The Government of the Republic of Trinidad and Tobago

MINISTRY OF EDUCATION

NIHERST

UWI SEISMIC RESEARCH CENTRE

Earthquakes Volcanoes Tsunamis

Seismology in Schools Programme

Trinidad and Tobago

Physics Workbook

"Earthquakes traveling through the interior of the globe are like so many messengers sent out to explore a new land. The messages are constantly coming and seismologists are fast learning to read them."

Reginald Aldworth Daly,

In Our Mobile Earth (1926)

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Introduction

Seismology is the study of seismic waves, most commonly experienced as earthquakes. Earthquakes occur when strain energy accumulates slowly within the Earth's crust due to tectonic plate motion and then is released suddenly at fractures in the crust called faults. This workbook aims to help students grasp fundamental concepts covered by the Caribbean Secondary Examination Certificate (CSEC) syllabus for Physics by exploring real-world applications of these concepts using basic principles of seismology. Activities presented in this workbook are linked to specific objectives detailed in the syllabus which will hopefully assist teachers in implementing the curriculum's module concepts and objectives through a hands-on and practical approach geared to reinforcing theoretical concepts.

The workbook covers a range of topics including: waves and optics, forces, earth deformations, Newton's Law and elements of seismology that are applicable to Physics. Students will be able to learn about the many applications of seismology and are challenged to develop knowledge and skills unique to the earth sciences.

Seismologists use earthquake data to monitor plate boundaries and prepare seismic hazard maps for earthquake-prone countries. They also analyse seismic waves to determine characteristics of earthquakes such as their location and magnitude. This workbook offers students a resource to better understand the science of earthquakes and their impact on students' own lives.

Seismology in the Classroom

Seismology can be used to demonstrate aspects of mechanics and waves optics which are outlined in the Caribbean Secondary Entrance Certificate (CSEC) Physics syllabus. The SIS Physics workbook is specifically designed to aid in the teaching of the aforementioned topics through a series of practical experiments and activities which are supported by the SIS kit box and the SEP Seismometer. This workbook can be used to reinforce the critical aspects of these broad topics, as students are encouraged to consider and discuss the following:

- What is an earthquake?
- What are the types of waves generated from an earthquake?
- What is deformation and how is it related to the Earth?
- What are the different wave parameters associated with earthquakes?
- What are some basic principles of earthquake engineering and design including the importance of a solid foundation, wide base, symmetrical design, and trusses?

The SEP Seismometer System

This is a basic seismometer utilising a ‘garden gate’ design that oscillates from side to side when the ground beneath its rigid frame is disturbed either by local activity or seismic activity. The seismometer’s design and operation can be used to illustrate basic concepts in Physics and general seismology. This workbook can be used to reinforce specific syllabus objectives listed. Students are encouraged to explore topics such as: forces, types of waves, aspects of seismometer design and detection & location of earthquakes using seismometers. This is all done using real earthquake data from local SEP seismometers (Figure 1) and stations around the world, as well as software known as jAmaSeis.

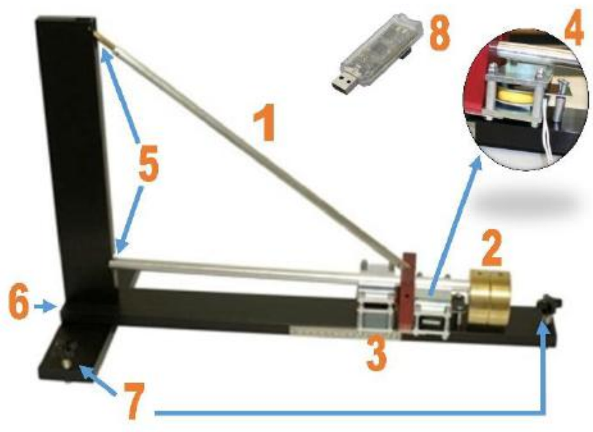


Figure 1: The SEP Seismometer

Key

1. Rigid suspension arm or moving boom
2. Brass mass
3. Magnetic eddy current damping -
4. Magnetic and coil velocity transducer - Uses electromagnetic induction to detect ground motion (velocity) and eddy current damping.
5. Pivot points – To allow the moving boom to oscillate freely.
6. Rigid Frame (Long base part, short base part and upright part)
7. Levelling screws – To adjust the horizontal level of the rigid frame and boom which must be centred.
8. USB Digitizer – To connect to your computer with jAmaSeis.

The Seismology Kit Box

This workbook is designed to be used with the equipment in the seismology kit box, but several of the activities can be implemented without the kit box equipment. Teachers and students can adapt the activities uniquely for different teaching needs. The activities have been designed to cater to a wide range of ages (approximately 8-18) and different stages of learning. The activities are designed to be as interactive and informative as possible, and to prompt engagement within the classroom.

The Contents of the Seismology Kit Box

Key

1. Geophysics foam Earth
2. Plastic container
3. Marbles of various sizes
4. Spaghetti sticks
5. Marshmallows
6. Slinky model
7. Microphones
8. 3.5mm audio jack combiner
9. 3 types of wooden fault block models
10. Auxiliary extension cable
11. Earthquake simulator model
    - Concrete brick
    - String
    - Newton meter
    - Pulley
    - Sandpaper board
    - Meter Rule

Teacher Preparation

To make the best use of this resource, teachers are required to be comfortable with concepts of wave theory and optics in addition to having a working knowledge of the jAmaSeis software. The IRIS website is a great tool for accessing real time earthquake data, and the British Geological Survey is one of the leading geological survey websites. All resources can be found at the website links below.

- Incorporated Research Institutions for Seismology: http://ds.iris.edu/
- The British Geological Survey: http://www.bgs.ac.uk/
- jAmaSeis Software Download: http://www.iris.edu/hq/jamaseis/

In addition to this, teachers can contact the SIS Team directly if further assistance is needed in the interpretation and delivery of the activities or lesson plans in this workbook via the Facebook page ‘Seismology in Schools – Trinidad and Tobago’ and the Edmodo platform at the following links:

1) Facebook page:
   https://www.facebook.com/Seismology-in-Schools-Trinidad-and-Tobago
2) Edmodo page:
   https://www.edmodo.com

Instructions for Edmodo.com

- The Online Learning Community can be accessed from the following website: http://www.edmodo.com/home
- If you already have an Edmodo account, **Login** and **Join** using the Group code **(ce5ags)**
- If you **don't** have an Edmodo account, to sign in, Click on **I’m a teacher**
- Type in group code **(ce5ags)** and **fill out the requested information**
- Copy your username and password and click **sign up**
- The next time you enter the website type in your username and password and click **login.**

CARIBBEAN SECONDARY EDUCATION CERTIFICATE (CSEC)

CURRICULUM SPECIFICATIONS AND CLASSROOM ACTIVITES

Curriculum Links and Activities

Curriculum Specification			**Seismology Activities**
CSEC Physics Syllabus 2015			
Section A: Mechanics			
Forces	3.1	explain the effects of forces	Forces :Activities 1-4
Deformation	3.13	investigate the relationship between extension and force	
Hooke’s Law	3.14	solve problems using Hooke’s law	
Energy	5.1	define energy	
Section C: Waves and Optics			
Types of Waves Wave Parameters	1.1	differentiate between types of waves	Waves: Activities 5-9, 10, 12 & 13
	1.2	apply speed, frequency, wavelength, period and amplitude	
	1.3	represent transverse and longitudinal waves in displacement position and displacement-time graphs.	
Sound: Production and propagation	2.1	describe how sound is produced and propagated in a medium	Sound: Activity 11
	2.2	relate the terms ‘pitch’ and ‘loudness’ to wave parameters	

Section A: Mechanics

I. Forces

OVERVIEW

In these activities students will observe how the build-up of forces lead to the generation of earthquakes illustrated by slippage using brick and sandpaper. A brick being pulled along a surface covered in sandpaper will be used to model the behaviour of an earthquake: Turning the pulley to build up tension in the string is like the build-up of stresses at a fault, and the brick's movement over the sandpaper is like the slippage that happens in an earthquake. Results will then be compared with real earthquake data and the brick and sandpaper will be evaluated as an earthquake model.

ACTIVITY 1 - Build-up of Forces

OBJECTIVES

1. Demonstrate how slip rates are not constant for all earthquakes.
2. Demonstrate stick-slip properties of faults.

MATERIALS

- Earthquake simulator model

Figure 2: The earthquake simulator model

PROCEDURE

1. Make sure the pulley is clamped onto the plank and attach the string from the pulley onto the force meter (refer to Figure 3).
2. Tie the string attached to the other side of the force meter, around the brick.
3. Stick or tape a ruler with a millimetre scale onto the plank and a pointer onto the brick: you should be able to measure the position of the brick against the scale to the nearest mm.
4. Start the brick at the end of the sandpaper furthest away from the pulley: make sure it is completely on the sandpaper.
5. **Wear eye protection**. Turn the pulley so it gradually increases the tension in the string (and the force on the brick) until the brick starts to move. Increase the tension slowly so that it takes several seconds before the brick slips (do not release the string; the brick should move forward slightly)
6. Try this a few times. Watch what happens to the force meter reading: does the brick always begin to slip when the force reaches the same value?

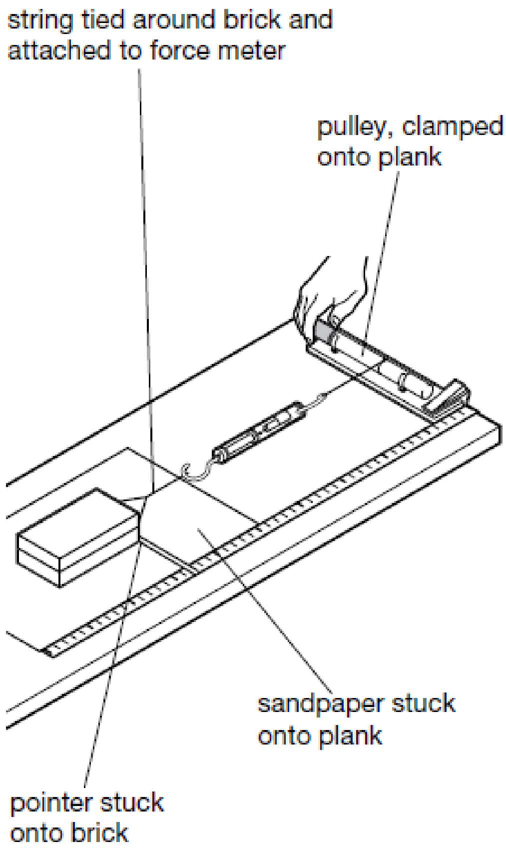


Figure 3: Set-up of the earthquake simulator model

ACTIVITY 2 - Looking at the Amount of Slip

OBJECTIVES

1. Explain the relationship between earthquake size and the force required to overcome the friction.
2. Compare and contrast experimental data of slippage frequency with data from real earthquakes

MATERIALS

- Earthquake simulator model
- Graph paper

PROCEDURE

1. Place the brick back at the start position. This time, measure how far the brick moves each time it slips. Record your results in a table or Microsoft Excel like the one shown below
2. Continue until you have at least thirty readings.
3. Plot a histogram using graph paper or Microsoft Excel to show the frequency for each size of slippage.
4. What do you notice about the relative frequency of large slippages?
5. Compare your histogram with a histogram showing the frequency of different magnitudes of earthquake.

Pointer Position (mm)	Slippage (mm)
500	0 (start position)
505	
512	
515	
525	

The pointer position scale can be modified to the scale of the meter rule used.

Optional

For better visualisation, a paper building can be constructed out of cardboard or folder material and attached to the brick as seen in figure 4.

Figure 4: Optional design to be used with the earthquake simulator model

DISCUSSION

A typical plot of class data from the brick and sandpaper investigation will show that large slips occur much less frequently than smaller slips. Using the results of their investigation, students can then compare these with observed earthquake data on the following page.

While this model accurately simulates the strain energy that slowly accumulates in rock surrounding a locked fault that is released in a sudden slip event, a process known as the elastic rebound theory, it is ultimately a simplification of a complex Earth system. Such simplifications must be understood to interpret the model accurately. Therefore the relationship between the model and reality should be clearly emphasised to students. This is particularly important for secondary school students, who often think of physical models as copies of reality rather than representations. For example, students should discuss how the fault plane of the model is horizontal due to the materials it is created from, and that such faults do not exist in nature.

