Activity: Standing Waves
Create standing waves in a wave tank. Examine the effect of frequency and length of wave pulse on wavelength (L), wave height (H), wave speed (S), and wave period (T).

Materials

- Long wave tank
- Paddle that fits snugly in the width of the wave tank
- Water
- Ruler
- Two paint stirrers or additional rulers
- Masking tape
- Metronome or sound recording of 100 beats per minute and 120 beats per minute
- Construction paper
- Pencil

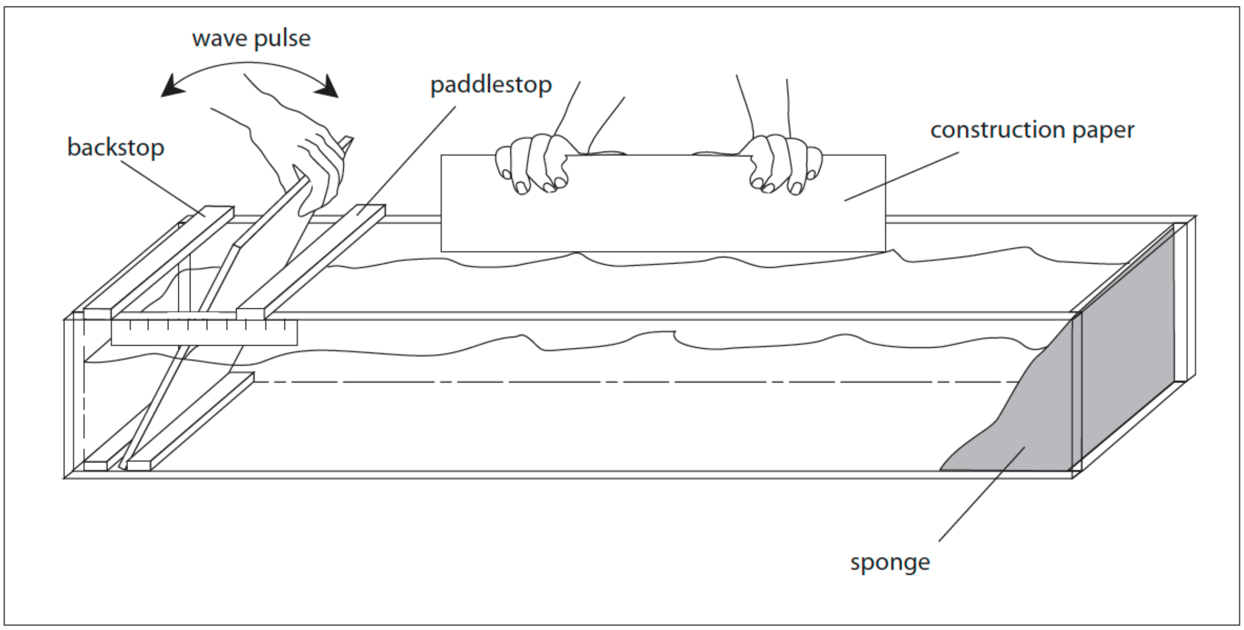

Fig. 4.5. Making a watermarked wave profile picture in a long wave tank. Byron image 3-1. Make wave tank more narrow and set initial paddlestop clearly 5 cm from backstop (do not label, just make change ruler). Take out sponge. Fill tank only half way. Label paddle groove. Put paddle perpendicular to backstop. Make construction paper longer

1. Set up long wave tank as shown in Fig. 4.5.
    a. Fill the wave tank about half way full with water.
    b. Tape one paint stirrer to the end of the wave tank as a backstop. The backstop should be positioned to prevent the paddle from going past vertical. The backstop keeps the paddle from splashing water when you move the paddle back and forth.

c. Tape one paint stirrer 5 cm in front of the backstop. This is your paddlestop. The paddlestop will help you to accurately control the amount of water pushed by limiting the distance the paddle can move.

2. Set your paddle in the paddle groove and practice generating standing waves. **Standing waves** do not advance; they appear to move up and down in place. Try to make as many standing waves in your tank as you can.

3. Make watermarked profiles of standing waves at two frequencies and two paddlestop distances.
    a. Make a standing wave at a frequency of 100 beats (waves) per minute and a paddlestop distance of 5 cm.
        i) Make sure the distance from the backstop to the paddlestop is 5 cm.
        ii) Use the metronome or sound recording to generate waves at a consistent and accurate frequency of 100 waves per minute. The paddle should hit the paddlestop once per beat.
    b. Print a watermark profile of the standing waves.
        i) Tape construction paper together to obtain a sheet about two-thirds the length of the wave tank.
        ii) Hold the construction paper lengthwise near the corners just above the water level.
        iii) To make a wave profile, dip the paper in and out of the water quickly, but carefully. The watermarks on the paper will show the profile of the waves at the instant the paper was dipped into the water.
        iv) Trace the profile of the waves with pencil before the paper dries.
    c. Label the watermark profile as shown in Fig. 4.6 with the following:
        i) Paddle-stop setting (cm)
        ii) Wave frequency (number of waves per minute)
    d. Analyze your watermarked profile for wavelength and wave height. Label these measurements on your watermark profile and record your measurements in Table 4.3.
        i) Measure the wavelength as the distance from wave crest to wave crest, as shown in Fig. 4.6.
        ii) Measure the wave height as the vertical distance from the trough to the crest, as shown in Fig. 4.6.
    e. Repeat steps 1a.-1d. for the following conditions:
        i) At a frequency of 120 beats (waves) per minute and a paddlestop distance of 5 cm.
        ii) At a frequency of 100 beats (waves) per minute and a paddlestop distance of 10 cm.
        iii) At a frequency of 120 beats (waves) per minute and a paddlestop distance of 10 cm.

