Wave Causes and Characteristics

What disturbing forces *cause waves?*

What restoring forces *resist waves?*

What are the differences between deepwater waves and shallow-water waves?

What three factors affect the maximum wave size?

How can a fully developed sea have waves that are bigger or smaller than the maximum theoretical size?

You now know what a wave is, the three types of waves, and the anatomy of a wave. Let's look at what causes waves and how they behave in the real world. *Disturbing forces* cause waves and *restoring forces* resist them. The intensity and duration of a disturbing force and the interaction of restorative forces give waves their characteristics.

Fluids tend to remain at rest on the Earth. They only move when something imparts energy to them—disturbs them. Disturbing forces that cause ocean waves include wind, changes in gravity, and seismic activity. Wind is the most common disturbing force through the friction of air passing over the water surface. Changes in gravity cause a wave you probably don't think of as a wave—the tides. These have characteristics that distinguish them significantly from what we normally think of as waves, so we'll look at them separately toward the end of this chapter. Seismic activity includes earthquakes and volcanic eruptions, which can cause tsunamis.

Each kind of disturbing force tends to produce waves with distinct wavelengths. Wind commonly creates wavelengths of about 60 to 150 meters (200 to 500 feet). The wavelength of the tides is about the size of the ocean basins, and tsunamis have wavelengths of about 200 kilometers (120 miles).

Gravity is the main restoring force for large waves and seismic waves. It tends to flatten waves by pulling water back to level. Gravity and the Coriolis effect are the primary restoring forces for the tides, because their wavelengths are so long. Surface tension is an important restoring force for the tiniest waves, called *capillary waves*, which have wavelengths of about 1.7 centimeters (0.7 inches) or less. Surface tension is caused by the strongly polar nature of bonds in water, which resists surface disturbances.

WAVELENGTHS AND DISTURBING FORCES OF IMPORTANT OCEAN WAVES

Wave type	Standard wavelength	Primary disturbing force	Primary restoring force
Wind wave (capillary)	Less than 1.73 centimeters	Wind	Surface tension
Wind wave (gravity)	Up to 150 meters	Wind	Gravity
Seismic wave	200 kilometers	Seismic activity	Gravity
Tide	Up to 17,000 kilometers	Sun and moon	Gravity and Coriolis effect

Figure 10-3

Wavelengths and disturbing forces of important ocean waves.

You can classify waves based on which restoring force has the most effect. Capillary waves are classified as such because the primary force countering them is surface tension. Capillary waves are the first to form as wind blows across still water. As waves grow larger, however, surface tension becomes relatively insignificant as a primary restoring force. Gravity—the weight of the wave—takes over, so we call large waves gravity waves. For practical purposes, most of the waves that concern us in oceanography are *gravity waves*.

Although disturbing forces can be somewhat random in their intensity, duration, and place of origin, waves tend to organize themselves into patterns. Waves that are not so organized travel at different speeds. The longest waves outrun the smaller ones. Eventually only waves of similar wavelengths are left traveling together. They are called *swell*, which is simply the rise and fall of a uniform wave pattern on the sea.

Groups of swells with similar characteristics tend to travel together in *wave trains*. The first wave in the train gradually loses energy, which is picked up by new waves forming in the trailing portion of the train. As the leading waves dissipate, the trailing waves form and join the train. The entire train moves at half the speed of individual waves through this process of dissipation and reformation. When the wave train reaches shallow water, the individual and group speeds become the same. This is because depth affects wave characteristics, leading to the concepts of *deepwater waves* and *shallow-water waves*. Deepwater waves occur in water that is deeper than half their wavelength. Water motion in orbital waves decreases very quickly with depth. If the water is deeper than half the wavelength, then no interaction with the bottom can affect the wave characteristics. A fish swimming at 20 meters (66 feet) wouldn't notice effects from a wave passing overhead if the wavelength is 40 meters (131 feet) or less. Because the bottom doesn't affect deepwater waves, their orbital motion progresses unaffected.

