Name_______________

OCEA 113: Lab 9
Waves

Introduction

All waves are generated by a disturbing force. For example, a rock thrown into a still pond will generate a disturbance and produce waves that radiate out in all directions. Ocean waves are caused by a similar transfer of energy. Waves can be initiated by wind blowing across the surface of the ocean (surface waves), between the boundaries of water with different densities (internal waves), or from the uplift or downdroping of large areas of the sea floor such as an earthquake or an underwater landslide (turbidity current).

Waves are simply energy in motion. Different types of waves can move in a variety of ways. **Progressive waves**, waves that oscillate uniformly and travel without breaking, are divided into three categories (1) **longitudinal waves**, (2) **transverse waves**, (3) **orbital waves**. Longitudinal waves are compressional meaning the energy is pushed and pulled in the same direction that the wave is traveling (similar to a slinky that contracts and expands as it moves). The disturbing force for a longitudinal wave is initiated in the same direction that the wave is traveling. The disturbing force that initiates a transverse wave travels at a 90° angle to the direction in which the energy propagates and generates a waveform that resembles a sine curve. Both longitudinal and transvers waves are considered **body waves**. An orbital wave shares components of both longitudinal and transverse waves, which generates motion in circular orbits. Waves in the ocean are orbital waves (Figure 1).

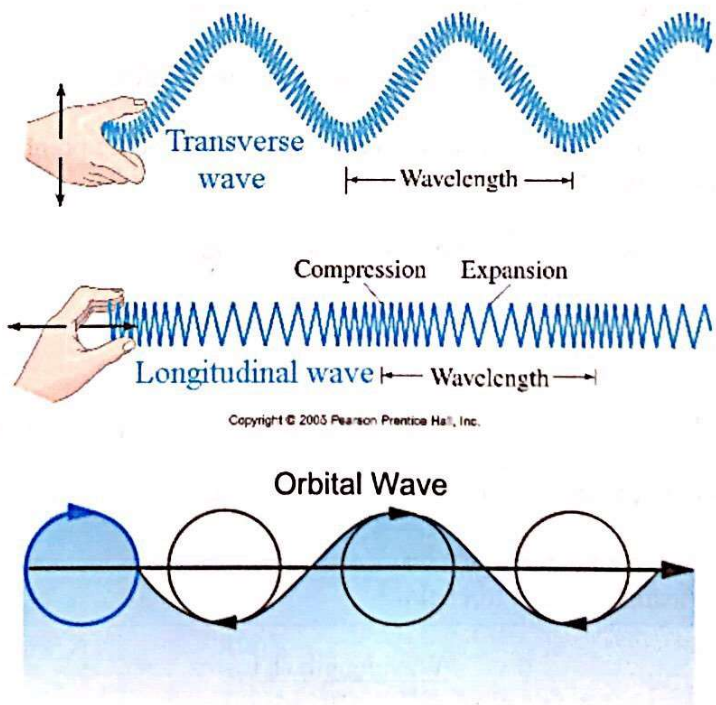


Figure 1. Progressive waves

Wave Terminology

In order to understand waves, it's important to first understand basic wave terminology. The terminology that you will need for this lab is illustrated in Figure 2 below and defined below the figure. Refer back to this information while you complete the lab when needed.