Table 4.3. Effects of frequency and length of wave pulse on wavelength (L), wave height (H), wave speed (S), and wave period (T)

	Number of wave pulses per minute (frequency)	
Length of wave pulse paddle-stop setting (cm)	Frequency (F) = 100 waves per minute = 1.7 waves per second	Frequency (F) = 120 waves per minute = 2 waves per second
5 cm	Wavelength (L) = Wave height (H) = Wave speed (S) = Wave period (T) =	Wavelength (L) = Wave height (H) = Wave speed (S) = Wave period (T) =
10 cm	Wavelength (L) = Wave height (H) = Wave speed (S) = Wave period (T) =	Wavelength (L) = Wave height (H) = Wave speed (S) = Wave period (T) =

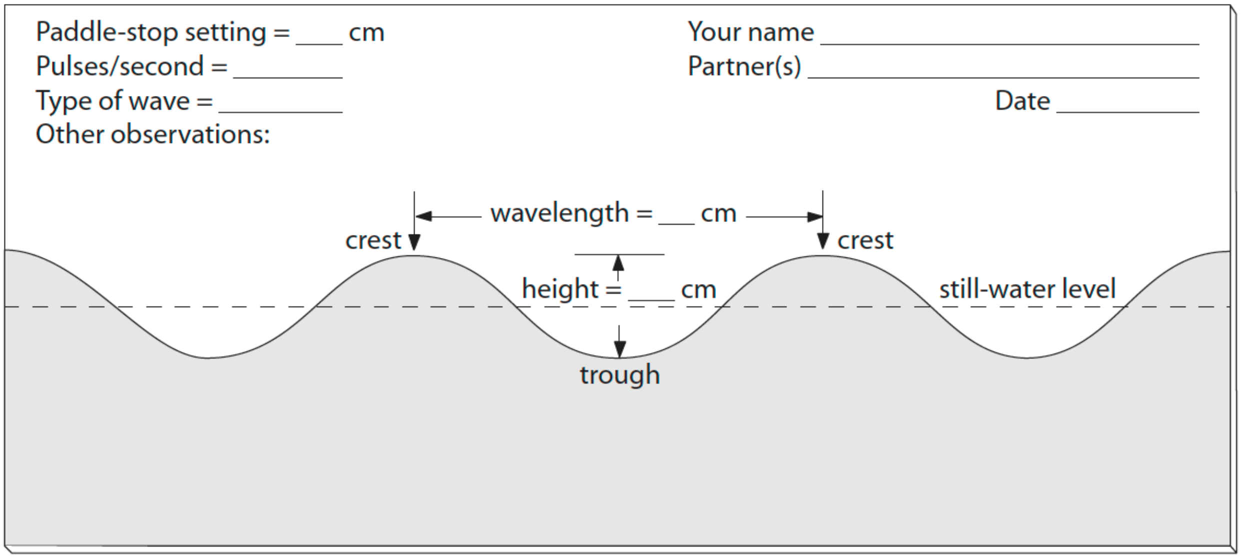

Fig. 4.6. Analysis of a watermarked wave profile picture. Byron image 3-2. Redraw to take out "type of wave".

Activity Questions

1. Standing waves form in the ocean under natural conditions when two wave sets of the same height travel towards each other. Explain how it is possible to simulate standing waves in a wave tank.

2. As the frequency of waves increased from 100 to 120 beats per minute, what happened to the wavelength:
    a. at the 5 cm paddlestop setting?
    b. at the 10 cm paddlestop setting?
    c. Do your results agree with the formula frequency = speed ÷ wavelength? Explain and make a generalized statement about the relationship between frequency and wavelength.

3. How did the frequency and paddlestop setting affect the height of the waves? Explain your findings.

4. A frequency of 100 waves per minute is equal to a frequency of 1.7 waves per second. A frequency of 120 waves per minute is equal to a frequency of 2 waves per second.
    a. Use this information and your measured wavelength to calculate wave speed in centimeters per second for each of the four standing waves you measured. Record your results in Table 4.3.
    b. Use your results to make a graph of frequency (x-axis) verses speed (y-axis) for each paddlestop setting.
    c. Use your graph to make a general statement about how increased frequency affects wave speed.

