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Ocean Waves

Introduction

The sea is rarely still—row upon row of waves roll across its surface, seemingly endless and eternal. At turns soothing, exhilarating, and terrifying, waves carry the power and the beauty of the sea and let them loose upon the shore. A wave is a complex mix of water and energy. Anyone who has watched breakers roll into the shore, or been seasick on a boat, knows very well that waves move. But surprisingly, the water in waves doesn't travel much at all.

Lesson

Within a wave, individual water molecules move in circles that get smaller with depth and eventually stop altogether. Boats or bottles or other debris floating on the surface don't go anywhere either, but simply bob up and down. The only thing waves do transmit across the sea is energy.

Wave anatomy is very simple. The highest surface part of a wave is called the crest, and the lowest part is the trough. The vertical distance between the crest and the trough is the wave height. The horizontal distance between two adjacent crests or troughs is known as the wavelength. All waves have this same basic anatomy. But wave behavior is a complicated dance, choreographed by the forces that cause them and the ocean around them.

Wind-driven Waves

Many things, from moving ships to earthquakes, to a bird skipping across the water, cause waves, but most are generated by wind. When wind blows across the sea surface, the friction between the air and water kicks up a series of small ripples. These bumps on the sea give the wind something to push against, and soon the ripples grow into waves. The waves grow higher, longer, and faster, reaching their maximum size when they nearly match the speed of the wind.

The longer and further the wind blows, the bigger and faster the waves become. [See presentation] This diagram of average wave height shows that small waves, shown in pink, characterize areas where islands interrupt the flow of wind and water. The largest waves on Earth, shown in orange and red, form where strong winds blow steadily across miles of open sea. In the long empty stretch between Antarctica and the Indian Ocean, even the average wave is 7 meters high.

In deep water, a group of wind-driven waves, called a wave train, develops into a series of harmonious, rounded swells. The train keeps moving even as it leaves behind the wind that formed it. In the open sea, wave trains soon encounter other sets of waves traveling in different directions and with different speeds, heights, and wavelengths. Interference between wave trains can produce a confused, highly irregular sea.

Sometimes, wave energy can be focused by the interaction of wave trains with currents or perhaps other waves to produce a freakishly large, or rogue, wave. The phenomenon of rogue waves is poorly understood, but it appears these waves can reach a height of 100 feet and are responsible for many shipwrecks.

When waves move into shallow water, their behavior changes dramatically. The definition of shallow water depends on the size of the wave—at a depth of half the wavelength, the wave starts to "feel the bottom"—the deepest circling water molecules come in contact with the seafloor. Friction between the seafloor and the water profoundly changes the speed, direction, and shape of waves. First, waves slow down as they drag across the bottom. The wavelength decreases, and the waves in the train start to bunch up.

If a wave is coming toward land at an angle, or the shoreline is uneven, some parts of a wave will feel bottom before other parts and slow down first. This causes the wave to bend, or refract, so that waves turn toward the shore or wrap around islands or headlands. As the water shallows, the energy in the wave can't move downward and instead is forced upward, increasing the wave height.

The deepest part of the wave slows down more than the top of the wave. The wave begins to lean forward as the crest rushes ahead of the base. Eventually the wave topples over and breaks against the shore. The wave collapses into foaming sheets of water, called swash, that roll up and then down the beach, carrying along sand and gravel.

Waves caused by the wind can erode the coast, bulldoze nearshore sediments, and generate strong currents. These effects are the cumulative result of wave after wave, day after day, endlessly pounding against the shore.

Tsunami

Another type of wave is much more powerful, able to remodel the coast, not over the space of years, but in just a few hours. These waves are the largest and most energetic on Earth and are called tsunami.

Tsunami have the same basic anatomy as wind driven waves, but their scale is quite different. In deep water, wind waves travel between 5 and 65 miles per hour, may reach heights of 45 feet, and are no more than a few hundred feet apart.

Tsunami are barely noticeable in the open sea – their height is just three feet or less, and successive wave crests are miles apart. These waves travel very fast, racing across an ocean at the speed of a jet.

Tsunami are caused by geologic events that push away a mass of water. Underwater landslides, volcanic eruptions, even asteroids falling into the sea from space, can spawn tsunami. But most are caused by earthquakes.

When a quake suddenly shoves a large piece of seafloor up or down, the entire overlying ocean moves too. The displaced water rushes away from the disturbance in waves that spread in all directions.

When tsunami come onshore, they behave generally like breaking wind waves, but with vastly magnified results. The water motion in a tsunami involves the entire water column, not just a thin layer at the top of the sea. When all of that enormous energy is compressed into shallow water, the wave grows to towering heights, as much as 100 feet or more.

As the wave rises, water is sucked into the crest from ahead of the wave, and the ocean actually pulls away from the shore. When the crest does arrive, the tsunami breaks with enormous force, much higher than the normal surf line, and the water from the collapsed wave can sweep far inland. A tsunami, like a wind wave, is usually not a single wave but part of a series. Because their length is so great, successive waves take several minutes to almost 2 hours to arrive.

Tsunami hammer the coast with great energy and can dramatically reshape islands and shorelines in minutes. Because they reach areas well away from the beach, they can engulf entire cities and then drag the debris and victims back into the sea.

Thankfully, tsunami are rare. But ironically, their infrequency increases the destruction and death they cause. In between disasters, people forget. Reefs, marshes, and mangroves that dissipate wave energy are destroyed for development. Buildings are constructed in danger zones. And when the next tsunami does arrive, many people don’t flee to safety, but instead let their curiosity draw them to the shore and to their deaths.

Global Impact

Coastlines are among the most energetic environments on Earth. There, waves concentrate the power of the wind, of earthquakes, and of undersea volcanoes on the thin strip of rock and sand that guards the edge of the continent.

Some attempts have been made to harness the relentless power of waves and turn it into electricity. Generator designs vary, but all rely on the up and down motion of waves to spin turbines and produce electricity. The idea of wave power is appealing—waves are free and non-polluting. Although the technology is still under development, it holds great promise and scientists estimate wave power could supply two times the electricity the world currently consumes.

Even as energy companies struggle to use wave power, the waves themselves continue their eternal work. Everywhere the land meets the sea, waves are working away to smooth and straighten and drive back the coastline. Waves slam ashore with great force, fracturing cliffs and widening caves. Gravel and sand rolled and flung against the shore abrade away rocks.

Wave refraction focuses the power of waves into protruding rocks and headlands, wearing them back quickly. Then the sediments made by wave action are rolled onto beaches and across bays. With time, waves turn jagged coastlines into smooth stretches of sand.

Although the cumulative effect of waves is dramatic, individual waves are not particularly powerful or remarkable. The exception to this is the tsunami. Tsunami are the most spectacular of waves. They also stand alone in their ability to spread death and destruction to every corner of an ocean. Spawned by events hidden from their victims by distance and the depths of the sea, tsunami strike with little warning and tremendous force.

Over all of recorded history, perhaps 1 million people have died in tsunami. The most deadly struck in 2004, killing more than 250,000 people from Indonesia to Africa. Spurred by this and earlier disasters, many governments are working to install warning systems and rebuild natural coastal barriers to tsunami. Unfortunately, the incredible power of these waves guarantees that tsunami will continue to extract a high toll from those who live and play along the shore.