Not only does the model provide a physical perspective on the generation of earthquakes, it also illustrates the concept of an earthquake's magnitude (Mw), and how the Mw can be calculated based on the physical features of the fault. In the model, the length and width of the fault section that slips during an event (represented by the dimensions of the block of wood) as well as the rigidity of Earth materials (represented by force meter) are constant for every event generated.
The only factor that can vary is the displacement or slip of the fault. As a result, there is a direct correlation between the amount of slip of the block and the moment magnitude of the event. While aspects of the mathematical relationship may be premature for some students' experience, all students will physically see this relationship by noting how much the "building" on top of the block moves in relation to the amount the block slips. The further the block slips, the more energy is released, and the more violently the building shakes.

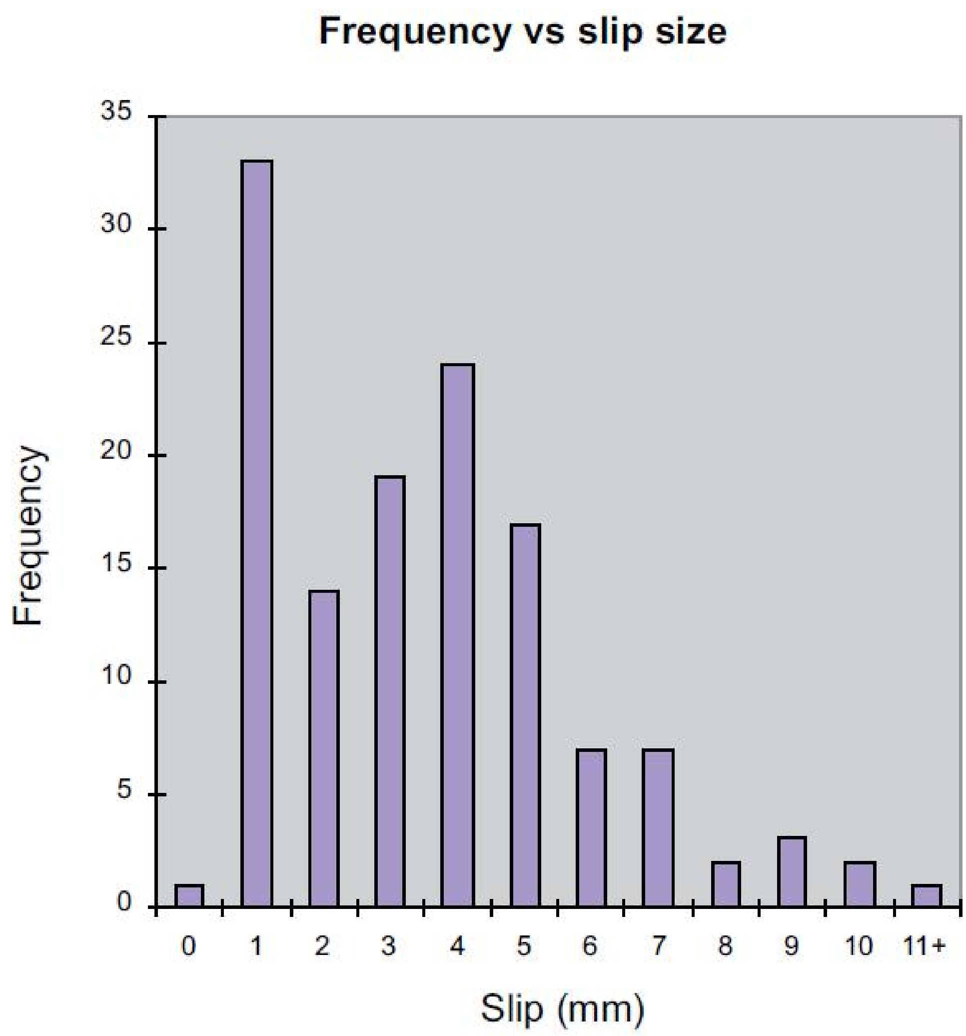


Figure 5: A histogram showing the frequency of slip sizes in an earthquake

II. Deformation

OVERVIEW

In activities 3 and 4, students will investigate the property of elasticity and determine the relationship between the applied force and the resulting extensions using sticks or dried spaghetti. Students will investigate how Hooke's law can be applied to rocks, elastic and plastic deformation and how faults and earthquakes are formed as a result.

ACTIVITY 3 - Bending Sticks and Earthquakes

OBJECTIVES

1. Describe the earth's dynamic structure using real life analogies
2. Describe how the earth moves, deforms and creates earthquakes.
3. Explain the concepts of elastic and brittle deformation.

MATERIALS

- Spaghetti Sticks

PROCEDURE

Either use one stick as a demonstration at the front of the class or distribute one stick to each student.

1. Start by applying a small amount of pressure to either end of the stick so it begins to bend slightly. This type of occurrence when applied to the Earth is referred to as crustal deformation. The application of tectonic forces initially causes the crust to deform in an elastic manner. If you release the pressure the stick returns to its original shape, like the Earth if the tectonic forces were removed.
2. Continue to apply force to the two ends whilst explaining that as pressure builds up it continues to bend elastically until it snaps much like an earthquake in the Earth, where the break is analogous to a fault. The sound of the 'snap' is heard because of the waves that are released. These sound waves can be compared to seismic waves that are released during an earthquake. This can be linked to Activity 7 "Wave Generation using the Slink Model" on page 22, to explain waves. This is an example of brittle deformation.
3. Variations in thickness can be compared to variations in rock strength, with thicker sticks being comparable to stronger rocks.

Figure 6: An illustration of spaghetti sticks bending

III. Hooke's Law

ACTIVITY 4 - Earth deformation

OBJECTIVES

1. Discuss the concepts of stress and strain in earthquakes.

MATERIALS

- None

PROCEDURE

Figure 7 below details a typical Stress-Strain graph whereby the Stress is representative of an applied force and Strain is the deformation caused as a result of the applied force which includes elastic, brittle or ductile deformation also known as plastic deformation.

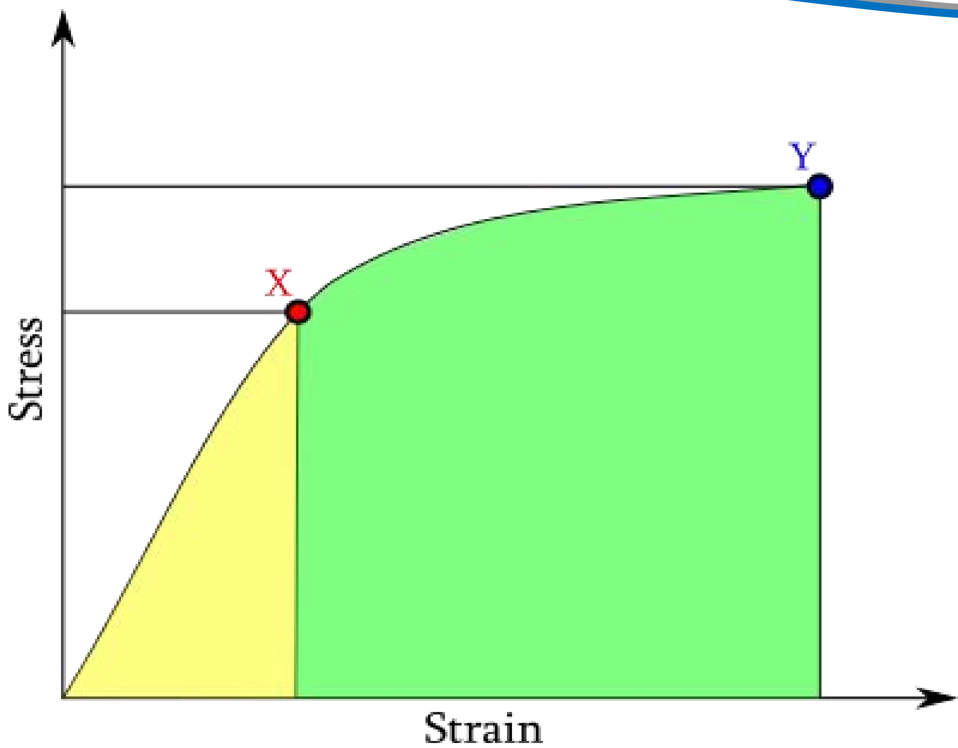


Figure 7: The relationship between stress and strain in and earthquake

Based on the Stress-Strain diagram, answer the following questions using the clues provided in textbox below.

elastic manner	*elastic limit*
permanent manner	*plastic manner*

1) At point X on the graph, the material has reached its _____________.
2) The material would undergo___________ at point Y on the diagram.
3) Within the yellow shaded area on the diagram the material behaves in a __________.
4) The material behaves in a ______________ in the green shaded area.
5) Indicate on the diagram the area where the material obeys Hooke's law, where the strain is proportional to the applied stress within the elastic limit of the solid.

DISCUSSION

Hooke's Law shows describes the relationship between springs and elasticity, Hooke noticed that the stress vs strain curve for many materials has a linear region. Within certain limits, the force required to stretch an elastic object such as a metal spring is directly proportional to the extension of the spring. This is known as Hooke's law. In relation to earthquakes, various segments of the Earth behave differently. Due to the cold, rocky structure of the crust, it is classified as a brittle material and thus undergoes brittle deformation. This type of deformation produces fractures which result in the generation of earthquakes. Unlike the crust, the mantle behaves in a plastic or ductile manner.

Section C: Waves and Optics

I. Types of Waves

OVERVIEW

In activities 5 to 10, students will observe how waves are created at a source and the subsequent propagation of these waves. The factors that affect various wave parameters and general wave properties will be investigated. To demonstrate how primary (P) and secondary (S) waves are generated during an earthquake and how they travel at different velocities, a slinky model will be employed. The Geophysics Foam Earth will be used to assist in explaining the evidence for the existence of a liquid inner core and the presence of a P-wave and S-wave shadow zone.

ACTIVITY 5 - Demonstration of Waves in a Ripple Tank

OBJECTIVES

1. Examine waveforms as a physical concept using water as the medium.

Figure 8: Marbles used to demonstrate wave patterns

MATERIALS

- Square plastic storage container as ripple tank
- Marbles (various sizes and mass)

PROCEDURE

1. Add around 5cm of water to the plastic container.
2. Drop a small ball into the centre (See Figure 9).
3. With the wave tank you can demonstrate:
   a. Size (amplitude) of the waves is related to the energy of the source (controlled by the mass and drop height);
   b. Waves expand outward (propagate) in circular wave fronts.
   c. Wave height decreases and eventually dies out with distance away from the source because of spreading out of the wave energy over a larger and larger area.

d. Waves have a speed (velocity) of propagation that can be measured by placing marks every 10cm on the bottom of the tank and timing the wave with a stopwatch; the waves reflect off the sides of the tank and continue propagating in a different direction after reflection. About 3-4, small floating flags can be used to more effectively see the motion of the water as the wave passes.

The velocity of propagation, attenuation of wave energy, and reflection of waves are important concepts for understanding seismic wave propagation, so experimenting with these wave properties in the water tank is a very useful exercise[1].

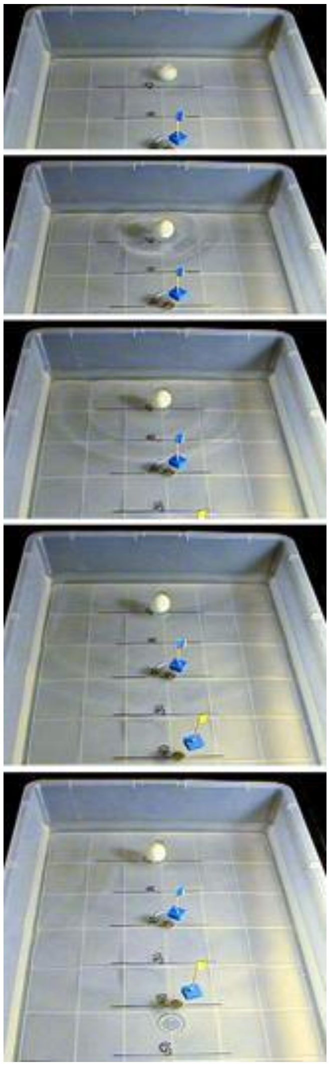


Figure 9: Wave patterns being demonstrated in a container with water

[1] Additional ripple tank experiment – www.youtube.com/watcht?v+IKMLI5PEbYI

ACTIVITY 6 – Human Wave Particles

OBJECTIVES

1. Identify waveforms as a physical concept.
2. Differentiate between longitudinal, transverse and surface waves.

PROCEDURE

To give students a better understanding of P and S-waves, we can demonstrate these waves by using students as the particles:

- For longitudinal waves, have a line of 10 -12 students standing very close together, shoulder to shoulder; a gentle push at one end of the line should be transmitted to the other end, making the end person step out. This demonstrates how P-waves travel.
- For transverse waves, have the same line of students standing side by side with arms linked; if the person at one end of the line bends forward, this will make the next person bend forward, and so on. Standing at the same separation but without arms linked does not transmit the effect when the end person bends forward: this is analogous to the way S-waves are transmitted through solids but not through liquids.

