Wave Basics – Tutorial Script

Waves are one of the most hypnotic and active parts of the ocean. We see them when we visit a beach or see movies or images of the ocean. These waves are actually moving energy – energy that is transferred to the surface of the water in a location potentially far away from the location where we actually see the wave now. That energy is then carried to the beach, where it is used to move sand, erode rock, and sculpt the coastline. Whatever is left over is transferred to heat energy and warms up the sands and rocks on which it hits. Surfers and boarders take advantage of this energy and ride it – a free ride – without the electricity requirements, entrance fees, or lines of the more standard amusement parks. And no closing times. In some parts of the world, this wave energy is harnessed and used to produce electricity for local towns or industry. However, as wave energy changes throughout the day and year, it cannot provide a consistent flow, and is most useful when there is an effective way to store it when it exists in high amounts for use on the calmer days.

Some waves, called **chop or sea**, are produced by winds locally, but most of the waves you see at a beach, called **swell**, are coming from winds in far-distant storms, sometimes thousands of miles away. **Tsunami** are rare waves that come from a landslide or earthquake that could also have happened thousands of miles away. And the most common and consistent waves that hit our beach, usually twice a day, are called **tides** and are caused by differences in the gravitational forces felt by different parts of the Earth to its neighbor the moon, and to a lesser extent the Sun. We'll talk more about these tidal waves in a future video tutorial.

When discussing wave formation, it is useful to distinguish between the two types of forces that cause waves – the **generating force** and the **restoring force**. The generating force is the one that pushes water up across its boundary with the air. Waves move along the boundaries between two different density medium. In the ocean, we see waves move along the ocean surface, along pycnoclines within the deeper layers, and along the seafloor. Waves that move along the pycnocline can have an impact on submarines and marine life that live along the pycnocline. Imagine being in a submarine that is built to withstand only 1,000 meters depth of pressure. If it is hanging out in the pycnocline at close to that depth, and a wave passes along the pycnocline the submarine can be moved, by that wave, down to deeper depths without warning. It is thought that some of the submarine disasters that have occurred without other explanations might have occurred because of this phenomenon. This image shows layers of plankton being moved into a wave shape by waves moving along the pycnocline.

Now that we know where waves occur – along boundaries – let's go back to the forces that create them. The generating force pushes water from one layer up into the other layer. The restoring force pulls it back to where it was, trying to restore the balance. Between the two, we get an oscillating motion – and as long as the generating force is continuously pushing, and the restoring force continually pulling back, the wave will continue to form in the location of the disturbance and send out its energy in all directions away. When the generating force stops, the waves all dissipate from the area of the original disturbance, and the water returns to its original shape. Let's look at some examples:

When you blow on the coffee in your coffee cup, you are creating a small disturbance that is pushing the air boundary into the water boundary. The restoring force, in this case, is the surface tension of the water, which through hydrogen bonding connects the water molecules to each other and creates a skin. Small ripples form that emanate out from the area over which you blew. When you stop blowing, the ripples diminish in size and then eventually disappear. We call these small waves that are restored by surface tension of water, **capillary waves**. If you blow too hard, you will blow the water up into the air, breaking the hydrogen bonds, and the restoring force will now be gravity that returns the water to its original shape. We call waves that are restored to their original shape by gravity, **gravity waves**. When waves are really small, the strength of the hydrogen bonds is stronger than the force of gravity. All waves in the ocean are either capillary or gravity waves, depending on which is their restoring force. As you can see in this image, if we let wind be our generating force, the main visual difference between the two is their size. The barest breeze will create small capillary waves, and as that wind increases in its intensity, it will turn into a gravity wave that can get bigger and bigger depending on the force of the wind.

