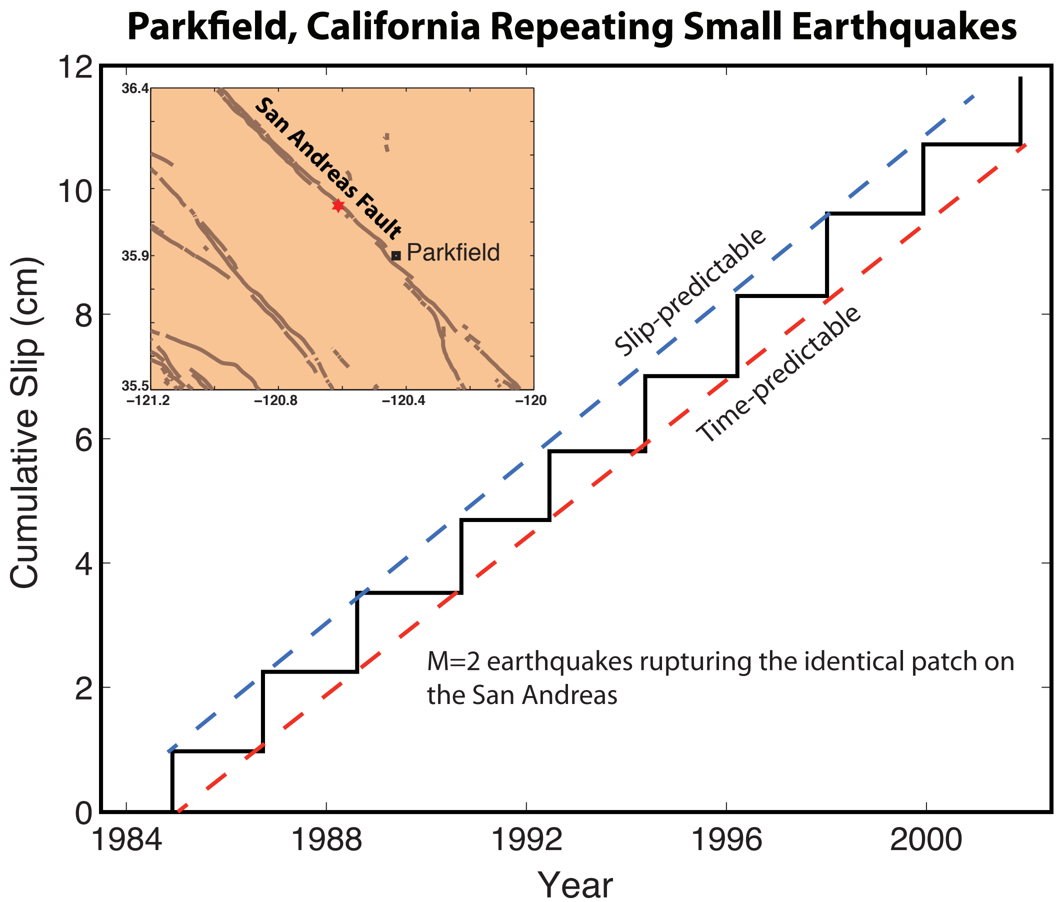

Figure 5. This chart illustrates repeating earthquakes in Parkfield, CA. Estimated best-fit lines are drawn in to see how the data compares to slip- and time- predictable hypotheses. The Parkfield section of the San Andreas Fault is one of the most periodic earthquake sequence known to scientists, but the sequence is still neither time- nor slip-predictable. Inset: map of the San Andreas fault in the vicinity of Parkfield.

Figure 6. Kelsey turns the fishing reel, which simulates constant tectonic plate motion. The slider is in frictional contact with the tile, which represents friction in a fault. The rubber band that joins the slider and the fishing reel simulates the earth's elastic crust.

