GEOS 100 – Fundamentals of Geology

LAB 2: Predicting Earthquakes

Big-Picture Questions:

– *How do earthquakes release energy through strain accumulation and elastic rebound?*

– *Can any aspects of earthquakes be predicted?*

– *How can earthquakes be described mathematically?*

Materials Required:

– Earthquake Machine model
– stop watch
– pencil
– calculator
– ruler or straight-edge

PART A – Getting Acquainted with the Earthquake Machine Model (*20 points*)

At your lab table is an Earthquake Machine, which is a model we will use to gather data to help us explore the behavior of earthquakes. Your lab instructor will provide a brief introduction to the Earthquake Machine and how it is operated. After that introduction, answer Questions A.1–A.3 below.

A.1) By drawing lines between terms, match each model component below to its physical representation. (*1 pt*)

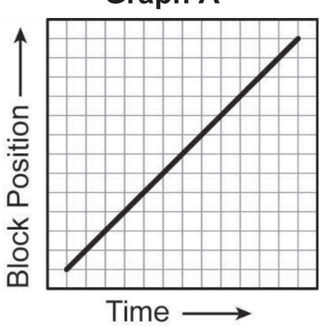
Crank	Earthquake
Distance Block Moves	Earthquake Magnitude
Moving Block	Tectonic Force
Sandpaper	Tectonic Plate
Wooden BlocK	Tectonic Plate Boundary

A.2) In the Earthquake Machine model, what type of energy does the rubber band have? (*1 point*)

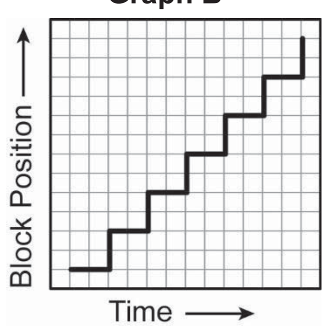
A.3) In the Earthquake Machine model, what type of energy does the moving block have? (*1 point*)

Below are four hypotheses (Graphs A–D) describing motion of the wooden block in the Earthquake Machine model. Before starting the model, observe Graphs A–D, and use your observations to answer Questions A.4–A.11.

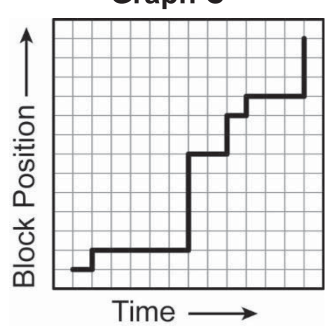
Graph A



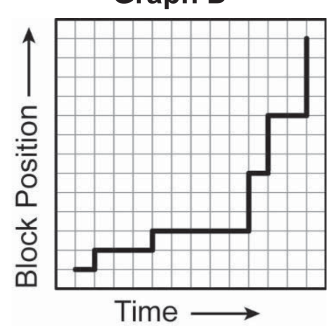
Graph B



Graph C



Graph D



A.4) In what way(s) are Graphs A–D similar? (*1 point*)

A.5) In what way(s) is Graph A different than the others? (*1 point*)

A.6) What feature(s) in the graphs represent(s) an earthquake in the model? (*1 point*)

A.7) In Graphs B, C, and D, the horizontal lines represent _______________ energy and the vertical lines represent _______________ energy. (*1 point*)

A.8) In what way(s) is Graph B different from Graphs C and D? (*1 point*)

A.9) In what ways(s) is Graph C different from Graph D? (*1 point*)

A.10) What could you predict about earthquakes if they followed the pattern in Graph B? C? D? (*1 point*)

Graph B: Graph C: Graph D:

A.11) Hypothesize about which graph (A, B, C, or D) best represents how the block will actually move when you run the model, and explain your reasoning. (*2 points*)

Let's test your initial hypotheses by using the Earthquake Machine to collect some basic *qualitative data* (i.e., data described by words, rather than numbers). To run the model, one of your group members should slowly and steadily turn the crank. All group members should make observations about the movement of the wooden block, and answer Questions A.12 – A.13 below.

A.12) Describe how the block moved. Do your observations lead you to change your answer to Question A.11? If so, how was the actual block motion different than your expectation(s)? (*1 point*)

A.13) What term do geoscientists use to describe the type of motion displayed by the Earthquake Machine? (Feel free to use your textbook and/or notes to answer this question.) (*1 point*)

Before moving on, let's take a look at some terms and units we can use to describe the physical parameters in our Earthquake Machine model. Use Appendix 1 to answer Questions A.14–A.25.

