The Spring-Block Model of Earthquakes

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The purpose of this experiment was to determine if a simple spring-block model using stick-slip friction could be used to model complex events such as earthquakes. Four wooden blocks were connected in a row using springs. Then a reel was used to pull a string attached to the first block at a constant velocity adding energy to the system. When enough energy was added, the blocks moved. The distance the blocks moved was related to the amount of energy the blocks released. A distribution of the distance the blocks moved versus the number of times that distance was seen, showed that the spring-block model successfully mimicked a plot of the Gutenberg-Richter law. This verified that the spring-block model was able to illustrate trends seen in the behavior of earthquakes.

INTRODUCTION

The origin of earthquakes has been debated for many years throughout the course of history. A suitable proposal was not found till the 1900's and even then was not accepted till a much later time. The idea of plate tectonics was first presented by Alfred Wegener [3] in 1912, but was not respected until the 1960's. This theory says that the Earth's lithosphere consists of many solid slabs of rock, which have evolved from the breakup of Pangaea, the ancient super-continent. These sub-layers in the Earth's crust extend 80 to 200 kilometers into the Earth's interior. The plates are in constant motion due to the production of heat given off from the decay of radioactive elements in the rocks in the interior of the earth [1].

The boundaries of tectonic plates come together in three main forms: rift zones, subduction zones, and transform faults. The rift zones occur around the oceanic ridge, when two plates move away from each other allowing new magma to rise and create a new piece of the lithosphere. Subduction zones occur near coastlines when the oceanic plate goes underneath the continental crust. Lastly the transform faults are produced when two plates converge together or slide past one another [2].

The two places where plates meet which are most pertinent to this experiment are at subduction zones and transform faults. As the tectonic plates move past and grind against each other they cause friction. The friction resists the plates from moving until enough stress builds up to overcome the friction. When that happens, the plates slip past each other releasing a tremendous amount of energy in the form of an earthquake. This principle provides the basis for my experiment, modeling earthquakes through the use of stick-slip friction.

Over the years there have been many ways to model earthquakes. Though none have been able to predict earthquakes. The general test for determining if a model is acceptable is if the model follows the Gutenberg-Richter law. The Gutenberg-Richter law relates the number of occurrences of a certain size earthquake to the number of occurrences of a different size earthquake [3]. A visual representation of the Gutenberg-Richter law can be seen in Figure 1.

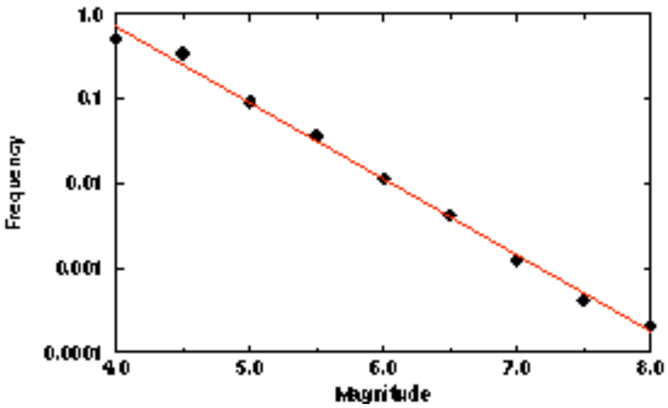

Figure 1: An example of the Gutenberg-Richter law. The data was taken from earthquakes that occurred around the world in 1995 From Reference [4].

The Gutenberg-Richter law is a power law, as seen in Equation 1, From Reference [4]

$$F(m) = A \cdot 10^{-m} \quad (1)$$

where F(m) is the frequency of a given magnitude earthquake, *A* is a proportionality constant, and *m* is the magnitude of the earthquake. The Gutenberg-Richter law is a straight line on a log-log plot of the frequency of an earthquake versus the energy it released; The slope of that line is approximately -1 [4]. The "Magnitude" comes from the Richter scale, in which the numbers are allocated based on the $\log_{10}$ of the energy released.

One of the first spring block models used to illustrate the Gutenberg-Richter law was the Burridge-Knopoff model [2], made in 1967. This model, based on differential equations, used many blocks connected in succession with springs and then all of the blocks were connected to a board moving at a constant velocity. As the board moved, some of the blocks moved with it and some did not. The energy given off by the moving blocks was based on which blocks moved. An illustration of the Burridge-Knopoff model is seen in Figure 2.

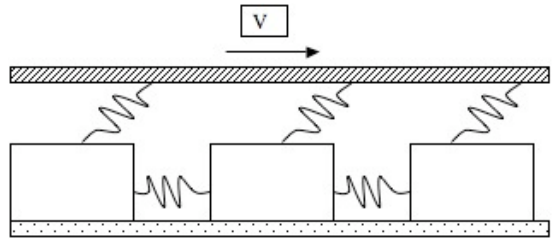

Figure 2: Example of the Burridge-Knopoff model for earthquakes.

In my experiment, I used a model very similar to that of Burridge and Knopoff to verify the Gutenberg-Richter law. One of the differences was that where the Burridge-Knopoff model attached every block to a moving board, I attached the spring connected to the first block to a string on a reel. The reel was then used to pull the string at a constant velocity. The model is shown in Figure 3.

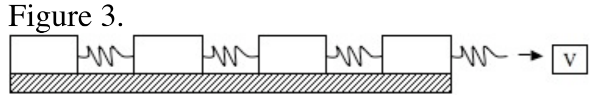

Figure 3: A diagram of the model used in this experiment.