Now let's return to generating force. There are three primary generating forces for waves in the ocean: wind, displacement of large volumes of water – think of a large splash when you jump in the ocean or when you drop a rock in a puddle – and uneven forces of gravitational attraction between the Earth and the Moon and the Sun. This image here shows these different generating forces and the different heights, periods, and names of the waves that are produced. Wind-generated waves include the tiny capillary waves, chop, swell, and seiche. Some seiche can also form through splashes generated by earthquakes or landslides, but most of those waves are called tsunami. As you can see from this image, the potential for the tallest waves – as high as 100 meters occur for swell. The next highest are tides. And the longest period – the longest we have to wait after one wave has hit the shore until the next one comes is 12 hrs and 25 minutes or 24 hours and 50 minutes, which are the periods of tidal waves. Tsunami, with an average period of 15 minutes are the next longest. Most waves tend to have periods of a few seconds.

Here is a picture of a fictional, idealized wave. The **amplitude** of this wave is the vertical distance from its midline or **equilibrium surface or still water level** to its highest point, called its **crest**. That number should be identical to the vertical distance from the equilibrium surface to the lowest point, called the **trough**. The equilibrium surface is the level the ocean surface would be at if there were no waves at all. The wave, remember, is a disturbance above and below this line. The **height** of the wave is the vertical distance from crest to trough. It is twice the amplitude. The **wavelength** is the horizontal distance from one trough to the next or one crest to the next or any one spot on the wave to the place where that exact identical spot appears again. Based on the definition of wavelength, can you determine how many wavelengths are visible in this image? If you guessed one and a half, you are correct.

Wave base is another very important characteristic of a wave. It is a depth below the wave under which the water and anything in the water, including fish, scuba divers, or submarines, feels no motion – feels no disturbance – doesn't even notice there's a wave above it. The wave base is calculated by halving the wavelength and then descending that distance from the equilibrium surface or still water level. This image shows what the motion of the water looks like as we descend towards the wave base. As waves of energy move across the surface of the oceans, the particles move in a circular orbit – returning to their original position. Waves represent moving energy, not moving water.

This video of a slinky will help explain. Although slinky waves are NOT the same as ocean waves, they can help illustrate our point. As energy is transferred to one end of the slinky, it makes each individual slinky piece moves sideways, returning to its original position. The slinky is not traveling up this concrete driveway. But the waves are. They're traveling up and then back down. As long as the generating force is continual, the waves will continue moving back and forth. In fact, because the waves are confined to a limited space they create a standing wave. In the oceans, we call these standing waves **seiches**, and they can typically be found in small basins, embayments, or lagoons. This image from Lake Geneva in Switzerland show a seiche that is a regular feature here due to local wind patterns. The results of these seiche are very similar to the results produced by young kids creating standing waves in bathtubs – water sloshes up and over the basin and floods the surrounding areas. The largest standing wave in the world's oceans are the tidal waves, as their generating force, the difference in gravitational forces experienced on different parts of the Earth from the Moon and Sun, never ceases, and they are confined to large ocean basins. In reality, they are simply seiches of water sloshing back and forth across the world's oceans. Both tsunami and wind-generated waves in the open ocean are **progressive waves** – they are generated in one location and then move outward from that location eventually dissipating their energy on distant shores. Their generating force is not continuous. This footage from the slinky shows a progressive wave that dissipates over time. There are two kinds of waves that a slinky can demonstrate – a sideways or transverse wave, similar to earthquake waves that run along the land surface or the bottom of the ocean after an earthquake – and compressional waves or longitudinal waves, another kind of earthquake wave, and the kind of wave that sound is – compressing and expanding air as the waves travel from the source of the sound to your ear. Again, in all cases, the waves represent an oscillating motion of the air or water in response to the moving energy. The air doesn't move from the computer speakers or headphones to your ear – the sound wave moves. The air stays where it is and oscillates as the energy travels through it.

For ocean waves, the oscillation is orbital – in a circle. And that orbit becomes smaller and smaller as we descend toward the wave base, below which the oscillation is barely detectable. Everything that is in the water will move in this circular orbit – including seaweed that sits above the wave base, floating garbages or ships or rubber duckies, and surfers. In fact, this perfect curling wave that the surfer has caught displays clearly the orbital motion of waves. In this case, the surfer is heading into the barrel of the wave and is experiencing wave energy in the most hands-on way possible.