Measuring the fault friction in QuakeCaster

After running QuakeCaster just once, fault gouge is visible as a light dusting on the porcelain tile. Gouge occurs in real faults as a result of friction between rock materials when they slide past each other. Diane Moore and Michael Rymer (2007) are responsible for the discovery of talc, a type of fault gouge, within the San Andreas fault. This was a significant finding because it suggested that talc decreases friction within faults and could therefore be responsible for fault creep along the San Andreas (Moore and Rymer, 2007). Moore and Rymer made their discovery by assessing rock samples from the San Andreas Fault Observatory at Depth site. J. Byerlee's paper, titled "Friction of Rocks" also states that gouge decreases friction. He explains "the adhesion theory of friction" which states that surfaces touch at asperities and a great amount of shear stress is needed to overcome their contact (Byerlee, 1978). Rock materials appear to have a friction of about 0.65 when dry. For wet samples and for samples with fault gouge, it can be much lower, perhaps as low as 0.2. Using QuakeCaster, students can calculate the friction of coefficient by dividing the force before an event by the weight of the slider. Our tests have shown a friction of coefficient around 0.4. However, the coefficient can change during the experiment. For example, if fault gouge accumulates over multiple trials, the coefficient will most likely decrease. After running additional trials, we found evidence of decreased friction due to observed fault gauge. As figure 4 shows, the amount of force necessary to overcome friction decreased over multiple trials.

Measuring earth's elasticity in QuakeCaster

To determine if the rubber band behaved linearly over the range of forces it was subjected to in QuakeCaster experiments, we calculated the rubber band's stiffness. We did this by attaching a fishing scale to the rubber band, and then hanging weight from the scale. Then we measured how far the rubber band had stretched. If two times the weight is added to the rubber band, the rubber band should also double in length. The elasticity can be determined by dividing the increment in force by the increment in length change.

Figure 7. In one experiment, two sliders can be stacked. Students can observe the earthquake behavior of two sliders in comparison to the behavior of just one slider.

Audience Participation in QuakeCaster Experiments

Because the audience becomes involved in the prediction process during experiments, it is easy for them to see why it is so difficult to predict earthquakes. When teaching with QuakeCaster, members of the audience will be asked to predict events based on force and time. For example, audience members will observe the time between events and then will state whether or not they believe the same amount of time passed between these events. Observations are crucial to their understanding of earthquake behavior. Then, audience members will time the actual amount of time between events, which will either confirm or negate their observations. We have used QuakeCaster with college students, middle-school students, and the general public. People have been quite vocal and eager to share their observations and predictions. In some instances, however, audience members have hesitated to share their thoughts for fear of being wrong. The beauty of QuakeCaster, though, is that there is no wrong answer! Observations are part of the prediction process in laboratory and real-life settings.

Figure 8. Volkan uses the fish scale to record the force before an event and the force immediately after an event, while Kelsey turns the fishing reel. In this trial, Volkan is also timing when each event occurs. However, it is easier to have a third person hold the lap timer, because it becomes difficult for one person to record the force and time. This experiment allows students to see if minimum or failure stress is a reliable predictor of earthquakes.

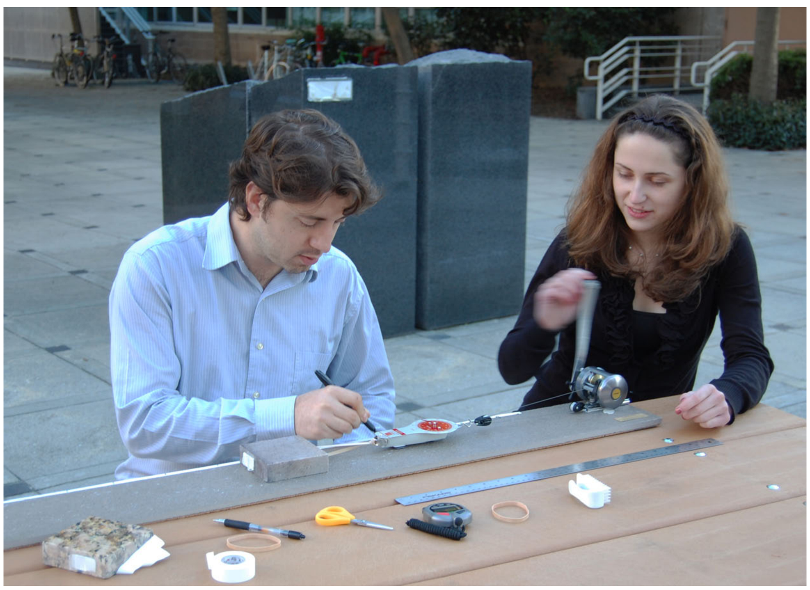

Figure 9. Volkan marks the rupture length for each event while Kelsey turns the fishing reel. A piece of white electrical tape was placed along the edge of the porcelain tile. Volkan marked the slider's front edge after each event. After marking rupture lengths, students can use a ruler to measure the distance between events.