A.14) Write an equation describing the *velocity* of the wooden block. (Appendix 1 may be helpful.) (*0.5 point*)

A.15) Using SI base units, what is an appropriate unit for velocity? (*0.5 point*)

A.16) Write an equation for the *acceleration* of the wooden block. (Appendix 1 may be helpful.) (*0.5 point*)

A.17) Using SI base units, what is an appropriate unit for acceleration? (*0.5 point*)

A.18) Use your answer to Question A.15 to explain your answer to Question A.17. (*0.5 point*)

A.19) Write an equation for *force* exerted on the wooden block. (Appendix 1 may be helpful.) (*0.5 point*)

A.20) Using SI base units, what is an appropriate unit for force? (*0.5 point*)

A.21) Use your answer to Question A.17 to explain your answer to Question A.20. (*0.5 point*)

A.22) Write an equation for *pressure* exerted on the wooden block. (*0.5 point*)

A.23) Using SI base units, what is an appropriate unit for pressure? (*0.5 point*)

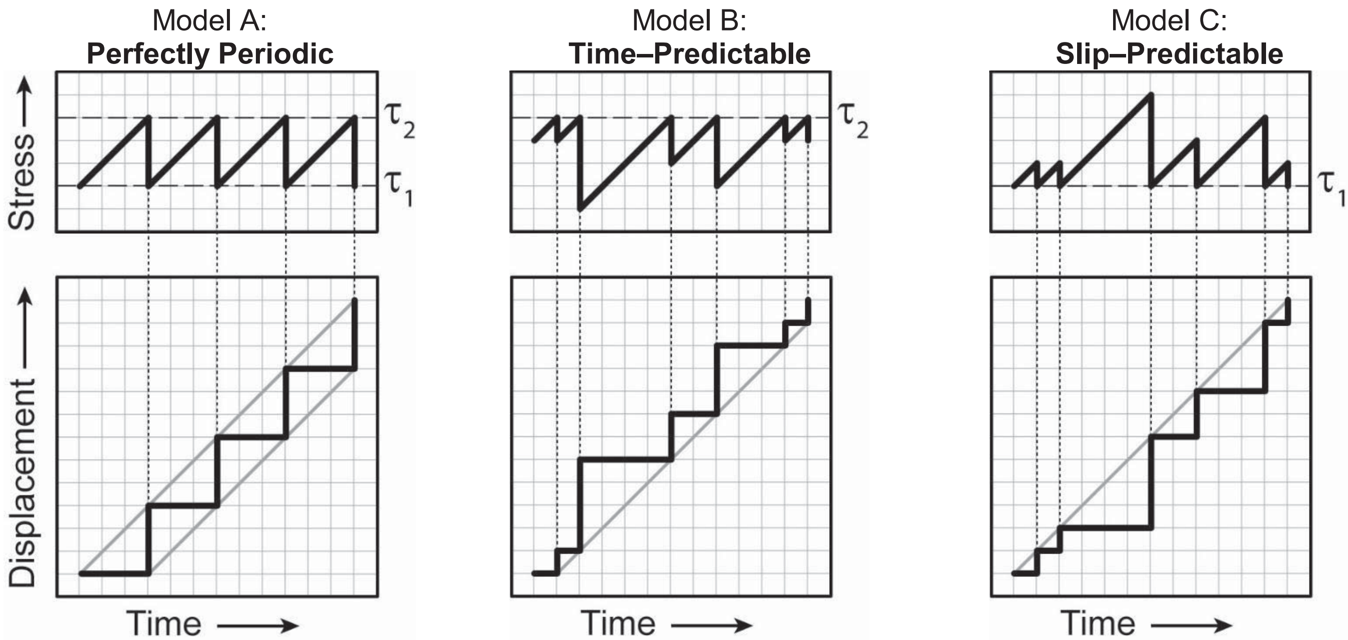
A.24) Use your answer to Question A.20 to explain your answer to Question A.23. (*0.5 point*)

A.25) What is the name of the derived SI unit for pressure? (*0.5 point*)

Similar to pressure, *stress* is also force per unit area. In the Earthquake Machine model, the type of stress (i.e., pressure) exerted on the wooden block is called *shear stress*. Shear stress is usually represented by the lowercase Greek letter tau (τ). The difference in τ when the wooden block slips can be represented as $\Delta\tau$, where the uppercase Greek letter delta (Δ) means "change in".

PART B – Testing the Validity of Earthquake Prediction Models (*30 points*)

The notion that some aspects of earthquakes might someday be predicted may not be too far-fetched. Our current understanding of earthquake behavior is described by Elastic Rebound Theory, which the Earthquake Machine demonstrates quite well. This theory, combined with the observation that large earthquakes on a least some faults (Shimazaki and Nakata, 1980) occur "quasi-periodically" – i.e., with some degree of regularity – implies that we might be able to measure 1) plate velocity along a fault, 2) accumulated strain on the fault, 3) movement on the fault during the last earthquake, and/or 4) the amount of time since that last earthquake in order to predict when the next earthquake will occur and/or how much displacement will occur during that next earthquake. Let's begin our exploration of this idea by looking at a few theoretical models for predictable earthquake behavior:



In the Perfectly Periodic model, earthquakes always happen when shear stress on a fault reaches the same high value, and each earthquake causes stress level on the fault to drop to the same low value. The same amount of movement that occurs during each earthquake, and the time between earthquakes is always the same.

