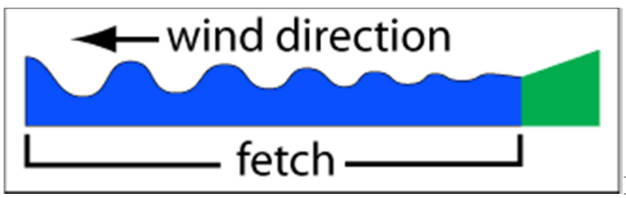
The Science of Water Waves

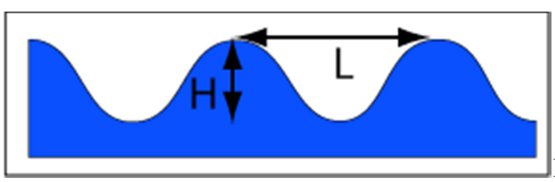
Water Waves

by Michael Konrad

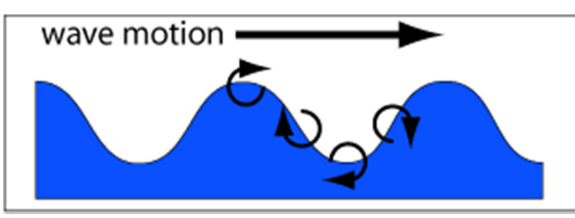
Any disturbance can cause a water wave. A pebble striking the surface, movement of a boat, movement of the earth during an earthquake, or the wind. Here we focus on wind generated waves, although the same principles apply to all water waves.



Fetch is the distance over which the wind interacts with the water surface to creates waves. The longer the fetch the bigger (higher) the waves are. If the shore (green in the diagram) is a hill, there will be a wind shadow which gives protection from the wind, but even if the shore is flat as a pancake and gives no protection, the waves become progressively smaller as you for upwind to the shore. Thus, rowing upwind toward shore is always an escape from waves.



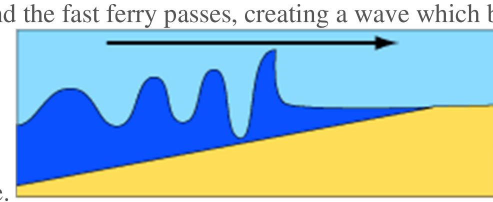
Height and Length of a simple wave (also called a sine wave) are indicated on the left. On the real water the surface often doesn't have this simple shape, rather the surface is the combination of waves with different lengths and heights.



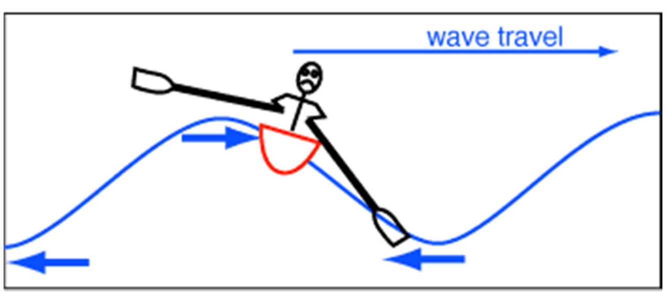
Motion of the water is different than the motion of the wave. Water at each location moves in a circular path, but the motions at different locations are "out of phase", which means that when water at the left of the diagram is moving to the right, water a quarter of a wavelength to the right is moving down, and water next to it is moving to the left, and next to it is moving up, etc. The overall effect is a an "apparent" wave moving to the right. Thus, the velocity (speed) of a wave is not at all the same as the velocity of the water.

The horizontal movement of the water when a wave passes is approximately equal to the up and down movement of the water. If you are on flat water and are parallel to waves made by a passing boat, your boat will move side-to-side as much as up-and–down as the wave passes under you. The side-to-side movement actually creates most of the difficulty in balancing the boat in such a situation. However, under typical conditions in the bay there can be such varied wave action that you can't easily distinguish horizontal and vertical motion.

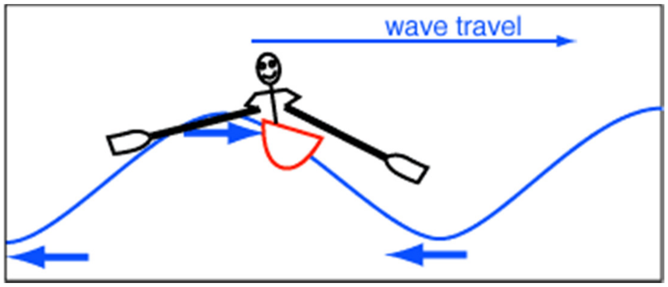
Using this knowledge in a common situation

You are rowing along the shore of Angel Island and the fast ferry passes, creating a wave which becomes steep as it moves into shallow water near the shore. 

Unfortunately, the direction of water movement at the top and bottom of the wave (thick arrows) rotate the boat in the direction you don't want to go. As you realize this you try to pull your down-hill oar up out of the water, but this just pulls you over more in the bad direction. I spare you, gentle reader, a picture of the result. As the wave carries your boat up to a crest you try to lean into it to keep the boat level, but it's natural to also push down on the down-hill oar to help.



The next time this happens try being more aggressive in leaning into the wave, but more importantly, you get your down-hill oar out of the water early. You can push the up-hill oar into the water to stablize the boat and prevent rolling too far in that direction. The water will be pulling your boat and oar tip in opposite directions here, so you won't get trapped like you did before with the down-hill oar.