DISCUSSION

Unlike waves in water confined to the surface, waves from an earthquake can propagate through the entire interior of the Earth.

There are 3 main types of waves.

- Compression waves, often known as Primary waves or P-waves
- Shear waves (often called Secondary waves due to their arrival time)
- Surface waves, sometimes called Love or Rayleigh waves

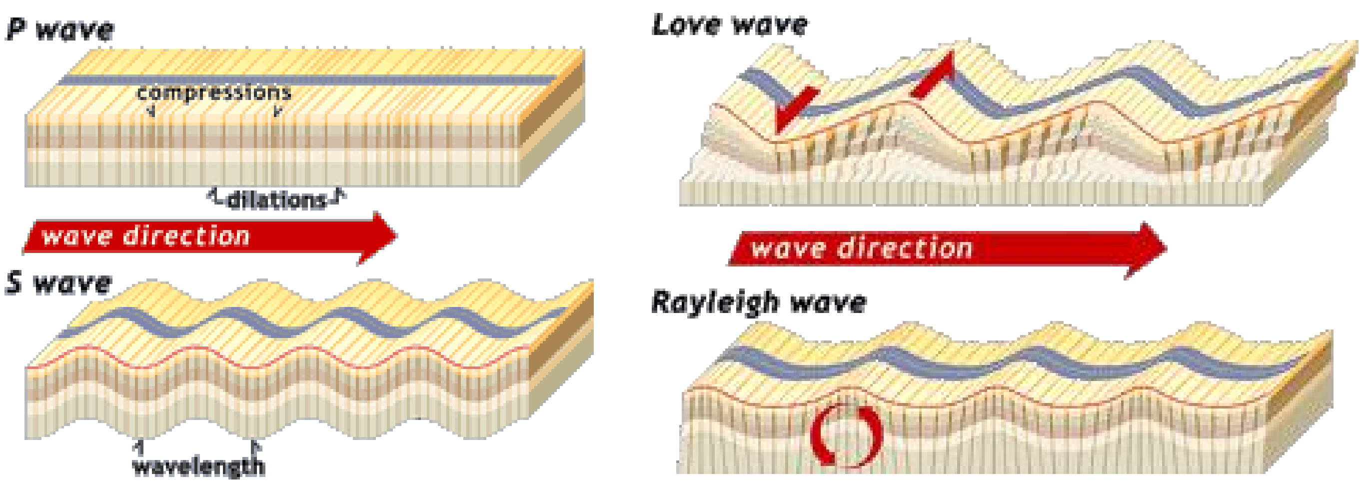


Figure 10: The properties of waves in an earthquake

Wave Type	Description of Particle Motion	Other Characteristics
P, Compression, Primary, Longitudinal	Alternating compressions and dilations (“pulls”) which are directed in the same direction as the wave is propagating (along the ray path); and therefore, perpendicular to the wave front[2].	P motion travels fastest in materials, so the P-wave is the first-arriving energy wave on a seismogram. Generally smaller and higher frequency than the S and Surface waves. P-wave in a liquid or gas are pressure waves, including sound waves.
S, Shear, Secondary, Transverse	Alternating transverse motions (perpendicular to the direction of propagation, and the ray path); commonly polarized such that particle motion is in vertical or horizontal planes.	S-waves do not travel through fluids, so do not exist in Earth’s outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S-waves travel slower than P-waves in a solid and, therefore, arrive after the P-wave.
L, Love, Surface waves, Long waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth’s surface.	Love waves exist because of the Earth’s surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, with low frequencies normally propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.
R, Rayleigh, Surface waves, Long waves, Ground roll	Motion is both in the direction of propagation and perpendicular (in a vertical plane), and “phased” so that the motion is generally elliptical – either prograde or retrograde.	Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves.

[2] Online Simple Wave Simulator for P waves and S Waves: http://www.physicsclassroom.com/Physics-Interactives/Waves-and-Sound/Simple-Wave-Simulator/Simple-Wave-Simulator-Interactive

ACTIVITY 7 - Wave Generation using the Slinky Model

OBJECTIVES

1. Explain travel paths of different waves during an earthquake.

MATERIALS

- Slinky model

PROCEDURE

You can use the provided slinky model to show how an earthquake generates P-waves and S-waves:
1. Five students - the 'observers' - each hold on to the unattached end of a slinky, so it is stretched out loosely across the room (not touching the bench top).
2. Another person – 'the earthquake' - should stand at X and give the box a quick push.
3. What kind of wave does each of the observers detect, an S-wave (transverse) or a P-wave (longitudinal)?
4. What happens if the earthquake push is at Y instead?
5. Now repeat the single push at X, with the three observers on the opposite side of the file all at the same distance. (Pull the slinkies to the same length and coil spacing).
6. What do you notice about the arrival time of the pulse at each of these observers?
7. Now have the three 'observers' stand at different distances, while holding the coils with the same spacing, as shown in the bottom diagram of figure 11.
8. What happens if you send the pulse now?

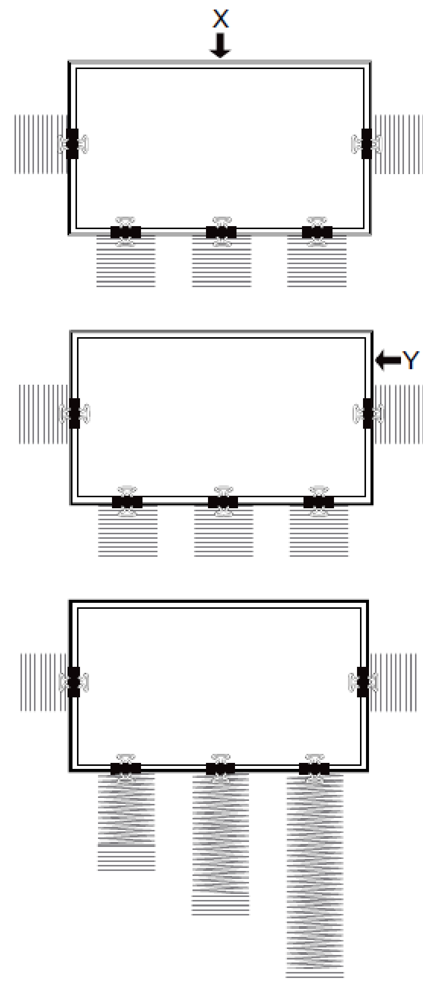


Figure 11: Slinky Model

DISCUSSION

If the three students immediately in front of you keep their coils to the same length and tension, then a single pulse will arrive at the same time for all three students[3]; if the three students stand at different travel distances (but still keeping the tension the same), then there should be a difference in arrival times of the wave pulses. This simulates the difference in arrival times for the same kind of wave at different distances from the earthquake. It is important to keep the coil spacing the same because differences in the coil spacing would be the equivalent to waves travelling through rocks of differing densities.

[3] Online Slinky Lab Interactive: http://www.physicsclassroom.com/Physics-Interactives/Waves-and-Sound/Slinky-Lab/Slinky-Lab-Interactive

Striking the box as shown, results in the three students immediately in front of you receiving P-waves, while the students at each side receive S-waves.

Pushing the box at the point marked Y will mean that one student detects a compression wave first, while the other detects an expansion wave[4].

Figure 12: Illustration of how to use the Slinky Model

ACTIVITY 8 - Attenuation and Earthquakes

OBJECTIVES

1. Demonstrate the properties of attenuation in an earthquake.

MATERIALS

- Slinky model
- Strips of foam

PROCEDURE

1. Use the slinky model from your seismology kit box
2. For one of the slinkies, place a strip of foam (about a 3m strip of 1cm thick foam 7cm wide; the 3m strip can be pieced together from 2-3 shorter pieces; tape or sew together the strips) in the

[4] Further understanding of waves using Online Mass on a Spring Interactive: http://www.physicsclassroom.com/Physics-Interactives/Waves-and-Sound/Mass-on-a-Spring/Mass-on-a-Spring-Interactive

extended coils. The foam should fit snugly within the coils and will absorb wave energy that is propagated along the slinky.
3. Assess the differences in propagating energy between the two slinkies.

DISCUSSION

The amplitude of the seismic signal decreases due to the absorption and scattering of seismic energy by the materials of the Earth, as the wave propagates from a source. An elasticity is the absorption of energy during propagation which causes the S-wave to attenuate. This effect is an important concept in evaluating earthquake hazards. Seismic waves propagate very efficiently in the eastern United States resulting in damage over a wide area from a large earthquake. In contrast, waves propagating in the western United States are attenuated by absorption of energy to a much greater degree and thus the area affected is reduced.

Superposition refers to the overlapping of waves. By combining the waves created, one giant wave or one straight line will result depending on if the slinky waves are in or out of phase.

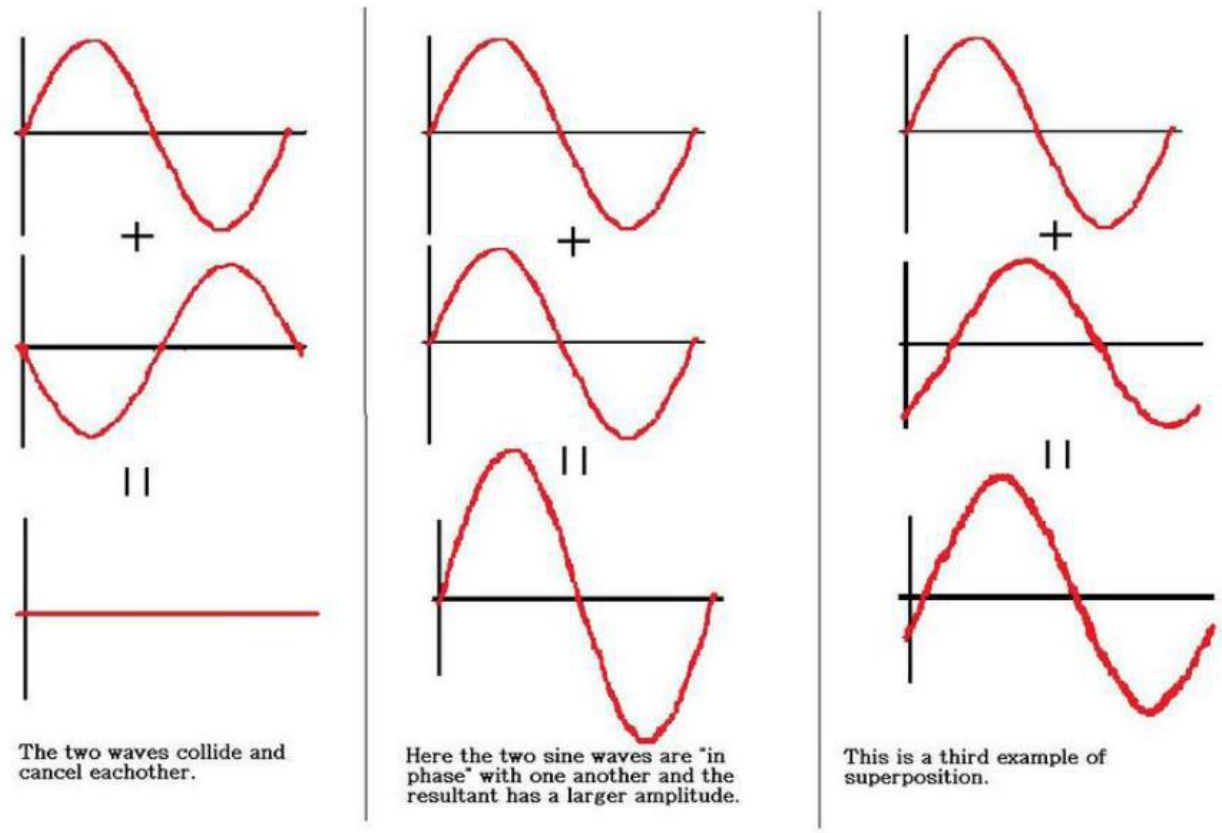


Figure 13: Graphs showing the superposition of waves[5]

[5] Extracted from: http://www.math.cornell.edu/~numb3rs/jrajchgot/507f.html

ACTIVITY 9 - Evaluating Travel Time

OBJECTIVES

1. Evaluate the travel times of P and S-wave when an earthquake is generated.

MATERIALS

- Slinky model

PROCEDURE

1. Use the slinky model provided in the seismology kit box.
2. Request 5 volunteers to hold the ends of the 5 slinkies (stretched out in different directions to about 3 - 4m each). *Please be cautious when opening the slinkies as they can become entangled very easily.*
3. A volunteer holds the wood block and generates P or S-wave (or even a combination of both) by hitting the wood block with a closed fist or causing the block to move quickly up and then down or left and then right. *The purpose of this demonstration is to show that the waves propagate in all directions in the Earth from the source (not just in the direction of a single slinky).*
4. Attach an additional slinky (with small pieces of plastic electrical tape) to one of the slinkies attached to the wood block
5. Stretch this slinky out to 6 - 8m.
6. For one of the other four slinkies, collapse about half of the coils and have the volunteers hold them in their hands, forming a half slinky, stretched out about 1½ - 2m.
7. Shake the wooden block to generate waves.