Recommended QuakeCaster Teaching Sequence (a 1-pg 'cheat sheet')

Elements of the earthquake machine:

Explain what each part of QuakeCaster represents in the earth.
Despite steady motion of plate interiors, earthquakes are infrequent at boundaries. Slider is in frictional contact with tile; elastic crust; steady reeling of plates.

Are earthquakes regular or random in time and in size?

Experiment and ask for observations.
Run stacked sliders (one atop the other) once and ask for conclusions (regular in size and time?)
Slowly run sliders twice more, with one person marking and another timing quakes.
Roughly, how large is the coefficient of variation (standard deviation/mean)?
Are quakes time-predictable? (must crank super slowly to see >1 sec recurrence times
Notice that there are rare foreshocks—short hops before the big one.

Expectations for the behavior of large versus small quakes

Experiment with earthquake sizes and ask for predictions and observations.
Run single slider: Larger or smaller quakes; more or less frequent quakes?
Think of this in terms of a force balance; forces pulling vs. resisting motion.
1906 and1857 (2 stacked sliders rupture in M~8)) vs. Parkfield (1 slider ruptures in M~6) analogy & Landers counter-example (3 sliders in series that rupture together in M~7.

Failure stress any more predictable than the size and time of quakes?

Experiment to test the failure-stress hypotheses and ask for predictions and observations. Attach scale and let people come up and watch the dial during quakes.
Notice that we only see partial stress drop—force never goes to zero.
Take a look at the powder forming on the tile: fault gouge!
We only have one small section of the San Andreas Fault at Parkfield to measure stress.
Our inability to predict quakes does not mean they are unpredictable.

Coulomb failure criteria as an easy way in to a difficult problem

Change the conditions of an experiment and ask for predictions and observations. Lifting slider or pulling on rubber band triggers quake *when close to failure*.
Stress trigger: Distinction between causing and triggering quakes.
Stress shadow: Inhibiting quakes by adding slider or relaxing rubber band.

Concept of a long fault with many sections: sliders in series

Experiment to show how earthquakes talk to each other through the transfer of stress. Ask for predictions and observations.
Which slider goes first/second/third? Strong interactions and feedback.
North Anatolian sequence, doublets, aftershocks; parallel fault systems.

