The Waves and Tsunamis Project

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ED53A-0323

Introduction & Overview

This project evolved as a collaboration between a marine seismologist at Woods Hole Oceanographic Institution, Ralph Stephen, and middle school teachers in Plymouth Massachusetts, Mary Lavin, Derek Strohschneider, and Richard Maichle. The project was carried out under the auspices of the Ocean Science Education Institute (OSEI),sponsored by the Centers for Ocean Science Education Excellence-New England (COSEE-NE), which ran a week-long summer program to involve research scientists in middle school education. The goal was to develop a classroom unit about wave properties. Demonstrating wave processes quantitatively in the classroom using slinky's and wave tanks can be difficult . For example, waves often travel too fast for students to actually measure amplitude or wavelength. Also when teaching propagating waves, reflections from the ends set up standing waves, which can confuse students and the waves can attenuate quickly, causing the amplitude to change along the string. In response to these difficulties Stephen and his Research Associate, Tom Bolmer, set-up a web page to display animations of waves traveling on different types strings.

The Plymouth Wave Lab is a web site that allows students to run animations of waves on strings. The lab is available online at http://msg.whoi.edu/String_Lab/New_String_Movies.html . The benefits of using the website quickly become obvious: The wave lab is able to show ideal waves on a string, in mpeg file format; students can start and stop the movie as they wish while they think about what is going on; "snapshots" of the movies are available as handouts to the students so that they can easily measure the wave properties.

In the classroom unit, students rotated through five different stations. The activities at each station were used to help students understand transverse and longitudinal waves, frequency, period, amplitude, wavelength, crest, trough, rarefaction and compression. The web site, called the Plymouth Wave Lab, was used as a supplement to the hands-on classroom activities. In addition, the team decided to use tsunamis in the curriculum, believing they would appeal to students and stimulate their interest, months before the Sumatra tsunami hit.

Five Messages

The OSEI team decided to focus on five "take away messages" that we wanted the students to learn in a classroom visit. These were consistent with the curricula framework for Massachusetts. "Tsunamis" were used (even prior to the Indian Ocean event on December 2004) as a "hook" to capture students' attention and provide a focus for the discussions.

First, all school children, and particularly school children who live near the coast, should be taught to run to high ground away from the beach if they feel an earthquake or if they observe that the water level lowers dramatically.

Second, tsunamis are an excellent example of the property of waves to transport energy without transporting mass. The water that impacted the beaches in Sri Lanka, for example, did not "come from" Sumatra; just the energy "came from" Sumatra.

Third, a ship at sea in deep water is unlikely to feel the tsunami at all. There are two reasons for this. The first reason is that the amplitude of tsunamis in the deep ocean is quite small, only a few centimeters. The second reason is that the time it takes the sea surface to rise and fall during the passage of the tsunami is from 5 to 20minutes. Such a small change in amplitude over such a long time is unlikely to be felt by a ship.

Fourth, tsunamis provide an interesting demonstration of the relationships between period (P) and frequency(f): P=1/f, and between frequency(f), wavelength (w) and velocity (v): v = w * f . For a tsunami wave with a period of 40minutes the frequency is about 0.0004Hz (cycles per second). The wavelength of a tsunami in deep water is about 500km (see the NOAA animation). From this we can compute the tsunami velocity to be about 200m/s or 450 miles an hour - about as fast as a commercial jet liner.

Fifth, many people might think that the NOAA tsunami buoys in the Pacific respond in some way to the sea surface response of the tsunami. The buoy, however, is just the platform for communicating the real time data to a satellite. Actually, the tsunami is measured by a pressure detector on the seafloor. (See the NOAA Deep-ocean Assessment Reporting of Tsunamis (DART) web page.) The bottom pressure sensors detect pressure fluctuations with periods longer than about 2minutes and they measure a change in sea level to better than 1mm (compared to a typical tsunami period of 6minutes and a small tsunami amplitude of about 3cm).

Together, these five messages advance the students' understanding of the interconnections between science, technology, engineering, and mathematics.