This shows how waves take different amounts of time to travel the different distances to the ends of the various slinkies. This variation in travel time is similar to what is observed for an earthquake whose waves travel to various seismograph stations that are different distances from the source (epicentre).

DISCUSSION

The differences in speed result in the different types of wave having different arrival times at a given station, and this effect becomes more pronounced the further the waves travel from the source. The seismograms at different stations will therefore be different, depending on the paths and distances travelled.

The seismogram shows labels for four phases (or ray paths) only, but typical seismograms may identify more phases, recognising both the type of wave and the path the ray takes from the earthquake epicentre to the seismic station.

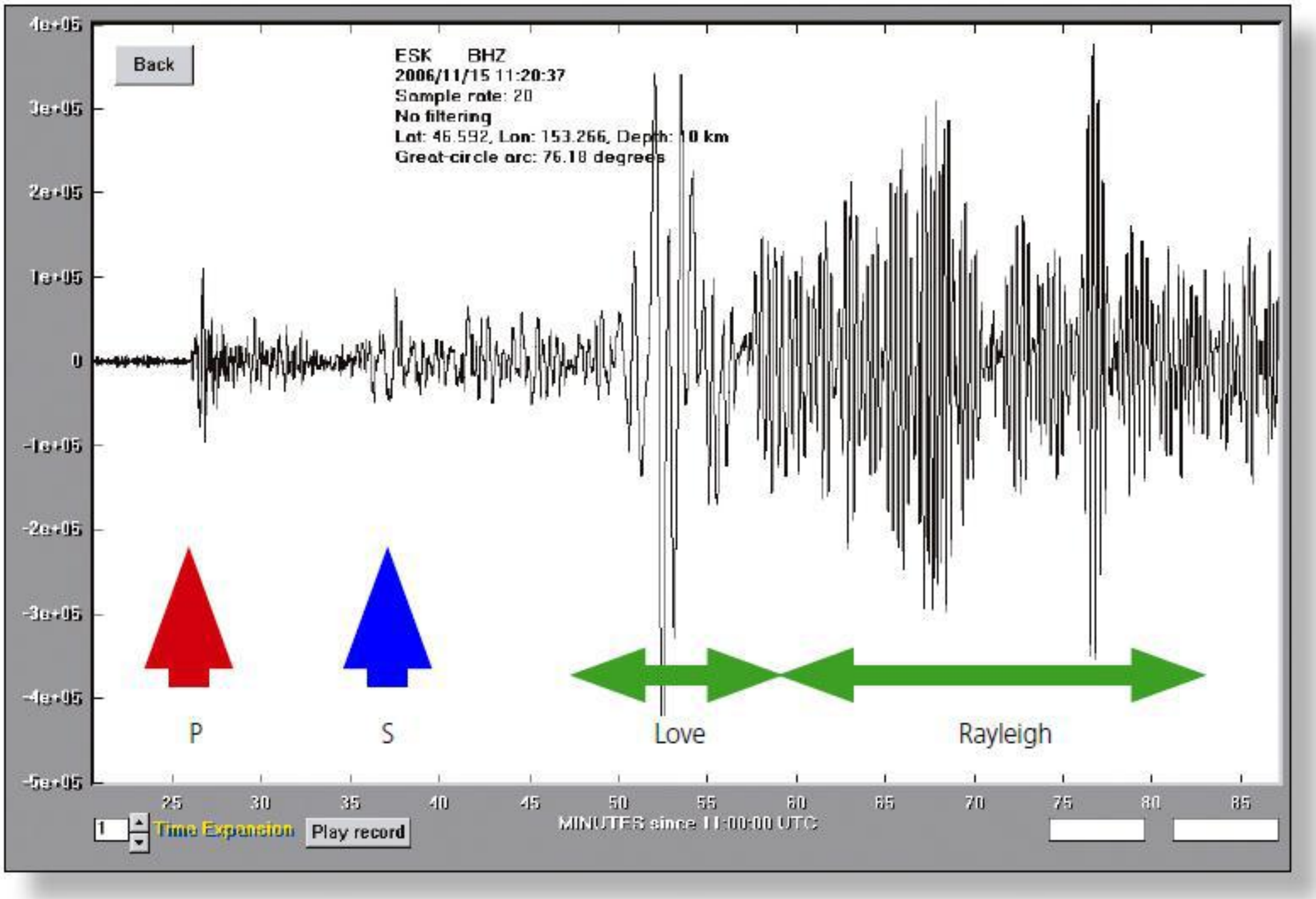


Figure 14: The various parts of a seismogram

ACTIVITY 10 - Travel Paths of Different Waves

OBJECTIVES

1. Explain the travel paths of different waves.
2. Evaluate the wave effect on structures.

MATERIALS

- Geophysics foam Earth model (refer to Figure 15)
- Paper/bristol board

PROCEDURE

P-waves arrive at the detector first, and only P-waves can be detected from the other side of the Earth. Does this suggest anything about the wave properties? Use the Geophysics foam Earth to help demonstrate the idea of shadow zones.

Figure 15: Geophysics foam Earth model

1. If you split the foam earth into two, it should be clear that the Earth is subdivided into a series of layers.
2. Using the diagram in Figure 16, draw and cut a stencil with the travel paths of the P-waves and S-waves[6].
3. When you emplace the stencil on the inside of the foam model, a gap is observed where no S-waves arrive directly from the earthquake:

   This is due to the presence of the Earth's "liquid" outer core. Here "liquid" means able to flow or move very slowly, but not necessarily liquid in the usual sense. Transverse waves are unable to pass through liquids, as such, a shadow zone is observed.

P-wave shadow zones are also apparent at angular distances of 104 to 140 degrees due to the P-waves being refracted by the liquid inner core. This is illustrated in figure 16.

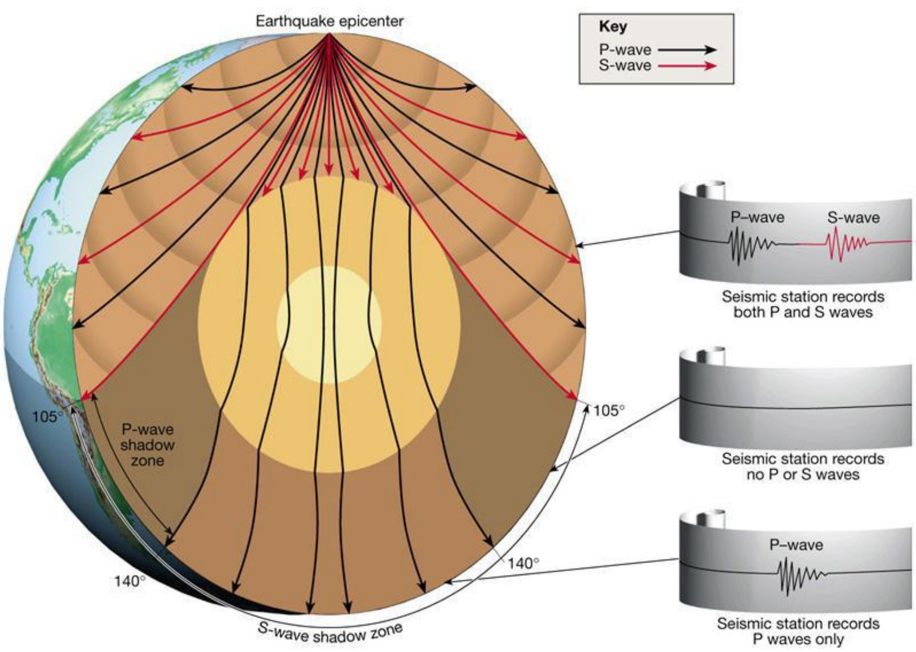


Figure 16: Travel paths of P-waves and S-waves in the interior of the Earth

[6] Please take note of the size of the globe.

DISCUSSION

Figures 17 and 18 conveys the travel paths of the primary (P-waves) and secondary (S-waves) within the Earth's crust. They describes some of the terminology used for travel paths based on reflection off the Earth's surface and internal core. It also illustrates how earthquakes can be felt at great distances from the focus point of the earthquake event. This is why seismic stations can detect and help to locate earthquakes.

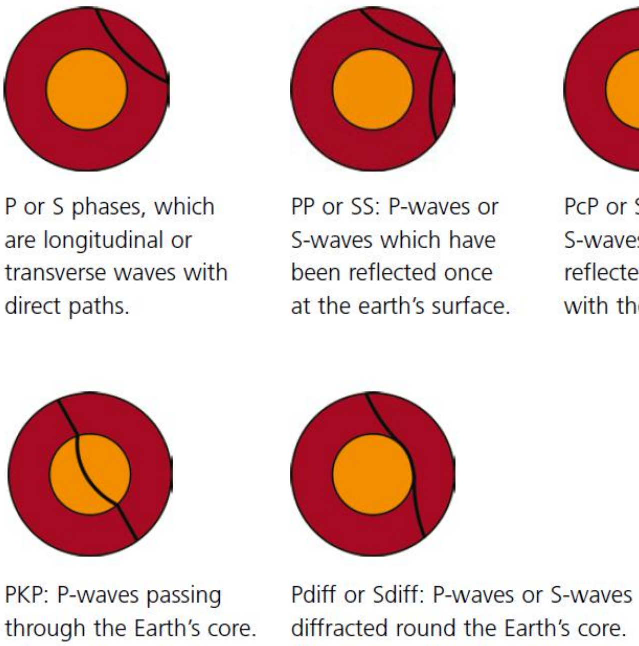


Figure 17: A Description of the Travel Paths of P-waves and S-waves (left)

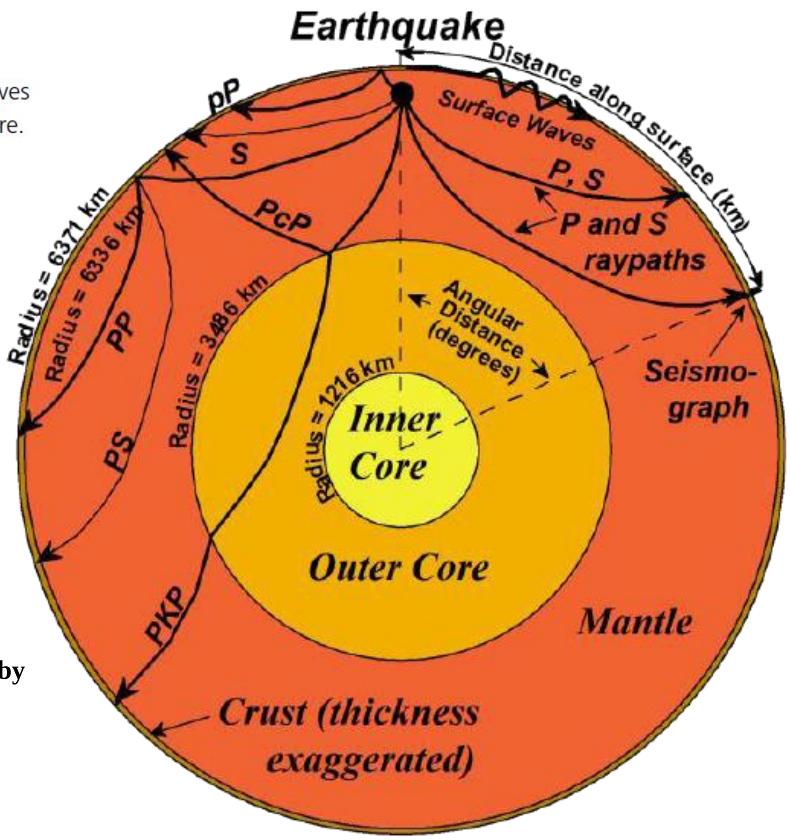


Figure 18: Examples of seismic phase names used by seismologists and the paths these represent (right)

Locating Earthquakes

OVERVIEW

In activities 11 – 14, students will be introduced to the concepts seismologists use to locate earthquakes. This includes analysing seismic waves that can be seen in seismograms.