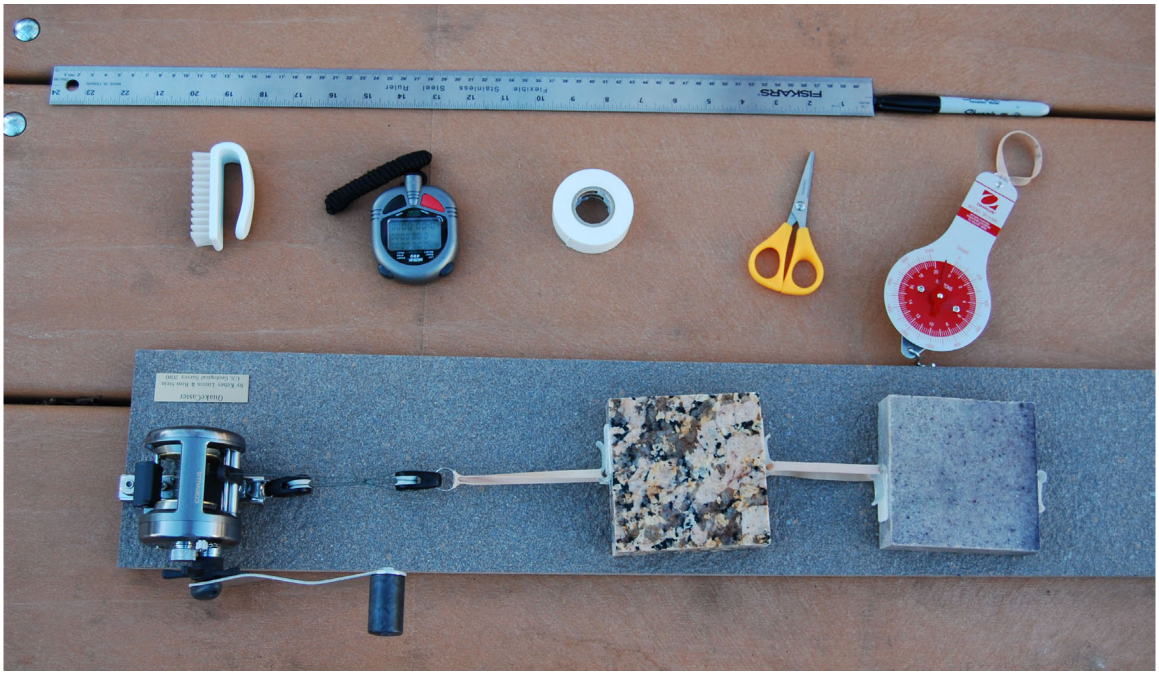

Figure 10. By attaching a rubber band between two sliders, students can see how earthquakes "converse" with one another through the transfer of stress. One student can turn the fishing reel, while the others can observe the sliders' interactions.

Conclusion

The results of QuakeCaster suggest that time- and slip- predictable hypotheses are not always reliable predictors of earthquakes. By carrying out QuakeCaster experiments, students can understand the difficulty scientists have in predicting earthquakes. The earth's behavior is not uniform, and earthquake occurrences don't always follow patterns. While we have only run a few tests using QuakeCaster, the model demonstrates how challenging it is to warn the public of the likelihood of an earthquake in a specific time period.

Acknowledgements

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Appendix: How to Build QuakeCaster and Parts Buying Guide

Parts and Equipment:

- 2-3 granite sliders
- 48 x 6 inches porcelain tile
- Sandpaper
- 4-6 photo clips
- Ruler
- Masking tape
- 3M 4200 Marine Adhesive Sealant
- Corvalus 300 fishing reel
- Custom handle to replace Corvalus handle
- Drill, screws
- Ronstan Series 19 Slide with Jib Sheet Fairlead and Spring-Loaded Track Stop, C-Track Traveler System, and Plastic End Cap
- 2 small pieces of rubber
- 2 pulleys
- Thin metal wire
- 1 keychain ring
- Cork
- Exacto knife
- Spray-on adhesive
- Size 64 rubber bands
- Force (stress gauge)
- Stopwatch
- Small brush
- White electrical tape
- Marker
- Pelican case
- Extra foam for Pelican case

Step 1:

- Gather materials.
    - Obtain at least 2 granite sliders. Each should be approximately 4 x 4 inches.

Step 2:

- Cut porcelain tile to desired length. This must be done by a tile-cutting company. In this experiment the tile has dimensions of 48 x 6 inches. Tile should be at least 24 inches long in order to see the full experiment.

Step 3:

- Prepare the sliders for use.
    - Using sandpaper, roughen the backs of 2 photo clips.

- Using a ruler, mark the center of one side of a slider. Also mark the center of the opposite side.
- Use a big dollop of 3M 4200 Marine Adhesive Sealant on the back of one photo clip. Attach it to the center of one slider's side. Let dry. Repeat for second photo clip and opposite side.
- Repeat previous step for second slider.

Photo clip attached to granite slider.

Granite sliders. Each slider is 4 x 4 inches.

Step 4:

- Prepare the fishing reel for use as a crank.
    - Remove the handle of the Corvalus 300 reel. Replace with a longer handle. This will lessen the weight you feel when turning the handle during the experiment, and it will decrease the amount of times you have to turn the handle to produce an earthquake. For this model, the handle is 7¾ in. long.

Custom 7¾ inch handle replaces Corvalus handle.

- Unscrew the handle on the *Ronstan Series 19 Slide.*
- Place reel on slide. Drill holes through reel's base in alignment with the slide's holes. Choose small screws to hold reel in place on slide. The screws cannot be too tall because it will be difficult to screw them in.
- Attach the reel to the slide.