Project History

This experiment grew out of collaborative work in the Ocean Science Education Institute (OSEI), which develops and implements high quality ocean science education for middle school students through projects that connect with existing district curriculums and effective science educational practices. OSEI is a project of the Center for Ocean Science Education Excellence-New England (COSEE-NE), an NSF-funded partnership between the New England Aquarium, the University of Massachusetts/Boston, and the Woods Hole Oceanographic Institution (WHOI). The OSEI format includes a five-day workshop, numerous classroom visits, and two follow-up days. During the 2004-2005 school year, researchers and Massachusetts middle school teachers, district science coordinators, and facilitators teamed up to produce district-wide, inquiry-based science curricula for middle school students based on current ocean science research. To find out more about OSEI and other COSEE-NE programs, please visit our website at **www.cosee-ne.net**.

Class Outline

The following notes were used by Ralph as an outline for his classroom visits:

1) Introduction (7.5 minutes) - Talking with some powerpoint slides and answering questions.
  a) Who am I?
  b) What is WHOI?
  c) What do I do? Life at sea.
  d) Students should consider "scientist" as a career.
  e) Education required.

2) Waves (7.5 Minutes) - Talking with some powerpoint slides and answering questions.
  a) Why do we care about waves? What would life be like without waves?
  b) Types of waves.
  c) Tsunamis as an example of waves. Tsunamis have small amplitude (few centimeters) in the deep ocean but the amplitude grows in shallow water (10's of meters) and the waves "break".
  d) Waves transport energy without transporting mass.
  e) Wavelength, amplitude, period and frequency
  f) The Plymouth Wave Lab.

3) Introduction to the demonstrations of different wave phenomena at five stations. (5 minutes)

4) Students work with the five hands-on demos in small groups (about 5 minutes each). Written instructions with questions at each station.

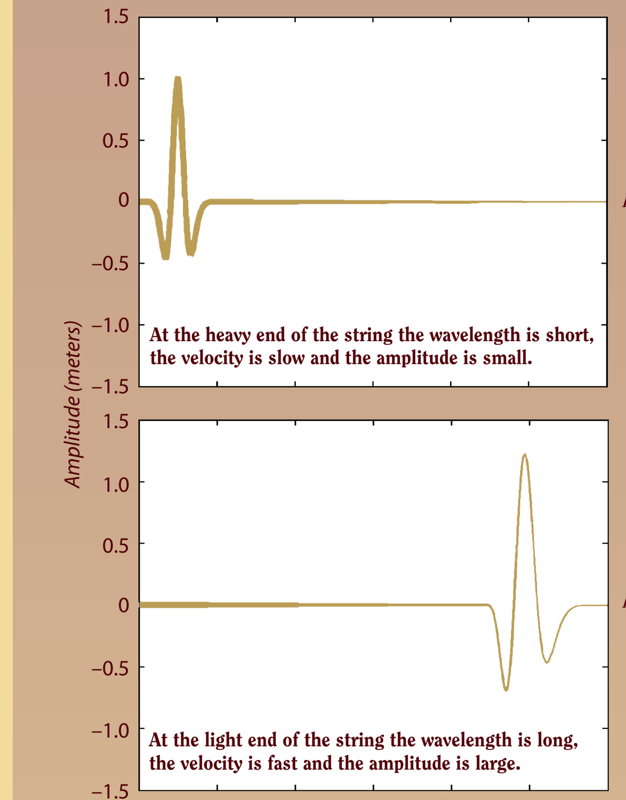

Figure 1: Snapshot at 0.25 sec.

Figure 2: Snapshot at 1.15 sec.

Figure 3: During the classroom visit students generated "tsunamis" by exciting waves on a tapered string of elastic bands, paper clips and washers.

Figure 4: Frequency and period are used to describe waves. Here students measure the frequency and period of a pendulum.

Station Questions for the NE COSEE OSEI Wave Class

This is a list of questions for the five stations in the "wave class". The stations can be run through in any order.