ACTIVITY 11 – Using Sound as an example of locate earthquakes

When an earthquake occurs, energy is released into the Earth in the form of a wave. The further away from the earthquake you are, the weaker its affects are. Conversely, the closer you are to an earthquake's epicentre, the more powerful the earthquake will feel.

OBJECTIVE

1. Locate an earthquake using sound.

MATERIALS

- SEP sound source locator (2 microphones, adaptor and extension lead).
- Computer with suitable sound-editing software installed (Audacity[7] or any other applicable software).

PROCEDURE

1. Connect the two microphones to the adaptor on the extension lead, and plug the lead from the adaptor into your computer's microphone socket.
2. Open the sound-editing software: when you are ready to start, you should be able to see two input channels on the screen.
3. Get someone to clap once: what do you notice about the trace for each microphone? How is the response to a clap similar to a seismogram? Make sure you know which trace on your screen matches each microphone.

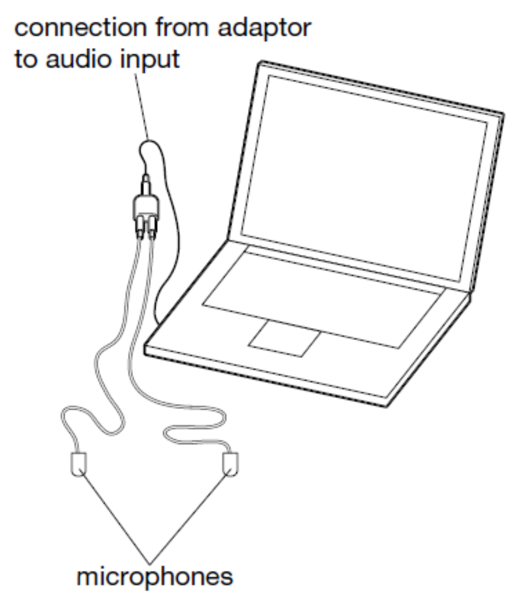


Figure 19: Setup of source locator

[7]Download link: http://www.audacityteam.org/download/

4. Now move the microphones so that they are as far apart as they can be without pulling the leads tight.
5. Get someone to clap just once again, standing the same distance away from each of the microphones.
6. What do you notice about the signal you get from each microphone?
7. What happens to the patterns you see on screen if the person who claps is standing much closer to one speaker than another?

ACTIVITY 12 - Interpreting the Signals

OBJECTIVE

1) Same as previous activity.

MATERIALS

- None

PROCEDURE

The two diagrams each show simplified images of the two sound traces from microphones X and Y, produced when a student clapped at an unknown position (A, B or C) in the laboratory.

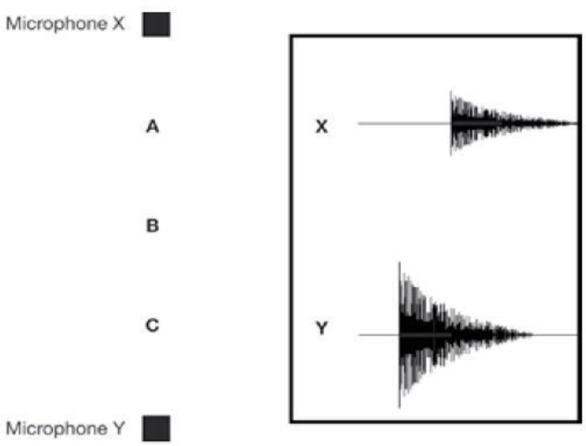


Figure 20: Sound traces 1

1. Use the sound traces to decide which location of A, B or C is the most likely for the source of the sound. How did you decide this?

2. Why can't you identify with certainty which position the source was at? If you could also see the input from a third microphone at position Z, would you have been able to tell where the source was?

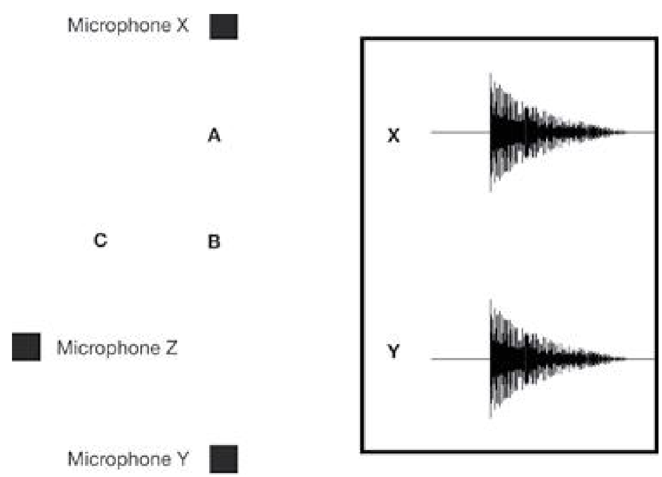


Figure 21: Sound traces 2

3. You could work out the difference in distance the sound travelled if you know the time scale on your screen and the speed of sound: suppose the separation of the two sharp peaks is equivalent to 0.005 seconds, and the speed of sound is 330 m/s, what is the difference in distance?

ACTIVITY 13 - Understanding a Seismogram

OVERVIEW

Earthquakes are commonly known as the sudden shake you feel in the earth. During a large earthquake, you can also see the shaking by looking at buildings, lights poles or the ground. This is difficult to measure by observation, so earthquakes are translated to a visual representation using seismometers. These diagrams are called seismograms which seismologists use to analyse an earthquake.

OBJECTIVES

1. Identify key information shown by a sesimogram

MATERIALS

- jAmaSeis software[8] (optional)
- Sample data provided

PROCEDURE

A seismogram is the wiggly trace that records the vibrations caused by an earthquake at a particular recording station. Once you know what some parts of a seismogram show, you can start to understand how seismologists can use seismograms to learn more about earthquakes.

[8] jAmaSeis Download: http://www.iris.edu/hq/jamaseis/

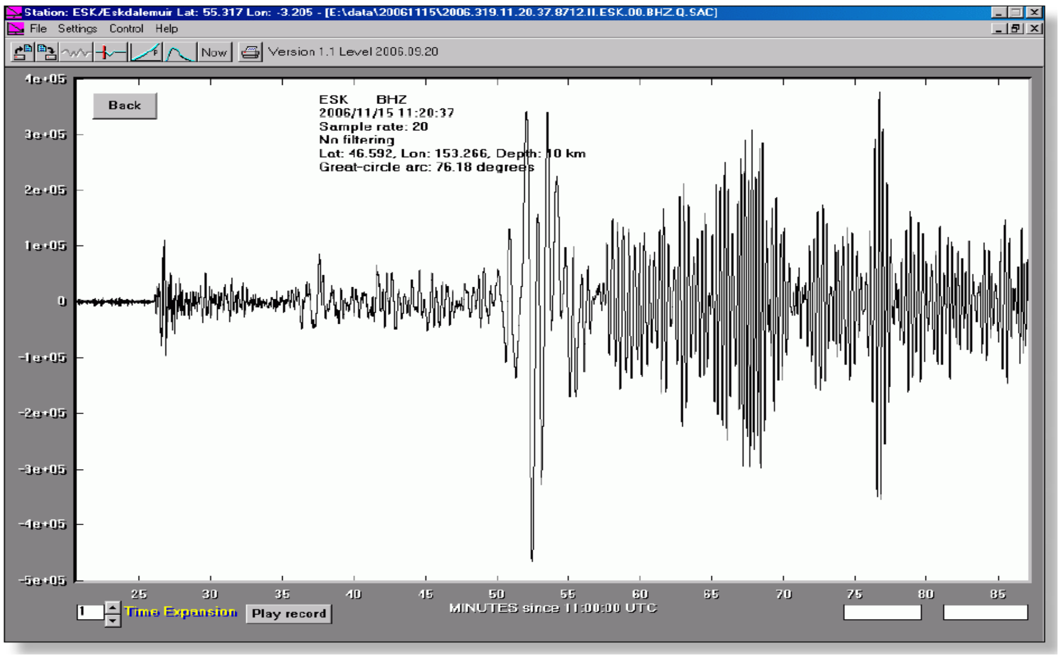


Figure 22: A seismogram of a real earthquake event (a Magnitude 8.3 event in the Kuril Islands)[9]

1. The seismogram is based on data from Eskdalemuir seismic recording station. What is the location of Eskdalemuir (Latitude and Longitude values) shown?
2. This seismogram shows information for a particular earthquake, at Latitude 46.592°, Longitude 153.266°, and Depth 10km. Find this information on the diagram, then write down the information given in the line below it: it tells you the distance from the earthquake to the recording station in degrees (a degree is equivalent to about 111km on the Earth's surface).
3. The horizontal axis shows time in minutes since an identified time (11.00.00 UTC in this example). For the chosen earthquake event, the predicted arrival times for the first P-waves and S-waves at this location are as follows: P-waves 11:26:13; S-waves 11:35:57. Mark the corresponding 'wiggles' on the screenshot.
4. As well as P-waves and S-waves ('body' waves), there are also surface waves, which are much slower. Mark the zone on your seismogram corresponding to the first group of surface waves, and label these 'Love waves'. Mark the zone corresponding to the second group of surface waves, labelling this 'Rayleigh waves'.
5. The average frequency content of the different wave types in this plot is 0.2 Hz for P-waves, 0.05 Hz for S-waves and 0.01 Hz for Surface waves. In the crust, P-waves have an average velocity of 6.5 km/sec, S-waves 3.7 km/sec and surface waves 3.5 km/sec. What is the wavelength of these different wave types in the crust?

[9] A larger diagram followed by sample data can be found in Additional Resources on pages 41-43.

ACTIVITY 14 - Exploring jAmaSeis

OBJECTIVES

1. Use jAmaSeis software to analyse seismic data[10].

MATERIALS

- Computer with jAmaSeis Software installed.
- Internet

PROCEDURE

Downloading Data

To download the sample data for this activity, log on to: http://geoserver.iris.edu/node/202382 . Download the three (3) **.sac** files from the stations that recorded the event at the Northern Mid-Atlantic Ridge. The file will automatically be downloaded to your computer. Be sure to save this file in a location that is easy to access. This will be helpful when you need to access this data later on.

Using jAmaSeis

Run the program and locate the 'Go To Event View' tab on the top right corner.

The Event View Window

This window allows users to analyse earthquake data that would have been extracted from the Stream View Window or downloaded previously. To add the data you previously downloaded select "**Add Station**". This will give you the option to browse to the location where you stored your downloaded data.

Alternatively, after selecting data from the Stream View Window, clicking "**Extract Selection**" will take you to the "**Selection View**" window where data can be edited before clicking "**OK**" to move to the **Event View** window.