Ronstan Series 19 spring-loaded track stop. Remove the handle.

Ronstan Series 19 Slide with Jib Sheet Fairlead and Srping-Loaded Track Stop. Handle is removed.

Step 5:

- Attach fishing reel to porcelain tile.
    - Tape over the top of the *Ronstan 19 Series Track* with a piece of masking tape. This will prevent glue from protruding through the holes.
    - Mark off one end of the track in order to leave one hole completely clear of glue. This will help when attaching the reel to the track.
    - Measure the furthest distance the reel can be placed from the tile's edge. Mark this point; the middle of the track will be placed here.
    - Place the middle of the track at this point. Using masking tape, tape around the edges of the track on the tile. This will provide a box for where to glue the track onto the tile.
    - Using a fair amount of West Marine's 4200 Marine Adhesive Sealant, glue over the bottom of the track. Do NOT put glue behind the marked end. One hole needs to remain open in order for the reel to attach to the track.
    - Glue the track onto the tile. Make sure the track is placed where the reel's handle has space to turn.

Front side of track.

Step 6

- After the glue has cured and the track is securely in place, put a piece of rubber under each side of the reel to prevent it from wobbling.
    - Slide the reel (now screwed onto the slider) onto the track (now adhered to the porcelain tile) and lock it into place.

Place rubber underneath the sides of the reel, which will be mounted on the track car

Step 7

- Set up a pulley system in order to alleviate the weight you feel when turning the handle.
    - Bend a thin metal wire at the bottom of the reel/slider to create an outline of a square. The metal wire can be attached to the front screw.
    - Before fully attaching the wire to the screw, add a pulley to the wire. Thread the spectra through the pulley. The Spectra is a low-stretch line. It is a trademark of Honeywell Int. It is braided filaments of high-modulus material used in sailing and finishing lines. Spectra can be bought online.

Spectra and pulley system.

- Continue to thread the spectra through a second pulley, bring the spectra back towards the reel, and then back towards the front pulley. Tie the spectra to the front pulley.

Pulley system reduces the weight you feel when turning the handle.

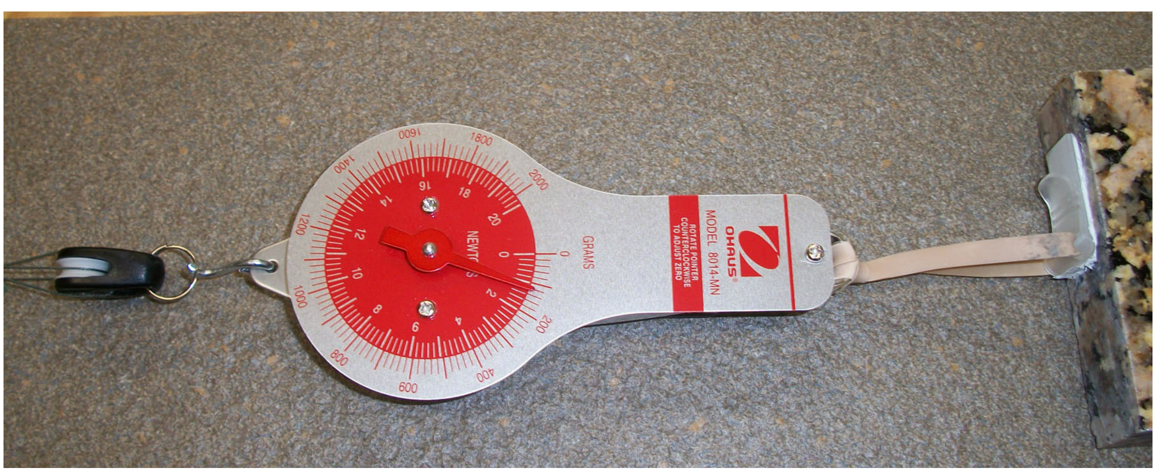
Front pulley.

Step 8

- Add a layer of cork to the bottom of the porcelain tile.
- Lay out cork over bottom of porcelain tile and cut, using an exacto knife, around the edges.
- Spray one side of the cork with Home Depot's spray-on adhesive and attach the cork to bottom of porcelain tile. Let dry.