1) Simple Harmonic Motion Stand - This station shows a mass bouncing on a spring. It demonstrates frequency and period. Pull the mass down and release it so that it bounces up and down. With a stop watch or your own wrist watch measure the time it takes (in seconds) for the mass to return each time to the bottom position. Then take the time it takes for each cycle is called the period. Start the mass bouncing again and count how many times it hits bottom in a minute. This is the frequency in cycles per minute.

Period - P _______ seconds

Frequency - f _________ cycles per minute

[Further work: Convert the frequency to units of "cycles per second" by dividing the "cycles per minute" number by 60. Why? Then take the reciprocal of f (1/f). Compare this to the period.

Frequency - f _________ cycles per second

Reciprocal frequency - 1/f __________ seconds per cycle

Note: The unit of frequency is usually cycles per second. This unit is called Hertz (or Hz for short). The period should equal the reciprocal frequency. Does yours?]

2) Small Wave Tank - This tank contains a layer of (clear) lamp oil over a layer of (green) water. By tilting the tank slowly back and forth you can generate small amplitude waves that travel back and forth on the surface of the oil and at the interface between the oil and the water. These are like the wind-driven waves on the ocean far from the beach.

How do the waves that hit the beach differ from the waves that are farther offshore?

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[Further work: Are the wavelengths of the waves at the surface of the (clear) oil the same as at the interface between the oil and the (green) water? If not, how do they differ?]

3) Slinky - Stretch the slinky out on the floor. Stop all motion on the slinky. Move one end sideways to generate a transverse wave. Measure how long it takes for the transverse wave to reach the end of the slinky. Stop all motion on the slinky. Compress the coils at one end of the slinky and release them quickly to generate a compressional wave. Measure how long it takes for the compressional wave to reach the end of the slinky.

Time for transverse wave - _______ seconds

Time for compressional wave - _________ seconds

Which type of wave travels fastest on a slinky - transverse or compressional? _________________

4) Elastic Bands and Washers - Equal Weights - (See instructionss below) Two students stretch the elastic band between them hanging in the air. On this string, the same number of washers has been added at each joint between the elastic bands. One student - the receiver - holds the cord steady at his/her end. The other student - the source - flicks his/her end to send a transverse traveling wave down the string. The other student(s) should stand back from the string so that they can see the wave travel down the whole string. How does the amplitude of the wave change as it travels down the string?

[Further work: Can you excite a standing wave? How?]

5) Elastic Bands and Washers - Tapered Weights - (See instructions below) Two students stretch the elastic band between them hanging in the air. On this string, a different number of washers has been added at each joint between the elastic bands. The mass of the string gets less towards the end with the cord. One student - the receiver - holds the cord steady at his/her end. One student - the source - flicks his/her end to send a transverse traveling wave down the string. The other student(s) should stand back from the string so that they can see the wave travel down the whole string. How does the amplitude of the wave change as it travels down the string?

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[Further work: How does the amplitude behavior of the two elastic band demonstrations - uniform and tapered - differ?)

6) The Plymouth Wave Lab - This is a computer simulation of waves on a string. The instructor will show some examples in class, and then you can go to the web site below to see other examples on your own. At left (Figures 1 & 2) are snapshots at two different times (0.25sec and 1.15sec) of a pulse wave traveling down a tapered string (like a whip, Example #3). Measure the amplitude and wavelength of the pulse at each time (units of inches or centimeters are fine).

Amplitude at 0.25sec. ________________

Wavelength at 0.25sec ________________

Amplitude at 1.15sec ________________

Wavelength at 1.15sec ________________

How do the amplitude and wavelength change as the string gets smaller? ______________________

[Further work: How is this like a tsunami?] ______________________

How is this like a whip? ______________________

You can study these and other examples of waves on a string on the web at **http://msg.whoi.edu/String_Lab/New_String_Movies.html**

This is the word "tsunami" written in Japanese. The upper character, "tsu", means harbor. The lower character, "nami", means wave. So the word 'tsunami" means "harbor wave" in Japanese. It is a wave that only seems to occur in harbors or close to shore.