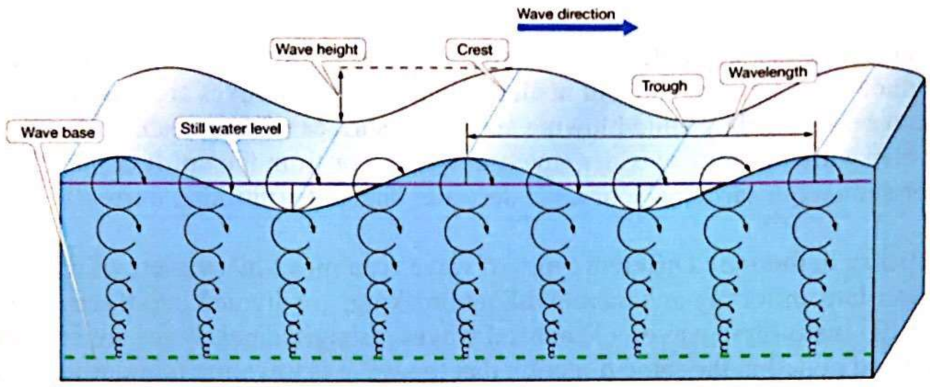


Figure 2. Basic wave structure

Crest – upper most displacement of the wave (top of the wave)

Trough – lower most displacement of the wave (bottom of the wave)

Still Water Level – halfway between crests & troughs, zero energy level

Wavelength (L) – the horizontal distance between any two corresponding points on successive wave forms (crest to crest or trough to trough)

Wave Height (H) – vertical distance between a crest and a trough

Wave Steepness – $\frac{\text{Wave height (H)}}{\text{Wavelength (L)}}$

Wave Period (T) – the time it takes one full wave (one wavelength) to pass a fixed position

Frequency (f) – the number of wave crests passing a fixed location per unit time

Wave Base – the maximum depth in which a wave causes significant movement of the water which is calculated using the equation below:

$$\frac{\text{Wavelength (L)}}{2}$$

Part 1. Understanding Deep-Water Waves

Deep-water waves are found in the ocean where the water depth is greater than the wave base (L/2). Deep-water waves do not come into contact with the ocean floor and thus occur in parts of the ocean where the water depths far exceed the wave base. Since the wave does not interact with the seafloor, deep-water waves are characterized by their wavelength and wave period. The wave speed of a deep-water wave can be calculated by dividing the wavelength by the wave period.

$$\textbf{Wave Speed (S)} - \frac{\text{Wavelength (L)}}{\text{Period (T)}}$$

To illustrate how we can use this equation to calculate wave speed, let's go through an example using Figure 3 below.

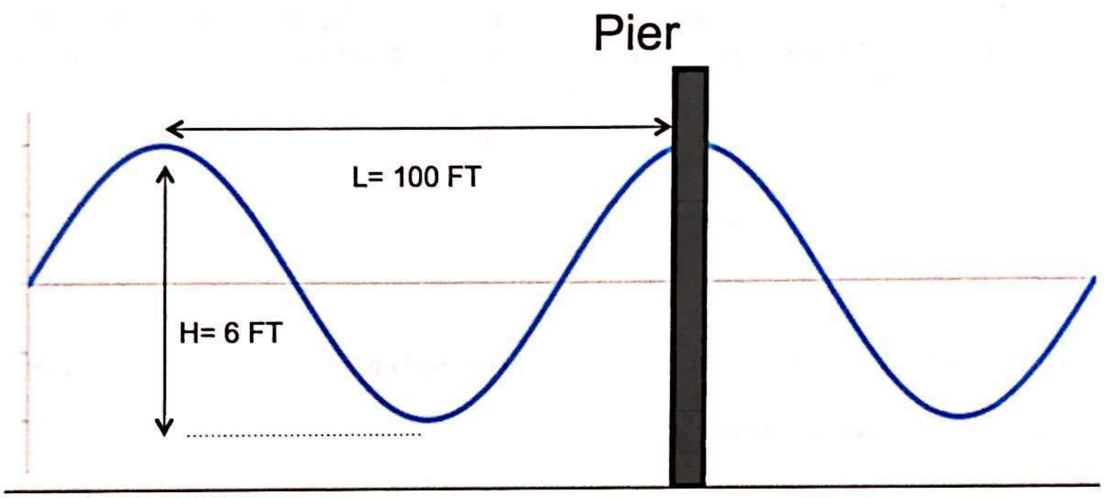


Figure 3.