Step 9

- Prepare the QuakeCaster for use.
    - Attach a size 64 rubber band to a photo clip on a granite slider.
    - Attach the *Ohaus* scale to the other end of the rubber band.
    - Link the scale with the pulley.

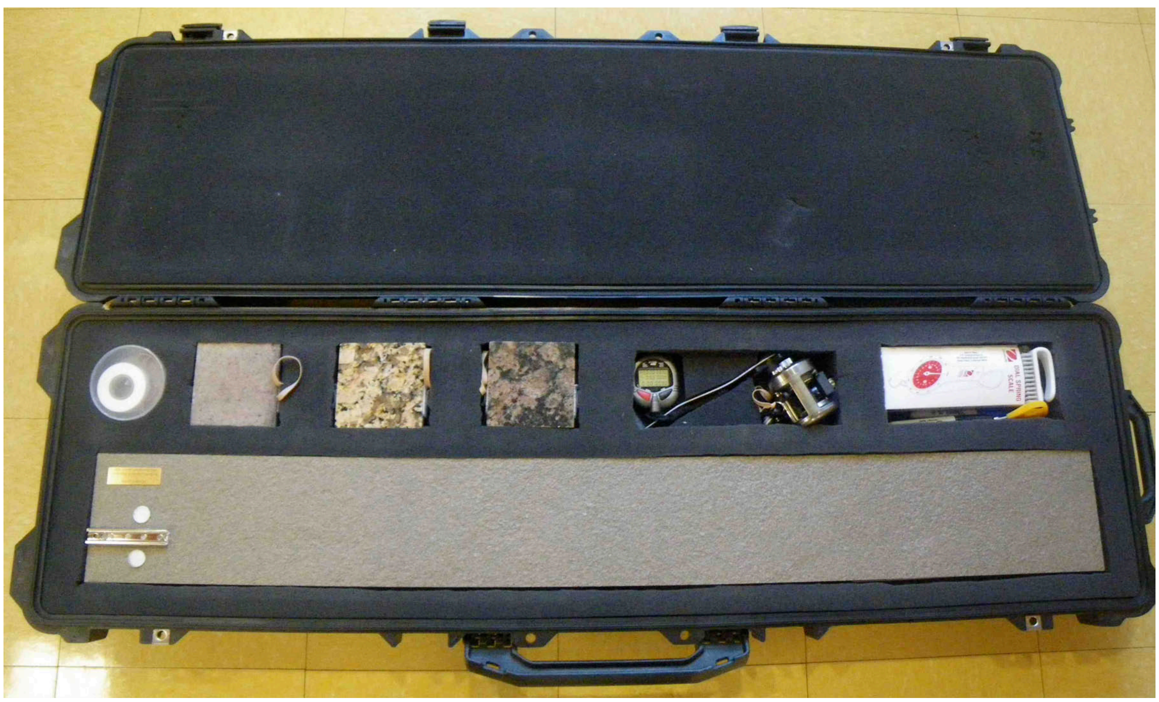


Pulley attached to Ohaus scale, which is attached to granite slider.

Stopwatch used to time quakes. Can store as many quake times in hundreths of sec (both quake interval, top number, and cumulative times, middle number) as desired, and then these can be scrolled through or downloaded to a PC.

Transport of QuakeCaster

Pelican case 1750 is designed for a shotgun, but fits perfectly. It has integral rollers (left side) and an end handle (right side of case), which is great at airports. With all gear inside, it weighs 38 lb. We put small carbiners from REI in the metal holes to make sure the case latches do not come open in transit.



Foam recesses for all parts so QuakeCaster survives airline baggage handling and airport security inspections. We carry a few Sharpie marker pens, scissors, tape, lots of extra rubber bands, and extra carbiners, in the case. We also carry a small shoe brush (far right) to remove the fault gouge that forms on the sliding surface.

Parts and costs for QuakeCaster*

*Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

This buying guide is based on locations nearest to the Bay Area, but most parts can be ordered online, and most cities offer the same services that we used, with suggested ways to find them below.