[10] If there are any issues in using the software, please refer to the Troubleshooting Manual for the SEP Seismometer or the Starter Guide, previously handed out to the lead teacher(s) for your school

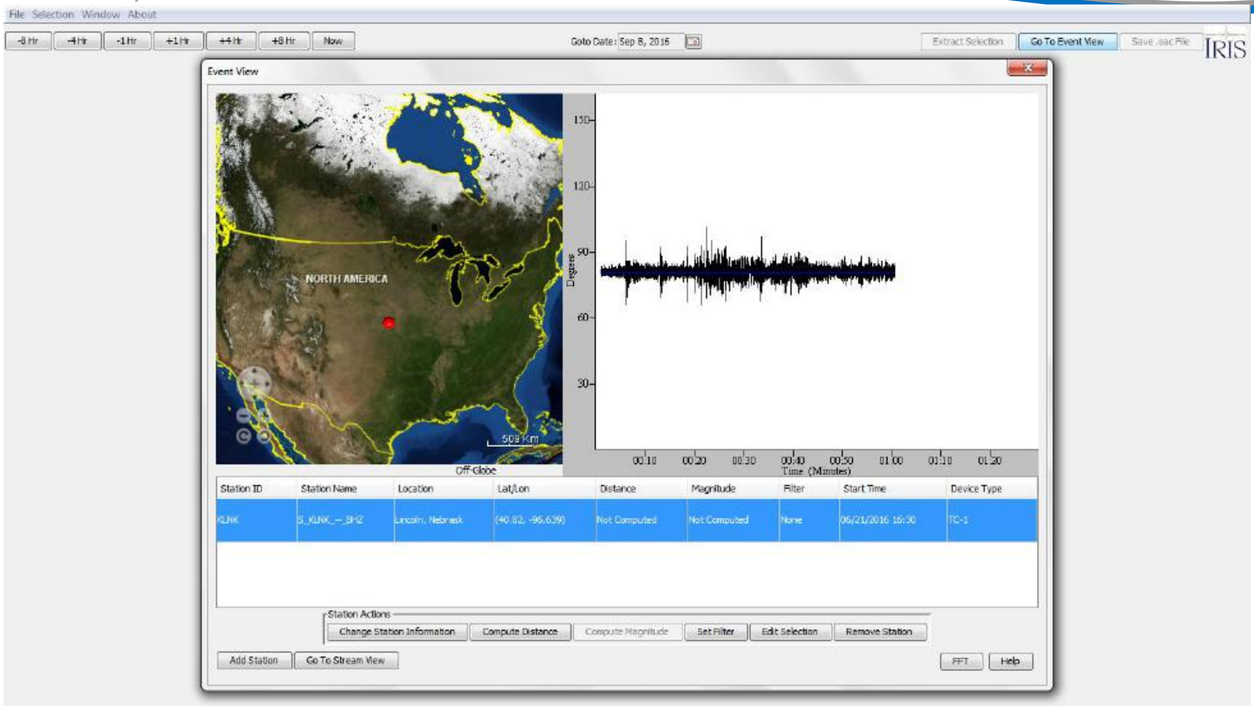


Figure 23: Sample image of Event View

1. From your observations, what seismic data is shown in the table?
2. Can you identify the data that needs to be calculated?
3. Click on the 'Edit Selection' tab and explore the seismograph. What observations do you make when using the features? Can you add or remove data from the seismograph?
4. Try uploading the additional two stations' data that you previously downloaded.
5. Can you identify which two countries the stations are located in?

Finding the Distance

To calculate the distance of an earthquake from a single station, select the current station in the **Event View** window. It will be highlighted in blue. Click "**Compute Distance**". This will open the "**Travel Time Computation Window**".

The earthquake waveform recorded at that station will be displayed. To the left of the window check "**Display Curves**" then un-check "**Surface Waves**". This will display in **BLACK** two curves showing the relationship between primary and secondary wave arrival times.

You will need to pick the arrival of Primary (P-waves) and Secondary (S-waves). To pick the arrival of the P and S waves double click on the waveform. The pick lines for the selected P and S waves, appear in **RED**. Primary waves are generally of high frequency and Secondary waves a lower frequency. Pick lines can be adjusted by dragging them along the wave form and removed by double clicking directly on them.

To compute the distance of the earthquake from the station, adjust the position of the waveform so that the Primary wave pick line intersects the "P" curve as the Secondary wave pick line intersects the "S" curve. On the map a circle will describe the distance of the event away from the station.

Have fun exploring and see if you can compute the earthquake distance for the event. Note that this takes some practice.

ACTIVITY 15 - Earthquake-Proof Structures

OBJECTIVES

1) Compare the effects of earthquakes of varying magnitudes on structures

MATERIALS

For the entire class:

- 10-20 sandbags consisting of 250 grams of sand in a sandwich sized zip lock bag. The bag should be taped into a sausage shaped cylinder for rigidity and ease of mounting onto the towers.
- 1 earthquake tower testing platform with a movable platform / shake table connected to a rigid frame by rubber bands, springs, or a motor. One design may be found in the Additional Resources.[11]
- 4 large binder clips to secure the cardboard bases to the shake table platform.

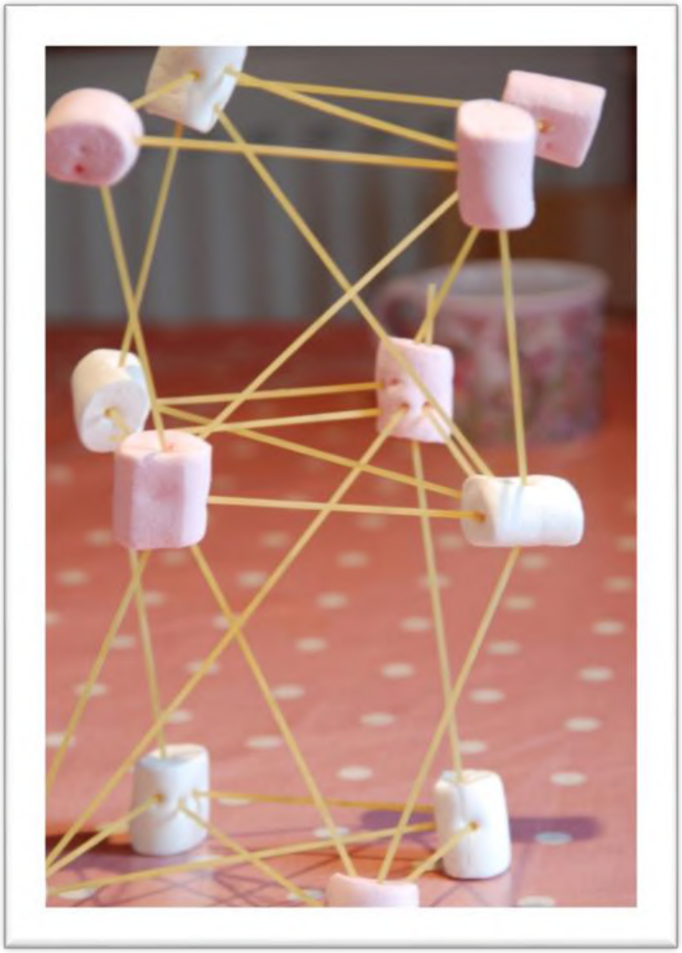
For each group:

- 1 cardboard base (approximately 25cm by 25cm)
- 30 straws
- 100 paper clips (one box)
- 20 straight pins
- 2 meters of string

CHALLENGE

Students should construct towers out of drinking straws that must withstand simulated earthquake vibrations and incrementally increasing loads of 250 gram sandbags. After each test, students have 2 minutes to repair any damage before the next begins. Students learn basic principles of earthquake engineering and design, as well as team skills essential to all fields of science and engineering.

[11] Instructions for constructing a shake table can be found on in Additional Resources on page 45.



A. Pre Activity – Simple Earthquake Proof Structure

A simple exercise can be conducted using spaghetti sticks and marshmallows. Each student is given 20 spaghetti sticks and 10 large marshmallows. They must briefly discuss and design a simple structure that can withstand a simulated earthquake generated from the cover of your seismology kit box storage container. Look at some of the designs they develop and briefly discuss strengths and weaknesses. Note that principles learnt during this exercise are essential for the accompanying challenge.

Figure 24: A simple marshmallow and spaghetti building replica structure

B. Preparation for Challenge

1. Build the earthquake shake table as described in Additional Resources on page 52. This is an activity that might be done as a whole class activity, (depending on age group/class size) or teachers may wish to prepare it ahead of time.

2. Do a trial run with a structure of your own design to see where students may run into trouble (two possible problem areas include securing the structure to the foundation and securing the joints).

3. Have the students help prepare 10-20 sandbags consisting of 250 grams of sand in a sandwich-sized zip lock bag. Each bag should be taped into a sausage shaped cylinder for rigidity and ease of mounting onto the towers.

PROCEDURE

1. Divide students into small working groups (2-4 students). Distribute the student handout[12] and explain the rules and requirements of this building challenge.

2. Demonstrate the testing procedures and show how the shake table works. Please refer to the Additional Resources for the teacher handout.[13]

3. Show students some of the different methods for joining straws together without folding the straws and compromising their integrity.

- Two straws may be pinned together with a straight pin.
- A paper clip may be partly opened up – the inner U pulled out from the outer U – and each U may be slipped into a different straw.
- Holes may be drilled with the pins and the string slipped through to tie straws together.

Figure 25: How to connect straws using paperclips

4. Allow students to begin designing and building.

5. Pause the class once or twice a class period for 5 minutes "Student Showcases or Student Displays" to point out various successful student designs or to address problems multiple teams may have encountered.

Tips and discussion prompts may include:

- Strategies for how to secure the structure to the foundation using paper clips, pins and/or string.
- A description of trusses and cross-bracing and discussion of their use in bridges, earthquake retrofitting, and other structural engineering.
- Would a better structure have a wide base or a narrow base?
- Would a better structure be symmetrical or asymmetrical?
- How can you secure the sand bags so that they don't fall off?

6. Once students have built their structures, have them answer the structural analysis questions posed on the towers handout:

- During construction, how did you test the strength and stability of your structure?
- During construction, what strategies did you use to strengthen the weaker areas? Why?
- What are the strongest parts of your building? Why?
- What are the weakest parts of your building? Why?

---

[12]Student Handout can be found in the Additional Resources on pages 46-47.
[13]Teacher Handout found in the Additional Resources on pages 48-49.

- Where did you use string in your structure? Why?
- Where did you use pins in your structure? Why?
- If you had 5 more straws, where would you add them? Why?

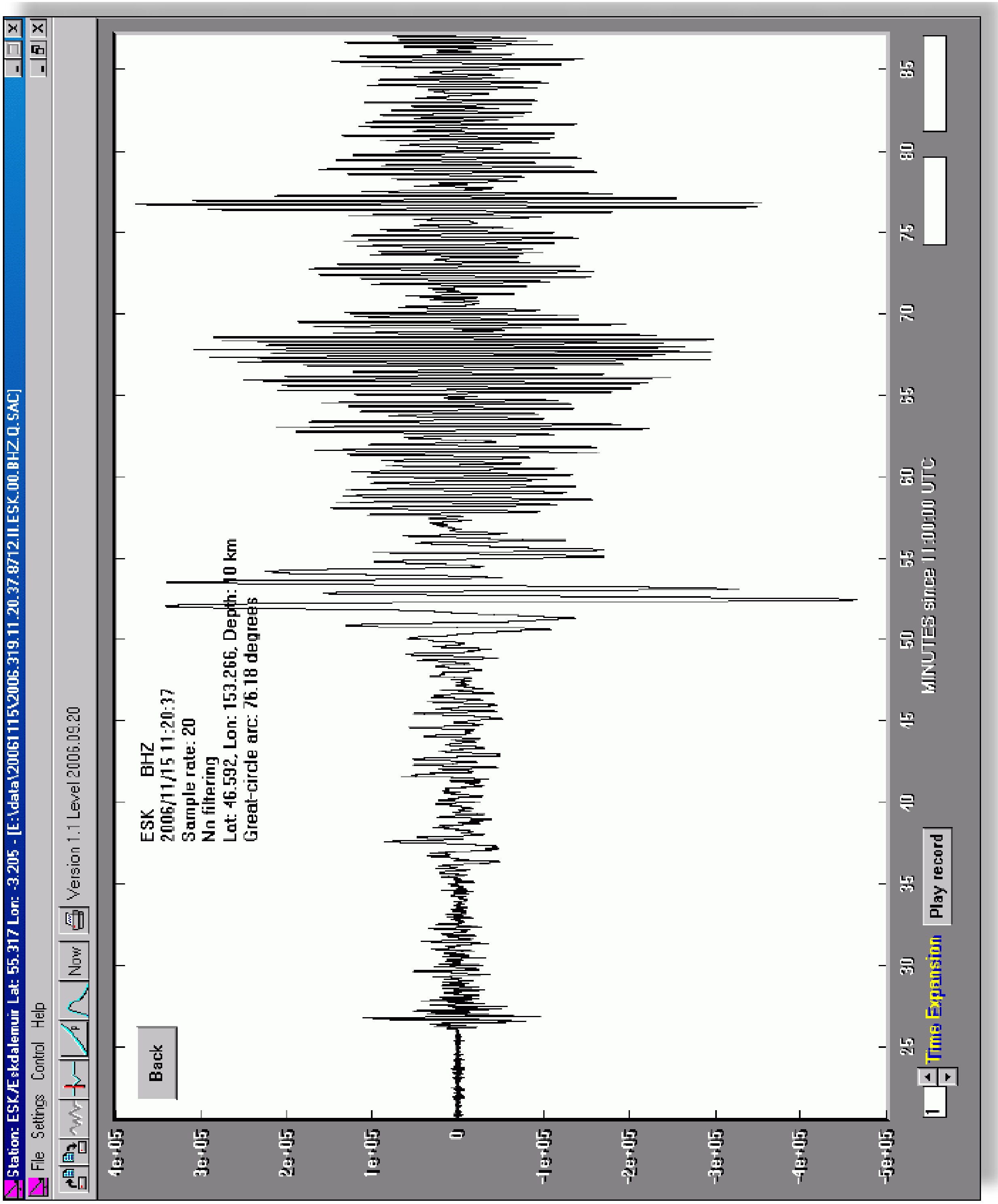
7. Test the structures. To save time, you may have the groups test their structures as they finish, which also allows work to proceed at a varying pace. Or, all teams can finish building on the same day, with testing taking place on the next day. In this way, the students can watch others and make observations, noting what worked and what didn't.