津波

This picture is often used to illustrate tsunamis. Oddly enough this is not a tsunami. It is just a breaking "wind wave" during a storm. You can tell by the wavelength. In this picture the wavelength, the distance between crests, is about as long as a boat, a few meters. Tsunamis have wavelengths of about 500km in deep water and about 1km in very shallow water. This picture, called "The Great Wave Off Kanagawa" (fugaku sanjurokkei kanagawaoki namiura) was created as a color woodcut by the Japanese artist, Katsushika Hokusai (1760-1849) in about 1831.

Instructions for Making Strings from Elastic Bands and Washers

An inexpensive "string" can be assembled from elastic bands linked together with small washers placed at the intersections of the elastic bands. For example, a uniform string can be assembled with five washers at each junction of the elastic bands. A tapered string can be assembled by starting with one washer at the first four junctions, two washers at the next four, and so on. These notes describe how to make two strings, one uniform and one tapered. Materials are available at office supply stores and hardware stores and can be purchased for about $20.

Materials:
1lb. - #32 rubber bands (3"x1/8")
500 - 2" paper clips (vinyl coated in six colors are nice)
1 roll - drafting or masking tape
400 - #10 (3/16") steel, flat washers
6ft of string

Procedure:
1) Identify 10 "volunteers" and 4 "assistants". The assistants pass out materials and the volunteers assemble the string. It is easiest if the volunteers are standing in a line. Ask the volunteers to number off from 1 thru 10 and to remember their number.

2) Ask Assistant #1 to give four paper clips to each volunteer. (It is nice if different colors are given to adjacent volunteers. For example, if you have six colors give one color each to the first six volunteers and then start the color scheme over again for volunteers 7 thru 10.)

3) For the uniform string, ask Assistant #2 to give twenty washers to each volunteer. Then the volunteers attach five washers each to each paper clip by sliding the washers over the arms of the paper clips until they are in the middle of the paper clip. For the tapered string, ask Assistant #2 to give each volunteer four times their number of washers. For example, volunteer #1 gets 4 washers, volunteer #2 gets 8 washers, and so on. Then the volunteers attach one quarter of their washers to each paper clip. Volunteer #1's paper clips get one washer each, volunteer #2's paper clips get two washers each, and so on.

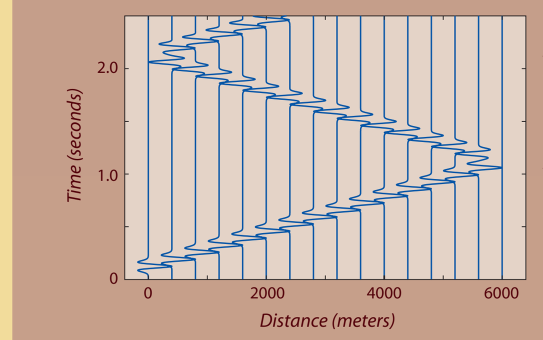
4) Ask Assistant #3 to give four rubber bands to each volunteer. Each volunteer should now assemble mini-strings consisting of paper clips and rubber bands alternately. This can be done by looping an elastic band around each end of a paper clip.

5) The volunteers now attach their mini-strings together to form a string of alternating elastic bands and paper clips.

6) Assistant #4 gives each volunteer four 1" to1-1/2" pieces of drafting tape. The volunteers wrap the tape around the paper clips to hold the washers in place. Ask volunteer #1 to attach the 6ft string to his/her end of the string.