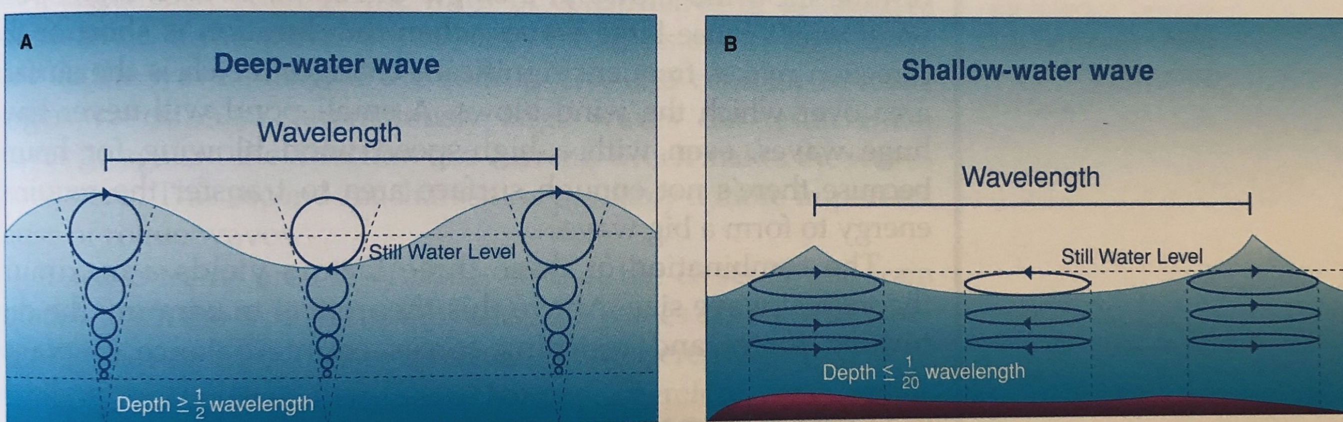

Figure 10-4

Deepwater waves.

Water motion in orbital waves decreases rapidly as depth increases. At a depth of one-half the wavelength, there is less than 5% of the motion at the surface. For this reason, waves are classified as deepwater when they are in water that is deeper than half their wavelength. When the water is deeper than half the wavelength, then no interaction with the bottom can affect the wave characteristics.

When the water is shallower than one-fourth the wavelength, the bottom creates drag that affects the orbital motion. This tends to flatten the circular motion into an ellipse. When the depth is about one-twentieth of the wavelength, the wave becomes a shallow-water wave. In depths between one-half and one-twentieth the wavelength, waves are transitional, progressing from deepwater to shallow-water characteristics.

Deepwater and shallow-water waves can exist at the same time. A good example is the giant wave created by the tides. By definition, this is always a shallow-water wave because the wavelength is about the size of its ocean basin. For a tide to be a deepwater wave, the ocean would have to be deeper than the diameter of the Earth! The wind creates waves, which can be deepwater waves on top of the tides. Capillary waves are almost always deepwater waves because the water only needs to be 0.9 centimeters (0.35 inches) deep.

As previously mentioned, wind waves grow due to friction with the air transferring energy to the water. As a wave grows, it presents a larger surface area to the wind, allowing more energy to transfer. The three factors that affect the growth of a wind wave are wind speed, wind duration, and *fetch*.

Wind speed is important because the wind must be blowing faster than the wave to give it energy. Wind duration is the length of time the wind blows in a single direction. Even a high-speed wind won't cause large waves when the duration is short or the direction makes frequent significant changes. Fetch is the surface area over which the wind blows. A small pond will never have huge waves, even with a high-speed wind blowing for hours, because there's not enough surface area to transfer the required energy to form a big wave.

The combination of these three factors yields a maximum theoretical wave size. Above this theoretical maximum, the disturbing forces and restoring forces counterbalance so waves

CONDITIONS FOR A FULLY DEVELOPED SEA WITH A GIVEN WIND SPEED

wind speed (kilometers per hour)	average wave height (meters)
20	.33
30	.88
40	1.8
50	3.2
60	5.1
70	7.4
80	10.3
90	13.9

Figure 10-5

Conditions for a fully developed sea with a given wind speed.

can't grow any larger. When an area has reached the maximum size, it is called a *fully developed sea.*

With wind speed, duration, and fetch all acting as independent variables, a fully developed sea isn't necessarily a large sea. As you can see in Figure 10-5, average wave heights for fully developed seas range from about a quarter of a meter (almost a foot) to about 15 meters (49 feet).

As in the example of the small pond, these three factors also influence the largest waves that an ocean can have. Remember that an ocean often has large, unobstructed stretches of water over which wind waves can develop.

Perhaps surprisingly, at times a wave can be larger than the maximum theoretical size for a fully developed sea. Scientists believe such a *rogue wave* results from the interaction of two closely related wave trains.

When wave trains come together from different areas, they affect each other in the form of constructive or destructive interference. If the waves are *in phase,* the crests and troughs coincide so the wave's heights are constructive and combine to make larger waves. Also, anomalously large waves can result when waves go against the direction of a current, which makes the waves more steep. This second mechanism is probably a more important cause of rogue waves.

If wave trains are *out of phase,* so that the crests of one train coincide with the troughs of the other, the waves cancel each other out. Neither constructive or destructive interference can act over distances greater than a few wave lengths. Therefore, for example, destructive interference cannot result in a relatively calm sea during strong winds.