In the wave in Figure 3 (above) the wave has a wavelength of 100 feet and a wave height of 6 feet. It is moving past the pier such that 10 seconds later one full cycle of the wave has passed. This means that if the wave has gone 100 feet in 10 seconds, the wave speed can be calculated by dividing 100 feet (L) by 10 seconds (P) which is equal to a speed of 10 feet per second.

Now apply what you learned in the example above to answer questions 1-4.

1. If a wave has a period of 8 seconds & a wavelength of 40 feet, what is the wave speed?

2. If a wave has a speed of 15 feet per second and a period of 3 seconds, what is the wavelength?

3. If a wave has a speed of 13 feet per second and a wavelength of 52 feet, what is the period?

4. A wave passes by you as you sit on your surfboard. It appears to be moving at 8 feet per second. 4 seconds later another wave passes by. What is the wavelength of the wave?

For equations 5 & 6, remember that the wave base is equivalent to half of the wavelength.

5. If a wave with a 40 feet wavelength is moving in 30 feet of water is it a deep-water wave? Why or why not? Show your work!

6. Imagine that you are a submarine captain navigating your vessel through the tropics. You have just been notified that there is a hurricane above you and that you need to dive deeper in order to stay clear of the storm. The seas currently have a height of 40 feet and a wavelength of 300 feet. How deep do you have to be underwater so that you can escape the wave motion?

7. For each statement below concerning deep-water waves, explain why the statement is true or false:

   a. The longer the waver, the deeper the wave base.

   b. The greater the wave height, the deeper the wave base.

   c. The longer the wave, the faster the wave travels

   d. The greater the wave height, the faster the wave travels

Part 2. Understanding Shallow Water Waves & Tsunamis

Shallow water waves, unlike deep-water waves, interact with the seafloor. Thus, the characteristics of a shallow water wave are determined by depth. Shallow water waves are found in locations when the depth of the water is less that 1/20th of the wavelength (L). The speed of a shallow water wave is calculated by taking into consideration the gravitational acceleration of the wave (a constant) and depth.

As deep-water waves transition into shallow water waves the wave speed decreases, the wavelength decreases and the wave height increases (Figure 4).

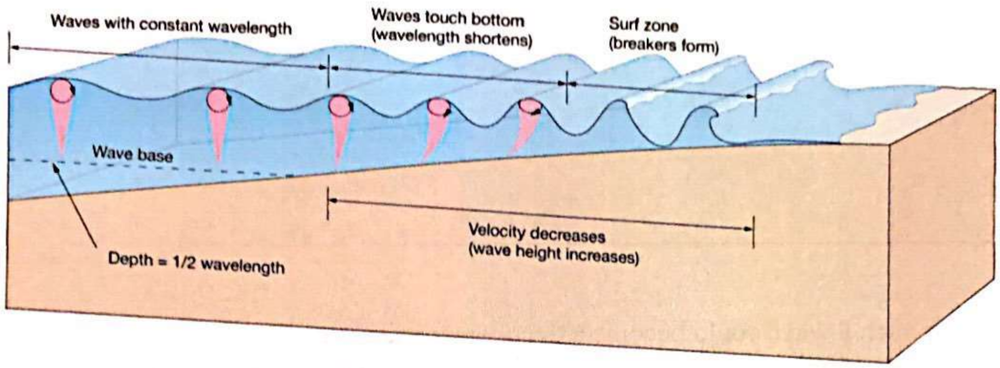


Figure 4.

When the wave steepness (H/L) exceeds the ratio of 1/7 (0.1428) the wave will break because the wave is too steep to support itself, thus this ratio dictates the maximum height of a wave.

1. If you are surfing and see a wave coming toward you with a wavelength of 100 feet and a wavelength of 15 feet, will the wave break before it reaches you or will you be able to catch the wave and ride it into shore?