EXPERIMENT

To create a working model for the experiment many items were required. Four hardwood blocks of the same material that were 15.5x7.5x4 cm were needed. Next, five springs that are the same length at equilibrium, and have the same spring constant. Then 14, 7.94 mm staples and staple gun were used to connect the springs to the blocks. Next, four pieces of clear plastic with dimensions of 15.5x0.20x9.0 cm were required. The pulling device used was a reel and one meter of string. Then 16 Number 6 screws roughly 1.5 cm in length were used. Next, eight small pieces of wood with dimensions 15.5x2.7x0.5 cm were required. Black acrylic paint and paintbrush were necessary. An Apple computer with OS 10, Data Studio and a Science Workshop 750 Pasco Interface was used. Finally, four Pasco Scientific ME-9204A Photogates were required.

The first part of building the apparatus was connecting the four blocks together. This was done using a staple gun to connect one end of the spring to a block, and the second end of the same spring to another block. The process was repeated until the four blocks were connected in a row with springs between them. A final spring was attached to one of the outer blocks, which was used to apply stress to the system.

A striped pattern stencil was then created on the clear plastic so that it could be used to determine the distance each block moved. A “picket fence” pattern was used because it allowed Pasco Scientific ME-9204A photogates to be used to determine the distance each block moved. In the pattern, the stripes and the spaces between them all had a width of $(0.5 \pm 0.1)cm$.

Four photogates were positioned, with one in front of each block. Then Data Studio was used to monitor the motion of each block. The data was collected in the form of a graph showing the distance recorded by each photogate versus time. An examples of a data runs from the experiment is seen in Figures 4.

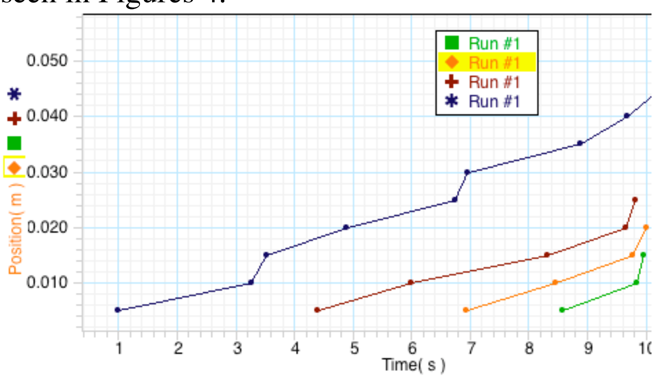

Figure 4: An example of the data obtained from Data Studio, using photogates to monitor the movement of each block, with each line representing a different block.

Figure 4 shows the raw data as received from Data Studio. The graphs show the position of each block at a given time, and from those positions the distance each of the blocks moved was inferred. A total of 25 data runs were conducted in order to obtain a distribution of the distance the blocks moved.

ANALYSIS AND INTERPRETATION

To determine if the model used in the experiment was accurate, the information collected in the experiment needed to be compared to the Gutenberg-Richter law. The results of the log - log plot are seen in Figure 13.

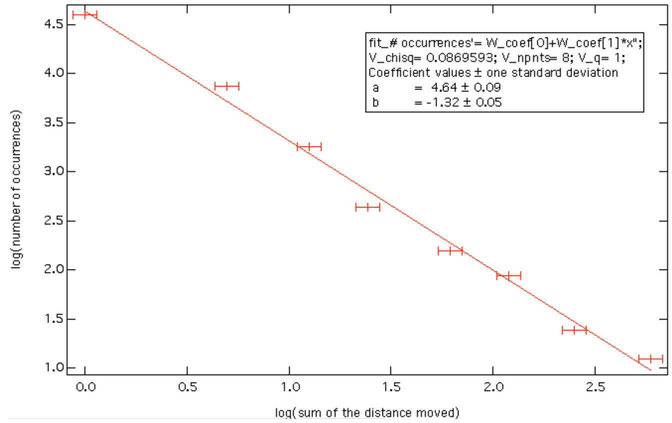

Figure 5: A logarithmic plot of the number of times a distance occurred versus the sum of the distances the blocks moved.

The plot in Figure 5, showed exactly what was expected. When the log of the number of occurrences of a given distance was plotted against the log of that distance, the data could be fit with a straight line. The *b* value in Figure 13 shows that the slope of the line is -1.32 ± 0.05, which is very close to the expected value of -1 as seen in the power-law from Equation 1. The *a* value shows the proportionality constant. The error bars were 0.06 cm because of the spacing between the bands. With the error bars added, the graph showed that the data was very similar to a plot of the Gutenberg-Richter law. This was very important and showed that the model could be used to study the behavior of earthquakes.

CONCLUSION

Based on the results of this experiment, it was shown that even very simple ideas such as spring-block models, can be used to imitate extremely complex events such as earthquakes. The data collected from the experiment was very close to what was expected; a straight line on a log-log plot. Similar to the Gutenberg-Richter law, I obtained a power of -1.32 ± 0.05 which was very close to the accepted power of -1. These results helped verify the validity of the stick-slip model.

ACKNOWLEDGMENTS

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1. Bruce A. Bolt, *Earthquakes* (W. H. Freeman and Company, New York, 1999), Fourth Edition, p. 137-139..
2. Agustin Udias, *Principles of Seismology* (Cambridge University Press, New York, 1999), p. 384-393.
3. Per Bak, *How Nature Works* (Springer-Verlag New York, Inc., New York, 1996), p. 85.

4.http://simscience.org/crackling/Advanced/Earthquakes/GutenbergRichter.html