5. The period of a wave is the inverse of its frequency. Use this relationship to calculate wave period in seconds per wave. Do waves with a longer period generally move faster or slower than waves with a shorter period? Explain your answer.

Teacher Tips and Tricks: Standing Waves Activity

Wave Tank

Clear Wave Tank

Long narrow wave tanks of clear plastic or glass are best so students can see the waves easily. This activity was trialed in an acrylic custom tank 1.40 m (~4.5 ft) long, 30 cm (~1 ft) high, and 12 cm (~4.7 in) wide. Frequencies of 100 and 120 waves per minute work well with this size tank. Different sized wave tanks will work just as well as long as the width is much narrower than the length. Depending on the size of the tank, the recommended frequencies may have to be adjusted.

Flower Box Tank

If you do not have a clear tank you can use a 30 inch long molded plastic window flower box (the longest size generally stocked at large home improvement stores).

- Increase the frequencies to 130 and 150 waves per minute and decrease the paddlestop distance to 2.5 and 5 cm so the wavelength is short enough for students to capture a complete wave profile.
- If your window box has decorative horizontal grooves, the water level should be below the groove to maintain a clean wave profile.
- A paddle groove can be created from clay or by building ridges with a hot glue gun.
- Instead of taping rulers or paint stirrers to the flower box to serve as a backstop and paddlestop, you can cut slits into the side of the box with tin snips or a hacksaw to create grooves where wooden skewers (or similarly sized objects) can sit.
- A longer wave tank can be created by cutting two flower boxes and securing them together with silicon adhesive to create a watertight seal. With this longer tank you can keep the frequencies at 100 and 120 waves per minute. Because the height of the waves with lower frequencies is higher, it is a little easier to create wave profiles.

Using Technology

Taking Pictures

If a clear wave tank is being used, students can take pictures of their waves to determine wavelength and height. Tape a ruler to the side of the tank (parallel to the width) to use as a distance reference. Images can be analyzed in an image- processing program such as ImageJ. ImageJ software was developed at the National Institutes of Health (NIH) and is open source (i.e. free!). Taking pictures of waves is an important option to keep in mind if students are struggling to get good wave prints.

Metronome

There are many free websites and programs online that provide metronome services. If you are doing the procedure as a class, you can use a metronome on speakers for the whole class. For groups progressing through the activity separately or if your class is too noisy to hear a metronome over speakers, individual metronomes have to be used. One option is for students to download a free metronome app to their phones and listen to the beats with headphones.

Data Collection

Watermark profile

Watermark profiles (a.k.a. waveprints) can be made using several types of paper, however, construction paper works the best. Obtaining usable profiles may take some practice. It may be helpful to have students work as a team.

- One person should focus on creating the waves with the metronome and paddle stop.
- One person can watch the waves in the wavetank and let the team know when standing waves have been created.
- One person can hold the construction paper and make the profile.

Watermarks are not permanent, they will dry out after a short period of time. As the construction paper dries, the wave shape may change as water is absorbed throughout the paper through capillary action. Thus, it is important for students to trace their profiles quickly so they can take their time completing measurements.

Replication

If the students are measuring wave heights and lengths that are not consistent with what is expected, taking repeated measurements may be necessary. Replicating and then taking an average reduces the influence of any unusual measurements.

Results

T-Table 4.3. Sample results for Standing Waves activity in a custom tank, Results will vary based on wavetank size and shape. Sample results are shown for two trials for each combination of frequency and length of wave pulse.

	Number of wave pulses per minute (frequency)	
Length of wave pulse Paddle-stop setting (cm)	Frequency (F) = 100 waves per minute = 1.7 waves per second	Frequency (F) = 120 waves per minute = 2.0 waves per second
5 cm	Wavelength (L) trial 1 = 53.0 cm trial 2 = 51.5 cm average = 52.3 cm Wave height (H) trial 1 = 2.0 cm trial 2 = 2.6 cm average = 2.3 cm Wave speed (S) = 88.8 cm per sec Wave period (T) = 0.59 seconds	Wavelength (L) trial 1 = 37.5 cm trial 2 = 38.0 cm average = 37.8 cm Wave height (H) trial 1 = 5.5 cm trial 2 = 5.7 cm average = 5.6 cm Wave speed (S) = 75.5 cm per sec Wave period (T) = 0.50 seconds
10 cm	Wavelength (L) trial 1 = 53 cm trial 2 = 50.4 cm average = 51.7 cm Wave height (H) trial 1 = 7.0 cm trial 2 = 5.5 cm average = 6.25 cm Wave speed (S) = 87.9 cm per sec Wave period (T) = 0.59 seconds	Wavelength (L) trial 1 = 37.5 cm trial 2 = 38.5 cm average = 38.0 cm Wave height (H) trial 1 = 8.0 cm trial 2 = 7.8 cm average = 7.9 cm Wave speed (S) = 76.0 cm per sec Wave period (T) = 0.50 seconds