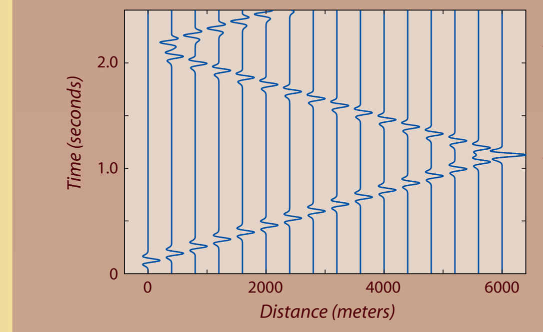
7) The string is about 10 feet long so you need plenty of room. Ask Volunteers #1 and #10 to pull the string until it is off the floor and reasonably tight. Volunteer #1 is the fixed end and should hold the end of the string. Volunteer #10 is the "source" and should flick the end of the string to send a traveling wave down the string. Usually only a few tries are needed to get the speed and amplitude of the flick large enough to have the traveling wave propagate down the length of the string. It is interesting to compare the amplitudes and speed of the propagating wave between the uniform and tapered strings.

Different Strings



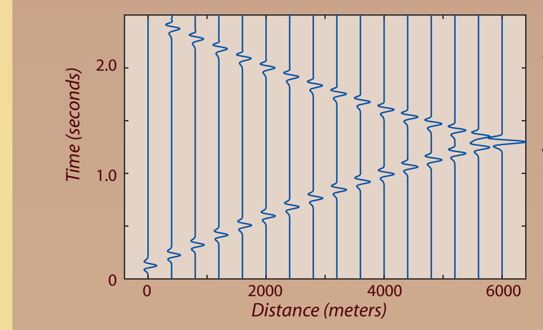
*Example 1: Time series for a wave on a string with a **fixed end**.*

*This figure shows time histories for selected points on the string. A pulse is started at the left hand side (like flicking a rope or garden hose). The wave travels down the string to the right and reflects from the fixed end. Note that the wave pulse comes back on the **opposite side of the string**.*



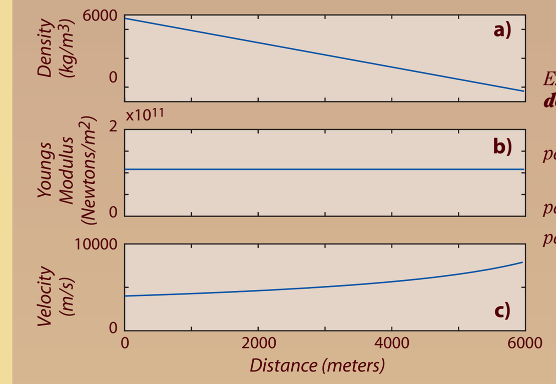
*Example 2: Time series for a wave on a string with a **free end**.*

*This figure shows time histories for selected points on the string. A pulse is started at the left hand side (like flicking a rope or garden hose). The wave travels down the string to the right and reflects from the free end. Note that the wave pulse comes back on the **same side of the string**.*



*Example 3a: Time series for a wave on a string with a free end – **density decreasing**.*

This figure shows time histories for selected points on a string. In this example the string has been made lighter gradually from left to right. As the wave travels down the string the wavelength increases, the wave velocity increases and the amplitude increases.

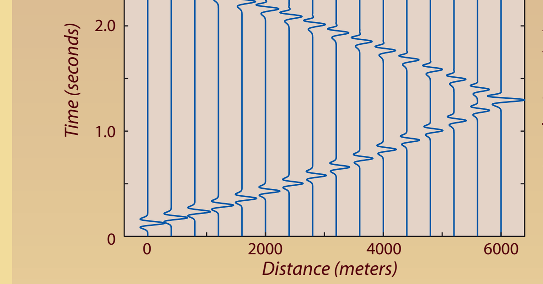


*Example 3b: A tapered string – **density decreasing**.*

*panel **a**): Density is decreasing linearly from 6750 to 1700 kg/m³ over 6000 m*

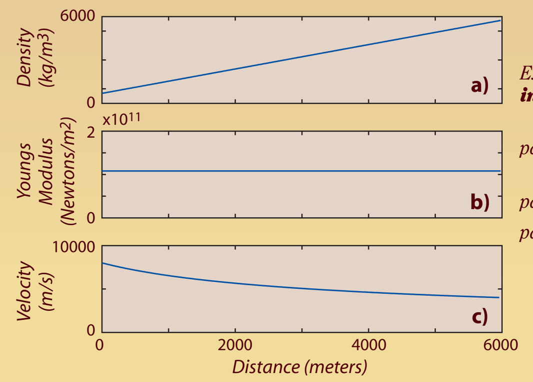
*panel **b**): Youngs modulus is kept constant*

*panel **c**): Velocity is increasing non-linearly from 4000 to 8000 m/s over 6000 m*



*Example 4a: Time series for a wave on a tapered string with a free end – **density increasing**.*

In this example the string has been made heavier gradually from left to right. As the wave travels down the string the wavelength decreases, the wave velocity decreases and the amplitude decreases.