Total cost of parts ~$600

48” x 12” sliding surface
Roca Tile (48” x 12” high-friction rock-like tile, manufactured in Spain)
‘Packstone Arena’ Porcelain Tile - $48.00
Sacramento office:
Phone: 916-361-2222
Address: Morena Tile
9778 Business Park Drive Suite B
Sacramento, CA 95827
Pacheco office:
Phone: 925-827-5511
Address: 5749 Pacheco Blvd.
Pacheco, CA 94553

Any dealer for Roca Tile will ship you the 48” tile. You could use a different tile, but high-friction 48” tiles are uncommon. Website: http://www.rocatilegroup.com

Cutting the sliding surface to make it 48” x 6”
Bullnosing By Craftsman
Porcelain Tile Cutting - $20.00 (to cut the tile down to 48” x 6”)
Chris’s Cell: 925-595-3273
Address: 155 Nardi Lane, Suite F
Martinez, CA 94553

Any company that can cut a 48” long, 1/4” thick, porcelain tile will do. You do not need a “bullmose” (rounded) cut.

Granite sliders
Marble City Company
Granite Samples - Free
Phone: 866-234-6896

Address: 611 Taylor Way #6
San Carlos, CA 94070
Email: jhenderson@marblecitycompanyca.com
Website: www.marblecityca.com

Any kitchen counter marble company has samples.

Cutting granite sliders to 4” x 4”
Sticks ‘N’ Stones
Granite Cutting - $30.00
Phone: 650-592-9380
Dave Walter’s Cell: 650-670-0116
Address: 947 Center Street
San Carlos, CA 94070
Email: stnst@sonic.net
Website: www.sticksnstonesinc.net

Any granite cutting company can cut the 4” x 4” sliders.

Fishing reel and marine adhesive sealant
West Marine
Corvalus 300 fishing reel - $90.00
3M 4200 Marine Adhesive Sealant - $13.00
Website: http://www.westmarine.com/

Ronstan Series 19 Slide with Jib Sheet Fairlead and Spring-Loaded Track Stop, C-Track Traveler System, and Plastic End Cap
Ronstan International Inc.
Ronstan Series 19 Plastic End Cap (RC81980) - $3.21
Ronstan Series 19 Slide with Jib Sheet Fairlead and Srping-Loaded Track Stop (RC81944) - $60.00
Ronstan Series 19 C-Track Traveler System (RC8190-0.3) - $15.00
Phone: 1-401-293-0596
Alan Prussia, Northern CA Rep’s Cell: 510-523-3600
Address: 45 High Point Avenue, #2
Portsmouth, RI 02871
Email: office@ronstan.us
Website: http://www.ronstan.com/

Pelican Case
Pelican Products, Inc.
Pelican 1750 Long Case - $220.00
Phone: 310-326-4700

Address: 23215 Early Avenue
Torrance, CA 90505
Email: sales@pelican.com
Website: http://www.pelican.com/

Extra foam for Pelican case
Tallman's House of Foam
Extra foam for Pelican case $14.00
Phone: 650-327-4300
Address: 150 Hamilton Avenue
Palo Alto, CA 94301-1618
Website: http://www.houseoffoam.net/
Any foam company can sell extra pieces of foam.

Ohaus Spring Scale
Tech support 800-672-7722 Spring scale with clock face
http://us.ohaus.com/us/en/home/products/product-families/DIAL-US.aspx
size of 2kg unit (8014-MN),
Any spring scale will do, but it is helpful to have an easy-to-read scale.

Cork, spray-on adhesive, white electrical tape
Home Depot, Lowes, or Michaels
Cork glued to base of tile - $10.00
Adhesive - $10.00
White electrical tape - $4.00
Website: www.homedepot.com
Any building supply store will have these materials.

Rubber bands, photo clips
Office Depot
Size 64 rubber bands - $5.00
Photo clips - $4.00
Website: www.officedepot.com
Any office supply store will have these materials.

Stopwatch for recording a succession of quake times
Ultrak 499 stopwatch (can connect to a PC*) $68.75*
Fitzones/Stopwatchcentral
Galt, CA
www.stopwatchcentral.com

Load cells and indicator panels (not yet tried)
http://www.lcmsystems.com/tension_load_cells.html