Figure 25: The testing of a straw structure

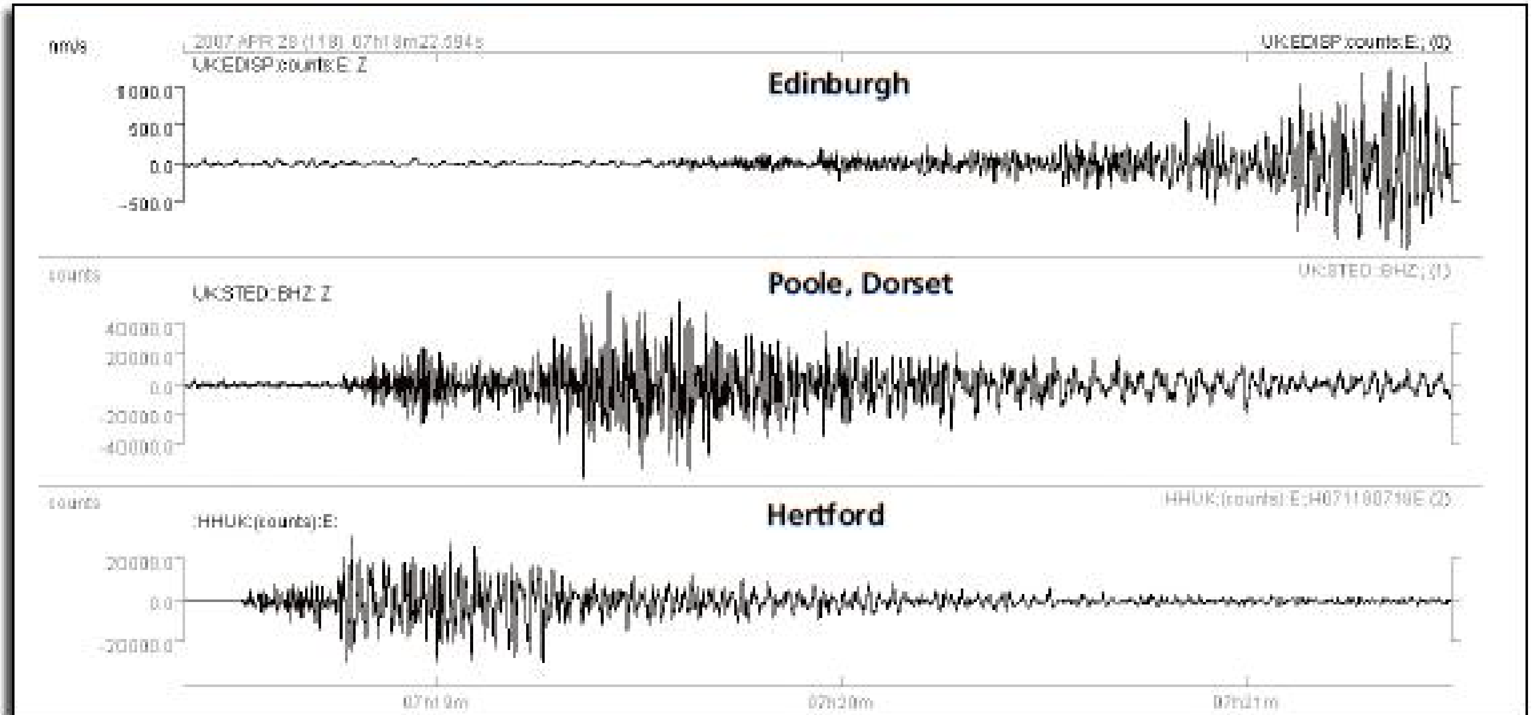
Table of Activities

Additional Resources

Activity 13: Seismograph followed by sample data



At 7.18am on n April 28th, 2007 a magnitude 4.3 earthquake occurred in the English Channel, near Folkestone. The seismograms below were recorded at three UK stations:

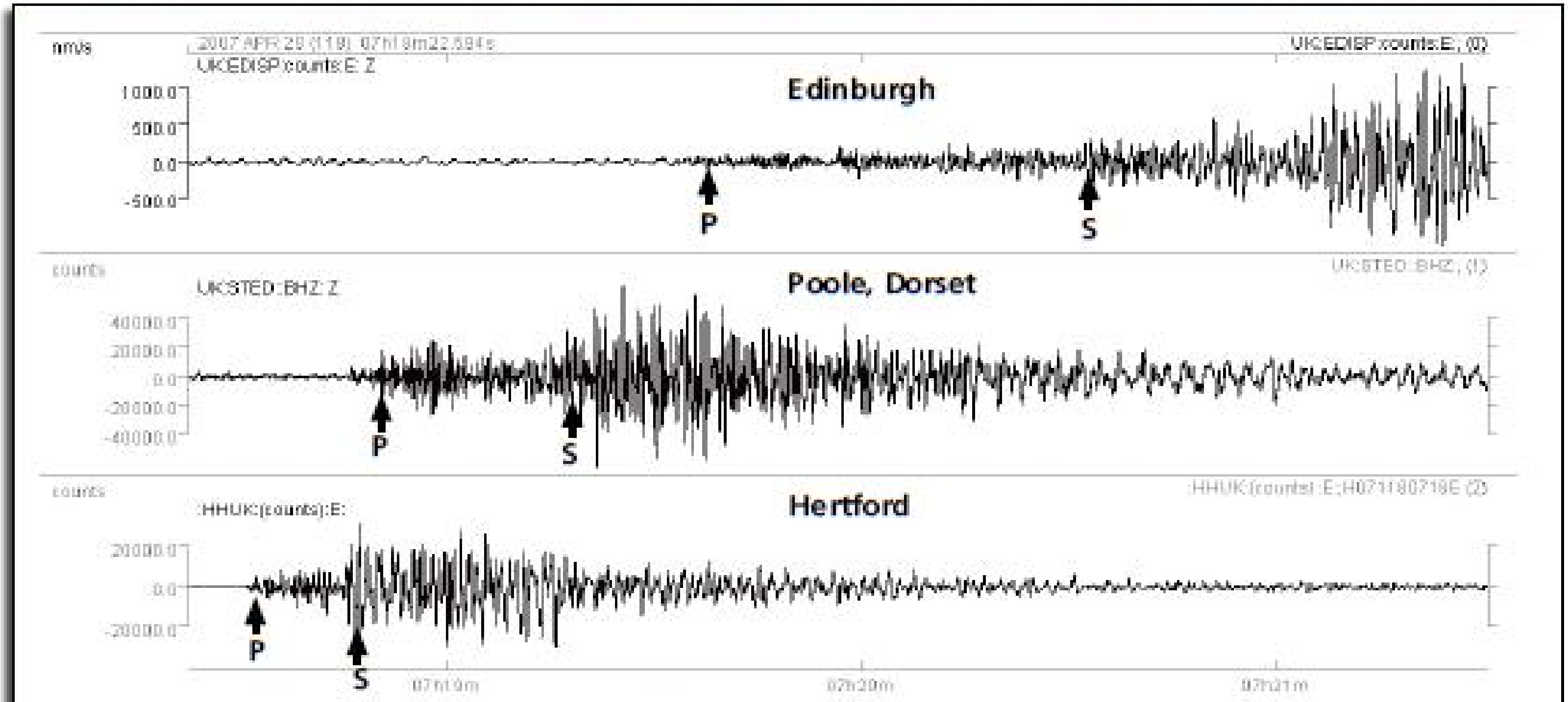


Seismograms provided by BGS: www.bgs.ac.uk/schoolseismology.

Station	Location	Latitude	Longitude	Sensor	Orientation	Bandwidth
EDISP	BGS offices Edinburgh	55.924	-3.179	SEP	East	15 sec-5 Hz
HHUK	Hailey Hall School, Hertford	51.778	0.015	SEP	East	15 sec-5 Hz
STED	St. Edward's School, Poole	50.74	-1.96	Guralp EDU	Vertical	30 sec-10 Hz

Event date	Time	Magnitude	Latitude	Longitude	Depth/ km
28/04/07	07:18.08	4.3	51.1	0.9	2

At 7.18 am on April 28th, 2007 a magnitude 4.3 earthquake occurred in the English Channel, near Folkestone. The seismograms below were recorded at three UK stations. The P-wave and S-wave arrival times at each station are marked:



Seismograms provided by BGS: www.bgs.ac.uk/schoolseismology.

Station	Location	Latitude	Longitude	Sensor	Orientation	Bandwidth
EDISP	BGS offices Edinburgh	55.924	-3.179	SEP	East	15 sec-5 Hz
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STED	St. Edward's School, Poole	50.74	-1.96	Guralp EDU	Vertical	30 sec-10 Hz

Event date	Time	Magnitude	Latitude	Longitude	Depth/ km
28/04/07	07:18.08	4.3	51.1	0.9	2

Seismology Word Search

E	S	U	B	D	U	C	T	I	O	N	H	E	C	N
L	T	N	V	E	L	O	C	I	T	Y	T	K	L	O
O	Y	G	O	L	O	M	S	I	E	S	G	A	K	E
C	S	F	T	R	U	P	T	U	R	E	N	U	C	L
N	E	L	O	T	C	R	A	H	O	I	E	Q	O	M
N	N	M	M	C	R	E	M	T	D	S	L	H	H	P
M	O	O	S	S	U	S	O	U	O	M	E	T	S	T
A	N	M	M	S	U	S	T	U	E	O	V	R	R	T
E	O	E	D	U	T	I	N	G	A	M	A	A	E	F
E	N	N	L	C	G	O	T	A	B	E	W	E	T	T
T	I	T	Q	N	V	N	T	U	O	T	O	M	F	S
C	E	N	O	I	T	A	R	E	L	E	C	C	A	R
D	C	L	E	C	S	L	E	U	I	R	F	F	T	U
S	D	E	F	A	S	V	A	R	M	T	G	E	N	R
Q	Y	D	S	E	C	F	S	A	K	A	V	O	R	A

acceleration	aftershock	compressional
earthquake	fault	focus
longitudinal	magnitude	moment
rupture	seismology	seismometer
subduction	velocity	wavelength

Activity 15: Instructions for Constructing Shake Table

To create your own very simple earthquake table that is more like a trampoline than a standard, motor controlled earthquake table:

1. Cut a piece of board or plywood into a 12” square. If you wish, create a raised edge for your platform by nailing lengths of 1/2” square dowel on top of each of the sides.
2. Mount wood screws on the underside of the plywood at each corner and at the center of each side. Don’t screw the screws in all the way, make sure at least 1/4” sticks up so you can loop a rubber band around it.
3. Construct a frame out of 2” x 4”s that fits around the wood square with around 1/2” clearance between the outer edge of the square and the inside edge of the frame. Make sure the 2” x 4”s are oriented so that the frame is 4” high.
4. Mount wood screws on the top edge of the frame at each corner and at the center of each side. Again, don’t screw in the screws all the way.
5. Loop a rubber band around each pair of screws so that the plywood square is suspended like a trampoline within the frame.

Activity 15: Student Handout

Earthquake Tower Challenge
100 points

You and your partner have been hired as the structural engineers in charge of designing a new 2-story art building. There are many building codes you must follow. Each floor of the building must support ***at least*** 250 grams of weight. Also, the building will be located near an earthquake fault; therefore your building must be able to withstand ***both*** small and large earthquakes. Since the building will be used for art classes, you may be as creative as you like with the shape and design of the building (it does not need to be box shaped).