Tsunami are waves that are generated by geologic movement of the seafloor. They typically have long wavelengths (>125 miles) and therefore they are characterized as shallow-water waves and controlled by water depth. Tsunami move at great speeds and can reach over 500 miles per hour.

2. Using the information above about tsunami and the information you have learned about shallow water waves, describe what happens when a tsunami comes ashore. Make sure to include how wave speed, wavelength and wave height would be impacted.

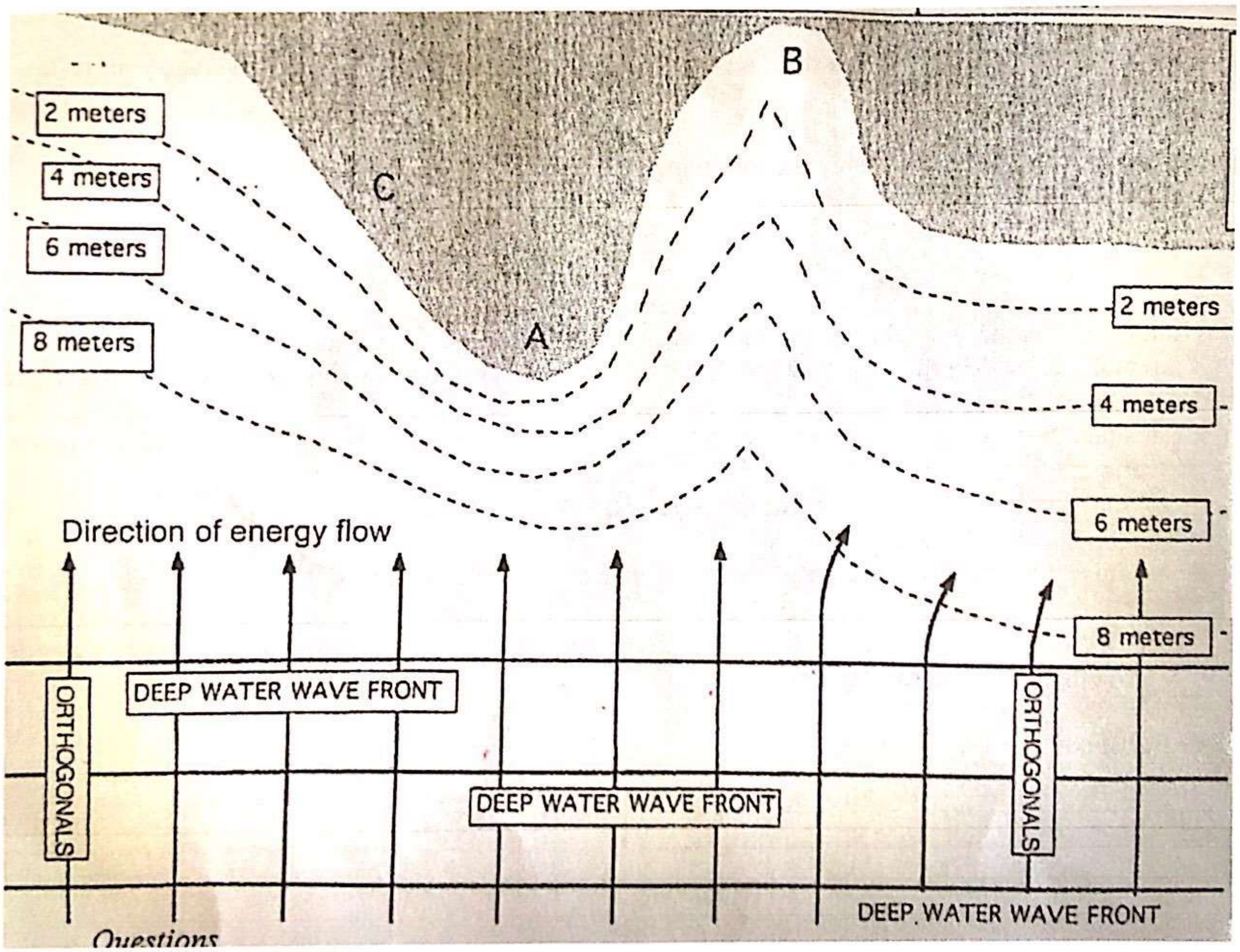
3a. What ocean depth would be required for a tsunami with a wavelength of 136 miles to travel as a deep-water wave?

b. Is it possible that such a wave could become a deep-water wave any place in the ocean considering that the deepest part of the ocean is about 7 miles deep? Why or why not? Show your work!