Speed of waves

Wave Length (feet)	Speed (knts)
2	2
4	3
10	4
20	6
40	8
100	13
1000	42

In deep water the speed (or velocity) of a water wave depends only on its wave length. Specifically, the speed is proportional to the square root of the wavelength. Thus, the longer the wave length, the faster the wave, or vice versa. The speed of a single wave is called the phase speed. Amazingly, the speed of a packet of waves (the group speed) is often not the same.

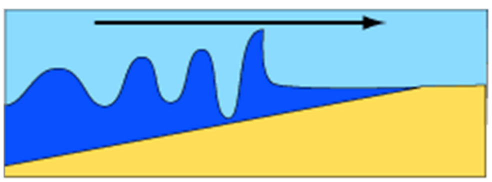
The table on the left gives the speed of waves of different wave lengths in deep water. “Deep” in this context is not an absolute value, but is relative to wave length. The simple relationship starts to to breakdown when the depth of the water is less than 1/4 th the wave length. At that depth the bottom exerts sufficient drag on the wave to slow its motion and thus decrease the wavelength [equations and more about wave speed].

Wave Length (feet)	Speed (knts)
2	2
4	3
10	4
20	6

40	8
100	13
1000	42

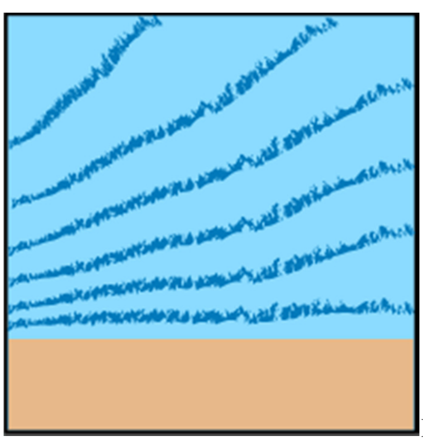
In deep water the speed (or velocity) of a water wave depends only on its wave length. Specifically, the speed is proportional to the square root of the wavelength. Thus, the longer the wave length, the faster the wave, or vice versa. The speed of a single wave is called the phase speed. Amazingly, the speed of a packet of waves (the group speed) is often not the same.

The table on the left gives the speed of waves of different wave lengths in deep water. “Deep” in this context is not an absolute value, but is relative to wave length. The simple relationship starts to to breakdown when the depth of the water is less than 1/4 th the wave length. At that depth the bottom exerts sufficient drag on the wave to slow its motion and thus decrease the wavelength [equations and more about wave speed].



Decreasing speed of waves as water becomes shallow has dramatic consequences on the beach. As the waves slow, their profile (Figure on right) is laterally compressed and since each wave must carry the same energy it becomes higher. As the wave approaches shore this process continues until the height exceeds 1/7 th the wave length and the wave becomes unstable. Then the wave breaks.

THL: Be careful not to row too near a sandy beach if there are significant waves, or you can get caught in the breakers. Beaches can be seductive because in a boat you will be on the “back” side of the breakers, and only see what looks like smooth waves. By the time you realize they are breaking it may be too late!



Here is a beach (seen from the air) with waves approaching at an angle of 45 degrees. The left side of each wave reaches shallow water before the right side, so the left side slows down before the right. This causes the wave to turn into the beach, so that when it breaks it is almost parallel to the shore.

The bottom is one of the causes of changes in wave direction as you row around Angel Island.

THL: Deep water can be your friend. As an example, waves in the Sausalito channel are typically lower than in the adjacent shallow water where boats are anchored. Of course if shallow water shelters you from wind or waves it may be a better choice.

Since a wavelength of 24 feet is of special interest to us,I have calculated the exact speed of such a wave as it moves across water of different depths. As you see, at a water depth of 1/4 wavelength (6 ft) the speed has decreased by only 4 percent, but at a depth of 1/8 (3 ft) of the wavelength the speed is 20 percent lower.

Depth of water (feet)	Speed (knts)
1000	6.57
6	6.29
3	5.32
1	3.32

Reflections

When waves approach a shore with a gradual depth profile, e.g. a beach, most of the wave energy is absorbed by the breaking of waves.

When waves approach a hard vertical surface,e.g. a concrete wall or a dock, most of the energy is converted into waves moving in the opposite direction, a reflection. Of course the reflected waves are superimposed onto the original waves, and the two sets of wave moving in opposite directions can create a real mess.

THL: Stay a safe distance from vertical surfaces if there are significant waves present in the area. A passing boat or ship may generate big waves that escape your attention until there is no time to escape. An example is the North anchorage of the Golden Gate Bridge (but there are special cases, e.g. rough water classes or the OWRC regatta, when there is a fast flood coming through the Golden Gate, and it is useful to be close to the wall since the current is slower there).

Waves, winds and currents: all together now

When waves run into water moving in the opposite direction, they are slowed, just as if they were approaching a beach. Wave length becomes shorter, wave height higher, and they may break. A good (bad) example of this is an ebb current flowing out of Raccoon Strait into waves coming in from the Golden Gate. Good rough water training, if that's what you want.

If waves run into current moving in the same direction, the converse happens: wavelength increases and waveheight decreases. An example is a flood current flowing through Raccoon Strait, which suppresses waves coming from the Golden Gate.