You are limited to the following materials:

- 1 cardboard base (approximately 25 cm by 25 cm)
- 30 straws
- 100 paper clips (one box)
- 20 pins
- 2 meters of string

Your building must meet the following requirements:

- The building must fit on the base. Attach your building to the base using pins, paper clips, or string.
- Your building must be at least 36 cm tall.
- Your building has 2 stories that are each at least 18 cm tall (approximately the height of 1 straw).
- Each story must support the weight of at least 1 sand bag (250 grams) without collapsing.
- A construction drawing with measurements and analysis must be submitted before earthquake testing.
- To survive an earthquake test, the building must not collapse for 10 seconds after the earthquake begins. The weights must stay on the building. You have 1 minute to repair any damage to your building before the next earthquake test.

Hints and tips:

- **PLAN CAREFULLY!** Additional supplies will not be provided.
- Remember these words of wisdom: “Measure twice. Cut once.”
- Use the concepts of tension and compression. If an element is in tension and not compression, you can use string instead of straws.
- Try building without pins first, then add pins where connections need reinforcement.
- Make sure that your foundation is very strong.

- Remember to design a way to secure the weights so that they don't fall off **AND** so you can add additional weights to the top story.

Grading:

25 points	Building stands by itself, fits on the base, is secured to the base, is at least 36 cm tall, and has 2 stories that are each at least 18 cm tall.
10 points	Building supports 1 sand bag on the first story.
10 points	Building supports 1 sand bag on the top story.
10 points	A clear, detailed construction sketch was completed. Straws and string should be easily distinguished. All-important design features and all critical measurements should be labelled on the sketch.
20 points	A structural analysis of your building was completed. The following questions should be answered clearly and completely:

- During construction, how did you test the strength and stability of your structure?
- During construction, what strategies did you use to strengthen the weaker areas? Why?
- What are the strongest parts of your building? Why?
- What are the weakest parts of your building? Why?
- Where did you use string in your structure? Why?
- Where did you use pins in your structure? Why?
- If you had 5 more straws, where would you add them? Why?

5 points	Building remains standing with 1 sand bag on the top story after a mild earthquake.
5 points	Building remains standing with 1 sand bag on the top story after a major earthquake.
5 points	Building remains standing with 1 sand bag on the top story and 1 sand bag on the first story after a major earthquake.
5 points	Building remains standing with 2 sand bags on the top story and 1 sand bag on the first story after a major earthquake.
5 points	Building remains standing with 2 sand bags on the top story and 2 sand bags on the first story after a major earthquake.

Bonus:

The building in each class that can hold the most weight and remain standing after a major earthquake will be awarded 20 bonus points.

Activity 15: Teacher Handout

Testing and Evaluating the Structures

Grading rubric: the structures must meet the following requirements:

- The building must fit on the base.
- The building must be at least 36 cm tall.
- The building must have 2 stories that are each at least 18 cm tall (approximately the height of 1 straw).
- Each story must support the weight of at least 1 sand bag (250 grams) without collapsing.
- A construction drawing with measurements and analysis must be submitted before earthquake testing.
- To survive an earthquake test, the building must not collapse for 10 seconds after the earthquake begins. The weights must stay on the building.

Point values

- 25 points – Building stands by itself, fits on the base, is secured to the base, is at least 36 cm tall, and has 2 stories that are each at least 18 cm tall.
- 10 points – Building supports 1 sand bag on the first story.
- 10 points – Building supports 1 sand bag on the top story.
- 10 points – A clear, detailed construction sketch was completed. Straws and string should be easily distinguished. All-important design features and all critical measurements should be labelled on the sketch.
- 20 points – A structural analysis of your building was completed. The following questions should be answered clearly and completely:
    - During construction, how did you test the strength and stability of your structure?
    - During construction, what strategies did you use to strengthen the weaker areas? Why?
    - What are the strongest parts of your building? Why?
    - What are the weakest parts of your building? Why?
    - Where did you use string in your structure? Why?
    - Where did you use pins in your structure? Why?
    - If you had 5 more straws, where would you add them? Why?
- 5 points – Building remains standing with 1 sand bag on the top story after a mild earthquake.
- 5 points – Building remains standing with 1 sand bag on the top story after a major earthquake.
- 5 points – Building remains standing with 1 sand bag on the top story and 1 sand bag on the first story after a major earthquake.
- 5 points – Building remains standing with 2 sand bags on the top story and 1 sand bag on the first story after a major earthquake.
- 5 points – Building remains standing with 2 sand bags on the top story and 2 sand bags on the first story after a major earthquake.

Bonus: The building in each class that can hold the most weight and remain standing after a major earthquake will be awarded 20 bonus points.

Observing the structure: If at any point the structure buckles to the point that the sandbags fall off or drop by more than halfway to the ground (a sandbag on the first story 18 cm high can fall as much as 9 cm and still be considered passing while a sandbag on the second story 36 cm off the ground can fall 18 cm), the structure should be considered to have failed that stage of testing. Students should be given 2 minutes to repair any damage to their structure between each stage of testing although no new straws or materials could be provided. The best structure in the class will likely survive until it encounters a major earthquake with 4 sandbags on the top story and 3 sandbags on the first story.

Testing levels:

Level 1. Place 1 sandbag on the first story.

Level 2. Place 1 sandbag on the second story.

Level 3. Create a Minor earthquake with 1 sandbag on the top story. Move the platform horizontally, side to side so that it touches the frame. No vertical motion is involved.

Level 4. Create a Major earthquake with 1 sandbag on the top story. Move one corner of the platform so that it touches the corner of the frame, as well as the table below, to start a major earthquake and lead to both horizontal and vertical motion.

Level 5. Create a Major earthquake with 1 sandbag on the top story and 1 sandbag on the first story.

Level 6. Create a Major earthquake with 2 sandbags on the top story and 1 sandbag on the first story.

Level 7. Create a Major earthquake with 2 sandbags on the top story and 2 sandbags on the first story.

Level 8. Continue major earthquakes adding 1 sandbag at a time, first to the top story, then to the first story.

Glossary

Term	Definition
acceleration	The time rate of change of *velocity* of a reference point during an earthquake. Commonly expressed in percentage of gravity. (a, equal to 980 cm/s^2).
accelerometer	An instrument used to measure *acceleration*. Used to measure the response of the ground or a structure to shaking in an earthquake.
aftershock	Smaller earthquakes following the largest or main earthquake in a series in a restricted area.
amplification(seismic)	The increase in surface *ground motion* at certain frequencies in unconsolidated sediments relative to the motion in solid rock.
amplitude(wave)	Maximum deviation from the normal of any wave-like disturbance.
aseismic	Almost free of earthquakes.
asthenosphere	The soft and probably partly molten layer of the earth below the *lithosphere*. Distinguished by low seismic-wave velocities and high seismic wave *attenuation*.
attenuation	The decrease in seismic signal amplitude caused by spreading of the wave and absorption and scattering of seismic energy by the materials of the earth as a wave propagates from a source.
Body wave	Seismic wave propagated in the interior of the earth. *P and S waves* are examples.
Brittle behavior	Failure (sudden loss of strength) at some critical stress either by breaking a long a new fracture or, most commonly, by frictional sliding on an already existing fracture.
Compressional wave	See *P wave*.
core	The central part of the earth, beginning at a depth of about 2900 km, probably of consisting of iron-nickel alloy; it is divisible into an outer core that may be liquid and an inner core about 1300 km in radius that may be solid.
creep(fault)	Slow movement along a fault that does not produce earthquakes.
crust	The outermost major layer of the earth; in Utah, ranging from 35 to 45 km thick and with a compressional seismic wave velocity (in rock) between 3.0 and 7.5km/s.
density	The mass per unit volume of a material.
displacement	The difference between the initial position of a reference point and a later position. In geology it is the permanent offset of a reference point across a fault.
Ductile deformation	Behavior in which rocks, at a critical stress, do not rupture but instead become permanently deformed by flowing.

earthquake	The shaking or vibrating of the ground caused by the sudden release of energy stored in rock beneath the earth's surface.
Earthquake source	The origination point of earthquake energy release.
Elastic deformation	A non-permanent deformation in which a solid returns to its original size and shape after an external deforming force is removed.
Elastic rebound	The release of strain energy by the abrupt movement of a fault with a resultant earthquake.
epicenter	The point on the surface of the earth directly above the point where the first rupture and first earthquake motion occur.
fault	A fracture in the earth along which the two sides have been displaced relative to each other.
Focal depth	The depth below the surface of the hypocenter or focus of an earthquake.
focus	The point within the earth where earthquake rupture begins.
foreshocks	Smaller earthquakes preceding the main earthquake in a series.
frequency	The number of cycles occurring in a unit time.
gouge	Rock crushed in a fault zone.
graben	A block of the earth's crust, usually elongated, that has subsided relative to adjacent rocks along bounding faults.
Hertz(Hz)	A unit of frequency, equal to the number of cycles per second.
hypocenter	The point within the earth where earthquake rupture begins; the focus of an earthquake.
intensity	A subjective numerical index describing the severity of ground shaking in an earthquake in terms of the effect on objects and humans.
lithosphere	The solid outer crust of the earth including the crust and upper mantle.
Love wave	A type of seismic surface having only horizontal motion transverse to the direction of propagation.
magnitude(earthquake)	A number that characterizes the size of an earthquake by measuring the motions recorded by a seismograph and correcting for the distance to the *epicenter* of the earthquake.
mantle	That part of the earth between the *crust* and the *core*.
moment	A measure of the energy released in an earthquake determined by strength of the fault and the area and amount of slip.
Natural frequency	The frequency at which an elastic system vibrates when set in motion by a single pulse.
outcrop	The area where a particular rock body reaches the surface.
P wave	A seismic wave that involves particle motion in the direction of propagation. It is the fastest traveling wave generated by an earthquake and therefore the first to arrive at any point.

period(wave)	The time interval required for one cycle of a wave.
plate	A large unit of the earth's *lithosphere* that moves relative to other plates and the interior of the earth.
Plate tectonics	The theory of movement and interaction of large plates of the earth's *crust* that explains earthquakes, volcanos and other geologic processes as consequences of the movement.
Rayleigh wave	A seismic surface wave involving elliptical motion in a vertical plane oriented in the direction of propagation of the wave.
Recurrence interval	The average time between specific events at a particular site.
reflection	Seismic energy that has been returned (reflected) from an interface of materials of different elastic properties.
refraction	Seismic energy that has been deflected by passing from one material to another with different elastic properties.
resonance	An increase in the amplitude of vibration of a body when the frequency of shaking is close to the natural frequency of the body.
Return period	See *recurrence interval*.
rigidity	The angular shear strain produced from applying shear stress to a body. See *shear modulus*
S wave	A seismic body wave involving shear motion transverse to the direction of propagation of the wave.
Seismic wave	An elastic wave generated in the earth by an earthquake or explosion.
Seismic zonation	Geographic delineation of areas having different potential for hazardous effects of earthquakes.
Seismic zone	An area with in which the seismic-design requirements are constant.
seismograph	An instrument for amplifying and recording the motions of the earth caused by seismic waves.
seismology	The study of earthquakes, earthquake sources, and the propagation of seismic waves.
seismometer	The sensor that detects the seismic wave energy and transform it into an electric voltage.
seismotectonic zone or province	A geographic area characterized by similar geology and earthquake characteristics.
Shear modulus	The ratio of shear stress to shear strain of a material during simples hear.
slip	The relative displacement of one of two points on opposite sides of a fault.
Slip rate	The average velocity of displacement of points on opposite sides of a fault.
stick-slip	Jerky frictional fault slip in which the opposing blocks of rock, held by friction, episodically and suddenly slide.
strain	The percentage change in the length, shape, or volume of a body

	subjected to deformation.
stress	Force per unit area acting on a surface within a body.
Stress drop	The difference between the stress across a fault before and after an earthquake.
strike	The bearing relative to north of a line defined by the intersection of a planar geologic feature, such as a fault, and a horizontal surface.
subduction	A plate tectonic process of one plate descending into the earth below another.
Surface waves	Seismic waves that propagate along the surface of the earth (Love and Rayleigh waves).
Tectonic earthquake	Earthquakes resulting from the release of strain by deformation of the earth.
tsunami	A large ocean wave usually cause by movement in the sea floor related to an earthquake or volcanic eruption.
velocity(seismic)	The time rate of displacement of a reference point in an earthquake or the speed with which a particular seismic wave propagates in a rock.
viscoelastic	A type of deformation in which a material behaves like an elastic solid when it is rapidly strained on time scales of seconds to hours, but deforms viscously by plastic flow over long periods of geologic time.
Water table	The upper surface of an unconfined body of groundwater.
waveform	A plot of the displacement produced by a seismic wave as a function of time.
wavelength	The distance between two adjacent crests or troughs of a wave.
wavelet	A seismic pulse usually consisting of 1½ or 2 cycles.

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