Part 3. Wave Refraction

Waves seldom approach a shore at a perfect right angle (90°), instead some segment of the wave with interact with the seafloor first and will begin to slow before the rest of the wave. This results in refraction, or bending, of each wave crest as it approaches the shoreline. The refraction of waves along an irregular shoreline distributes wave energy unevenly along the shore. Orthogonal lines are used to illustrate how energy is distributed. These lines are always oriented perpendicular to the wave crests and are spaced so that energy between lines is equal at all times and are used to show variations in wave energy.

For this exercise, you will predict the flow of wave energy understand how the wave energy is distributed along the shoreline. In Figure 5 (below), the dotted lines are isobaths which represent lines of equal depth. Each wave will refract along the coastline so that each orthogonal line will be perpendicular to the isobaths. **To complete this exercise, draw in orthogonal lines that initiate at each arrow and propagate toward the shore and answer the follow up questions below.**



1. What point on land is receiving the most energy? Why?

2a. Where is the best place to go surfing? Why?

b. Where is the best place to go diving (if you want to avoid strong waves)? Why?

Part 4. Shallow Water Wave Experiment

For this experiment, you will measure the speed of shallow water waves as a function of water depth and compare the results to the theoretically predicted wave speed. First, attain an aquarium and fill it with 1800 milliliters (1.8 L) of water. This is equivalent to a water depth of 1 centimeter. Now it's time to begin your experiment!

Step 1: Carefully lift one end of the aquarium about 2 inches off the table and quickly (but carefully) set it back down on the table to generate a shallow water wave. You should see a wave initiate and move travel across the aquarium.

Step 2: Measure the time it takes for the wave to make 3 complete round trips of the aquarium (to the other side of the aquarium and then back to the starting point). To start the measurement, wait until the wave reaches the far side of the aquarium and then start the clock. Make sure to record your time in the table below.

Step 3: To ensure the integrity of your data, repeat the measurement a second time and average your results in the table below.

Step 4: Calculate the wave speed using the following equation:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

You have measured the time in the experiment, and to calculate the distance the wave has traveled you can multiple the length of the tank (60 cm) by 6 (the number of times the wave traveled that distance).

Step 5: Calculate the theoretical speed of a shallow water wave. To calculate this we will use the following equation:

$$\text{Wave Speed (cm/s)} = 31.11\ \sqrt{\text{depth}}$$

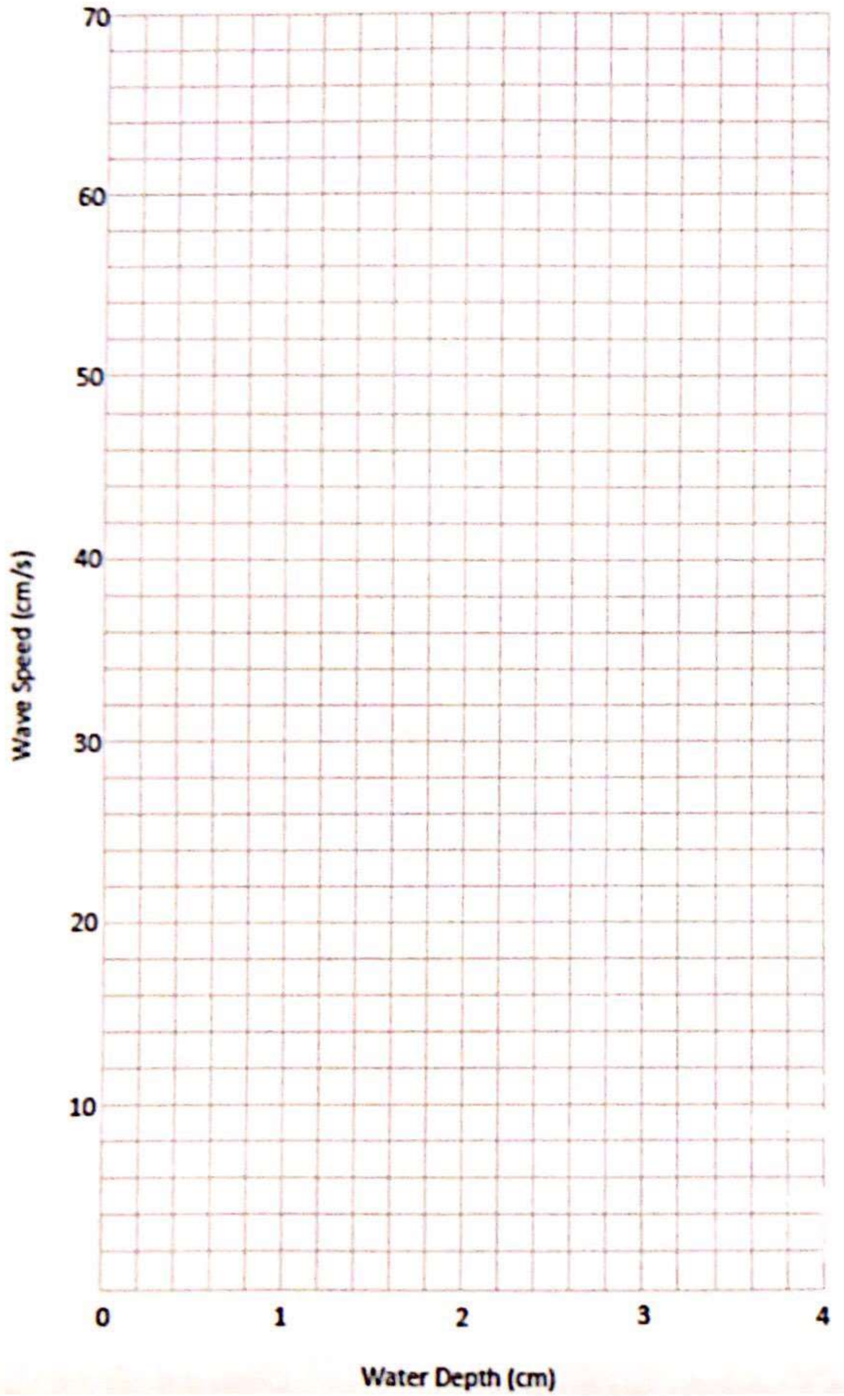
This equation accounts for the gravitational acceleration constant (31.11 cm per second).

Step 6: Repeat the steps for different water depths (2 cm, 3 cm and 4 cm). Each additional 1 cm of water depth will require an additional 1800 mL of water.

Data Collection:

Depth (cm)	Time #1 (3 round trips of aquarium)	Time #2 (3 round trips of aquarium)	Average Time (#1 + #2) / 2	Speed (calculated based on measured time)	Speed (calculated based on theoretical equation)
1					
2					
3					
4					

Once you have collected data for all water depths and calculated the empirical and theoretical waves speeds, plot the calculated speeds as a function of water depth on the graph on the next page. After plotting the points draw a reasonable cure through the data and label each one appropriately. Synthesize what you learned during the experiment by answering the follow up questions.



1. Compare the empirical and theoretical curves you plotted above. What can you conclude about the results? If you observe any differences between the curves what factors might drive those differences?