It's relatively rare for trains coming together to have exactly the same wavelength and to be synchronized. They're usually timed slightly differently, and interacting trains tend to alternate between

NOAA Corps Collection/NOAA

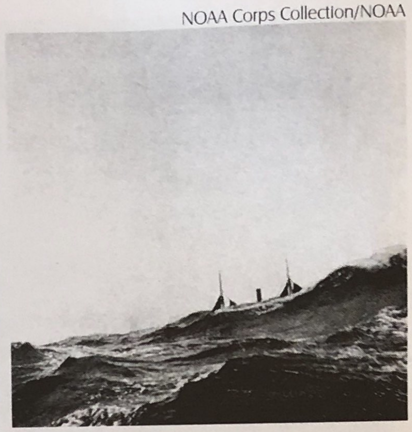

Figure 10-6

Antarctic sea waves.

Some of the largest wind waves in the world occur near Antarctica. They can circle the continent without encountering obstructing landmasses.

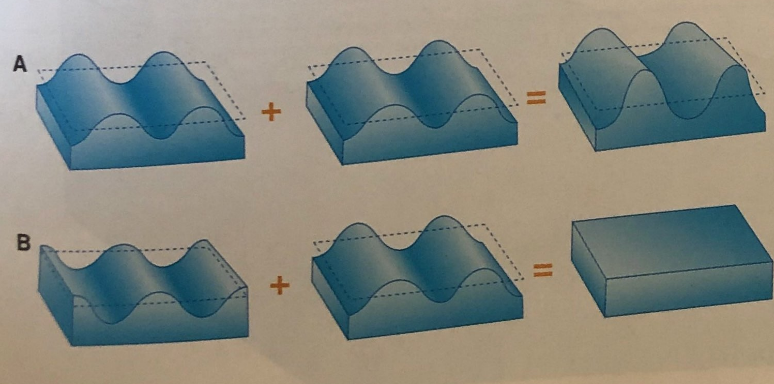

Figure 10-7

Constructive and destructive interference.

When wave trains come together from different areas, they affect each other in the form of constructive or destructive interference. If the waves are in phase **(A)**, the crests and troughs coincide so the wave energies are constructive and combine into larger waves. If they're out of phase **(B)** so that the crests of one train coincide with the troughs of the other, the waves cancel each other out. Note that real waves at sea never exactly conform to these ideal models of wave interference.

being constructive and destructive. This results in a mixed sea with periods of large and small waves. You've probably seen surf patterns that cycle from periods of calm, build to large waves, then regress to calm again, and so on. This is the effect of two slightly different wave trains coming together.

Internal Waves

What causes internal waves?

We think of waves as a phenomenon that occurs on the sea surface. However, a wave is energy that travels through matter, not just on top of it. Wind waves are progressive and occur where two fluids—water and air—meet. However, waves can move inside the ocean.

Internal ocean waves can occur within different density layers. These waves can be more than 30 meters (100 feet) tall, but they move slowly compared to surface waves. The wave motion in a deep layer can cause a thermocline or halocline to slowly rise and fall as the wave passes. A great example of internal waves is found in the wave machines available in science stores. These consist of two liquids with differing densities (and colors for visual effect) that you rock. The waves you generate in the lower, denser liquid are internal waves.

Scientists don't exactly know what causes internal waves. It's likley they get their energy from wind, gravity, or seismic forces, just like surface waves.

Courtesy of www.sf-raum.de

Figure 10-8

Internal wave.

This desk top wave machine shows an internal wave involving two liquids of differing densities.

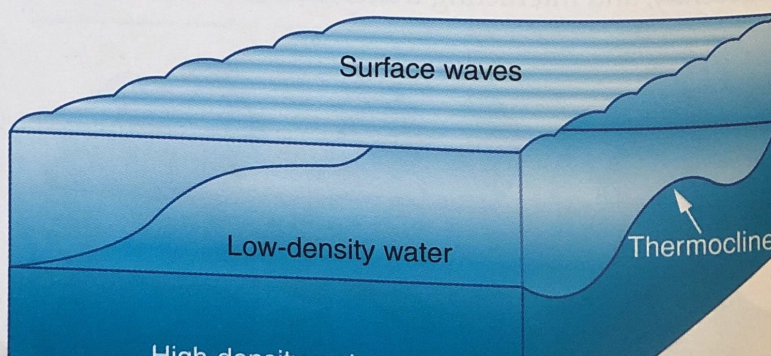

Figure 10-9

Internal wave.

Internal ocean waves can occur within different density layers. The wave motion in a deep layer can cause a thermocline, halocline, or pycnocline (density layer) to slowly rise and fall as the wave passes. Here two water layers of differing density create an internal wave.