If the Perfectly Periodic model is correct, we can measure 1) plate velocity along a fault, 2) the amount of time since the last earthquake on that fault, and 3) the amount of displacement during that earthquake, in order to *predict 1) when the next earthquake will happen and 2) how big it will be*.

In the Time-Predictable model, earthquakes always happen when shear stress on a fault reaches the same high value, but the size of the earthquakes is variable – so each earthquake causes stress level on the fault to drop to a different low value.

If the Time–Predictable model is correct, we can measure 1) plate velocity along a fault and 2) the amount of displacement during the last earthquake on that fault in order to *predict when the next earthquake will happen* – i.e., the next earthquake will happen when enough plate movement has occurred to reach the critical shear stress.

In the Slip-Predictable model, the shear stress at which earthquakes on a fault occur is variable, but earthquakes always cause stress levels to drop to the same low value.

If the Slip–Predictable model is correct, we cannot predict when the next earthquake will occur, but we can measure 1) plate velocity along a fault and 2) the amount of time since the last earthquake on that fault in order to *predict how big an earthquake would be for various time scenarios* – i.e., the longer the time since the last earthquake, the bigger the next one will be.

Use your observations of Models A–C to answer Questions B.1– B.11.

B.1) What aspect(s) of Models A–D are similar to the graphs you observed in Part A of this activity? (*1 point*)

B.2) Using an arrow and the symbol "EQ" on one of the models above, label an "earthquake". (*1 point*)

B.3) Using an arrow and the symbol "PE" (for "potential energy") on one of the models above, label an interval of time during which elastic strain is accumulating. (*1 point*)

B.4) What do the heavy black diagonal lines in Models A–D represent? (*1 point*)

B.5) What might be an appropriate unit for the heavy black diagonal lines in Models A–D? (*1 point*)

B.6) Generally, what physical parameter does the symbol τ represent? (*1 point*)

B.7) What do τ_1 and τ_2 in Models A–D represent? (*2 points*)

B.8) How are each of the earthquakes in Model B different? How are they similar? (*1 point*)

B.9) How are each of the earthquakes in Model C different? How are they similar? (*1 point*)

B.10) In Models A and B, what determines when an earthquake will occur? (*1 point*)

B.11) Assuming we can accurately measure 1) plate velocity and 2) the age and size of past earthquakes, what can we predict about earthquakes if their behavior is best described by Model A? Model B? Model C? (*1.5 pts*)

Model A:

Model B:

Model C:

Our Earthquake Machine is a physical model that will help us to test whether any of the three theoretical models (Perfectly Periodic, Time–Predictable, Slip–Predictable) for earthquake prediction has any relationship to reality. To test this hypothesis, conduct an experiment using the Earthquake Machine. In order for the experiment to go smoothly, each member of your group should fulfill one of the following roles:

PLATE TECTONICIST

Your job is to:

– ensure that the front edge of the block (i.e., the edge nearest the crank) is at the 0 cm mark at the beginning of the experiment
– turn the crank slowly and <u>steadily</u>
– start the stopwatch when you begin turning the crank
– pause the crank and the stopwatch each time the wooden block slips

PLATE VELOCITY RECORDER

Your job is to:

– read the elapsed time (in seconds) at which each slip event occurs
– calculate the average velocity (in centimeters per second) at which the measuring tape is being reeled in by the Plate Tectonicist
– record your measurements in Table B.2

MAGNITUDE RECORDER

Your job is to:

– measure the distance (in centimeters) the wooden block moves during each slip event – we will call this distance "magnitude"
– record your measurements in Table B.2

FORCE RECORDER

Your job is to:

– measure the amount of force (F, in Newtons) on the spring scale before (F_i) and after (F_f) each slip event
– record your measurements in Table B.2

B.12) Summarize your hypothesis regarding the predictability of the timing and magnitude of earthquake events. (*3 points*)

B.13) Explain how you will test your hypothesis. (*3 points*)

Table B.1 – Block Measurements (*1.5 points*)

Mass (g):	
"Fault" Area (cm^2)	
Average "Plate" Velocity (cm/s)	

Table B.2 – Results from Earthquake Machine Experiment (*2 points*)

Slip Event	Time (s)	Magnitude (cm)	F_i (N)	F_f (N)	$F_i - F_f$ (N)	$\Delta\tau$ (Pa)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Once you have finished your experiment and recorded your data, answer Questions B.14–B.16.