The period of a wave is how many seconds, minutes, or hours pass between waves. Imagine being on the beach and hearing a crashing wave. Count the seconds until the next wave crashes, and that's the period. Of course that's assuming that the waves that are crashing on the beach are all part of the same set of waves. In fact, there are often many different waves from many different locations approaching the beach on any given day at the same time. However, in this picture of Pacifica California, we can see a regular set of waves, called swell, that seem to be coming from one direction. The period of these waves is probably around 10 seconds. That means every 10 seconds, you can hear a wave crash on the beach. Or if you wait 1 minute, you should expect to experience 6 waves. Where are these waves coming from? There's no local wind producing them. However, thousands of miles away there is a storm system – perhaps a hurricane – perhaps a winter storm – and the waves that are kicked up in that area are called chop or sea. When they propogate outward from that storm area, they separate into regular sets of wave trains – all waves within which have the same height, wavelength, and period. These ordered groups or sets are called swell, and they travel thousands of miles to our beaches. What happens to them when they arrive? To answer that, we have to review a few more concepts. Let's talk first about wave speed. Like the more commonly known speed we associate with our cars on the highway, speed is simply distance over time. For a wave, the distance it travels in a given unit of time is its wavelength over its period. For example, tsunami have an average wavelength of 200 km and an average period of 15 minutes. When we divide those numbers, we get an average speed of a tsunami of 800 km/hr. That's how fast the energy of a tsunami wave travels across the ocean. Swell that approach our beach tend to move at speeds more like 33 km/hr. However, that speed will slow once the wave "feels bottom," which means once it enters water shallower than its wave base. This image reviews the wave base as the limit of orbital motion below a wave. We call waves that move through water deeper than their wave base **deep-water waves**. Note that this definition has nothing to do with whether WE think the water is deep or shallow but only if the wave does. If the wave's base is above the seafloor, it feels like deep water, and there's no interaction between the wave and the seafloor. Once a wave enters water that is shallower than its wave base, it now transfers its orbital motion to the rock or sediment on the seafloor. That transfer of energy will pick up and move sediment, erode rock, and generally cause a frictional slowing of the base of the wave. The top of the wave might still be moving at its original speed, but the base is slowing down. This causes waves to bunch up (their wavelengths decrease), grow taller, and have their circular orbits squashed into elliptical orbits. Transformation of a wave as it enters shallow water – slowing and growing taller until eventually its top crashes over, in a circular motion and it breaks onto the shore. Note: while height increases and wavelength and speed both decrease as a wave approaches shore, the period stays the same.

We can now return to this image from Pacifica of actual swell approaching the beach and see this transformation. Note: for purposes of this video only, if a wave is NOT a deep-water wave, we will call it **a shallow-water wave**. In truth, there is a a term known as a transitional-wave which sits between the two. We will not make that distinction. What kinds of waves are deep-water waves? And what kinds are shallow-water waves? And can they be one at one time and another at another time? Yes, of course. Remember, whether a wave is deep water or shallow water depends only on its wavelength and the depth of water it's travelling through. For example, when you blow on your coffee cup, you make capillary waves with tiny wavelengths. They do not feel the bottom of the coffee cup, so they are considered deep-water waves. But those same waves in a thin film of water on the ground WOULD feel bottom. They would then be classified there as shallow-water waves. What about chop versus swell? In the open ocean both chop and swell are deep-water waves. But as they travel towards the shore their wave base will hit bottom, and when it does, they become shallow-water waves.

For more information and more detail, continue on to the next video in the series.

[End credits]

<u>Waves Series:</u>
Part 1: Wave Basics
Part 2: Big Waves
Part 3: Rip Currents

Wave Basics
Geoscience Video Tutorial
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