*Example 4b: A tapered string – **density increasing**.*

*panel **a**): Density is decreasing linearly from 1700 to 6750 kg/m³ over 6000 m*

*panel **b**): Youngs modulus is kept constant*

*panel **c**): Velocity is increasing non-linearly from 8000 to 4000 m/s over 6000 m*

Student Evaluations

The classroom visit to Mr. Strohschneider's class was evaluated by the students in a "3-2-1 Reflection". The questions and some examples of the student's responses are given below:

1) What are three things that you learned or re-learned about tsunamis, waves, or the work of a research scientist from Dr. Stephen's classroom visit and waves lesson on April 8, 2005?

A) One thing I learned about tsunamis is that earthquakes cause tsunamis.

One of the things I learned about tsunamis is they have a very fast run-up.

One thing I learned was tsunamis are not necessarily bigger than wind waves.

B) Another thing I learned is the less weight on a wave the more it bounces.

Another thing I learned about tsunamis is when a tsunami is coming it gets really low tide within 10 or 15 minutes.

I also learned that tsunamis take a lot longer to reach shore.

C) Finally I learned that if a earthquake occured in the sea around the Canary Islands a super tsunami would occur in Plymouth.

The last thing I learned about tsunamis is when they do an expedition they look for all types of people to come like scientists, engineers, mechanics and other people.

Finally I learned that two signs of a tsunami are the tide suddenly gets lower, or if you feel an earthquake.

2) What are two things that you liked about Dr. Stephen's waves lesson and classroom visit?

A) One thing I liked is how Dr. Stephen presented his information.

One of the things I liked about Dr. Stephen's wave lesson was the powerpoint.

One thing I liked about Dr. Stephen's wave lesson was the slide show. I thought it was a good way to the present the info.

B) Another thing I liked is how Dr. Stephen spoke in the lesson.

The second thing I liked was all the activities he had set-up for us.

I also liked the different stations he set up for us. (the pendulum, elastics, slinky, computer, wave box)

3) What is one thing that you still would like to know more about? Or what is one thing that you still do not understand? Or what is one thing that you would have had more time for during Dr. Stephen's visit?

One thing I wished we went over more is the super tsunami.

When Dr. Stephen came I wish we had more time for the activities. My group only got to do two.

One thing I would still like to know is what weather conditions do you need to have a tsunami? Or do only earthquakes, volcanoes, etc cause a tsunami?

Conclusions

The teachers involved in the project will be using Ralph's curriculum again in the 2005/2006 school year, and it will be taught to 250 of the 500 seventh graders at PCIS. In addition, as a result of Ralph's involvement, Boston College's Seismic Observatory donated a seismograph to the Plymouth schools, and the teachers will receive training this winter on how to bring seismographic data directly into their classrooms.

Acknowledgments

OSEI Program Principle Investigator: Bob Chen, Ph.D. (UMass/Boston); OSEI Program Coordinator: Kim Frashure, Ph.D. Candidate (UMass/Boston); COSEE-NE Communications Manager: Catherine Cramer; Plymouth Public Schools Team: Science Coordinator Nick Micozzi; teachers Mary Lavin, Derek Strohschneider, and Richard Maichle from the Plymouth Community Intermediate School (PCIS) and Plymouth South Middle School (PSMC). Plymouth Wave Lab was written by Ralph Stephen, Ph.D. and Tom Bolmer under funding from the National Science Foundation under Grant #OCE-0424633.