B.14) Interpret your results, and answer the experimental question: Can earthquakes be predicted? Why or why not? (You may need to create a graph to help answer these questions…) (*4 points*)

B.15) In what way(s) is our model a good simulation of real earthquakes? (*2 points*)

B.16) Describe some of the major limitations of our model and experiment? (*2 points*)

PART C – Predicting Duration and Magnitude of Aftershocks (*15 points*)

An *aftershock* is no different than any other earthquake, except that it results from – and follows closely after – a larger-magnitude earthquake called a *mainshock*. Like other earthquakes, aftershocks can be destructive if they have a high magnitude and/or occur in areas where the local soil, bedrock, or structures are susceptible to a high degree of shaking. Given their temporal proximity to larger earthquakes, aftershocks can contribute substantially to public uncertainty and fear – particularly if the mainshock was very destructive.

The good news is that some aspects of aftershock earthquakes can be predicted! Way back in 1894, the pioneering Japanese seismologist Fusakichi Omori described an *empirical* (i.e., derived from observation of real-world data) relationship between the number of aftershocks and the amount of time after the mainshock. Omori's empirical law was modified by another Japanese seismologist named Tokuji Utsu in 1961 to give the expression we use today, called the *Omori-Utsu Law*:

$$N(t) = K(t + c)^{-p}$$

in which $N(t)$ is the number of aftershocks as a function of time (i.e., the number of aftershocks, N, for a given time, t, after the mainshock), t is the amount of time following the mainshock, measured in days (not calendar days, but 24-hour intervals following the exact moment of the mainshock), c and K are constants (that we won't worry too much about right now), and p is a variable called the *decay rate*. The decay rate is a very useful number that can help us predict the number of aftershocks for a given time after the mainshock and/or when aftershock seismicity will decay to background levels.

Before we try to use calculate the decay rate in order to make predictions, let's look at graphical representations of a simpler version of the Omori-Utsu equation. Use your observations of the figure presented by your instructor to answer Questions C.1–C.4.

C.1) Describe the general shape of the functions. (*1 point*)

C.2) How do you think the functions would look different if p were positive? (*1 point*)

C.3) Which function approaches zero the fastest? Which decays the slowest? (*1 point*)

C.4) Since we're using a simplified version of the Omori-Utsu equation, we are ignoring the constants c and K. Looking at the graphs, explain why the constant c is necessary to relate this equation to a physical process in the real world. (Hint: Does it make sense to think about aftershocks if $t < 0$? (*2 points*)

Use the Omori-Utsu Law to answer Questions C.5–C.7. Below are some logarithm rules that may be helpful to you:

$$\log x^y = y \log x \qquad \log x/y = \log x - \log y$$

C.5) Rearrange the Omori-Utsu equation to solve for K. Show your work. (*2 points*)

C.6) Rearrange the Omori-Utsu equation to solve for p. Show your work. (*2 points*)

C.7) Suppose a M7 earthquake strikes central Idaho. Within the first 24 hours after the mainshock, there 677 aftershocks were measured. On the third day after the mainshock, 211 aftershocks were measured. **Assuming c = 0.05** (a typical value), **find the decay rate (*p*) for this aftershock sequence. Show your work.** (*Hint*: Do you need to know a value for *K* in order to answer this question? Can you manipulate the equation using the log rules above in order to solve for *p*? Your instructor has a step-by-step example of how to solve this problem, but your group will earn 3 bonus points if you can solve it without that help!) (*3 points*)

C.8) Using the information in Question C.7 and the decay rate you calculated there, determine the number of aftershocks this area should expect 30 days after the mainshock. (*3 points*)

Before leaving lab, turn in the following to your lab instructor:

1) Pre-Lab 2 (via Blackboard)
2) Completed Tables 1 – 4
3) Your answers to Questions 1 – 19
4) Post-Lab 2 (via Blackboard)

APPENDIX 1

SOME COMMON PHYSICAL PARAMETERS IN THE INTERNATIONAL SYSTEM (SI) OF UNITS

SI Base Units:

Distance = meter (m)
Mass = kilogram (kg)
Time = second (s)
Temperature = Kelvin (K)

		Base Units:		*Derived Unit*:
Velocity =	Distance/Time	$m \cdot s^{-1}$		
Acceleration =	Velocity/Time	$m \cdot s^{-2}$		
Force =	(Mass)(Acceleration)	$kg \cdot m \cdot s^{-2}$	=	Newton (N)
Work =	(Force)(Distance)	$kg \cdot m^2 \cdot s^{-2}$	=	Joule (J)
Pressure =	Force/Area	$kg \cdot m^{-1} \cdot s^{-2}$	=	Pascal (Pa)
Power =	Work/Time	$kg \cdot m^2 \cdot s^{-3}$	=	Watt (W)