Big Waves – Tutorial Script

Let's return to this image showing all the different types of waves and their heights and periods. Remember that the tallest potential for a wave is for swell. Why is that? How can they get so big? Where are the biggest waves in the world? To create the largest waves, you want the strongest winds. But you also want those winds to blow in the same direction for a long period of time. And ideally, you want that to happen over the longest **fetch** – or area of ocean with no obstructions, such as islands or continents. This image of the world's oceans shows average wave height – with red and yellow as the tallest. Where are the highest waves? In the southern ocean around Antarctica. This is one of the reasons why voyages to and around Antarctica are so challenging. But why are the waves higher here? They have a strong, consistent, steady wind for a generating force – the Westerlies. And the fetch over which that wind blows in infinite. Notice that there are no obstructions in a straight line all around the planet where the westerlies blow. So the winds can continue to transfer their energy day after day after day, allowing for maximal wave height.

The tallest wave ever recorded was 34 meters, or 112 feet measured by a sailor from the bridge of the USS Ramapo. By lining up the crow's nest and the wave crest, while the stern of the ship was in the trough, they were able to triangulate an accurate wave height. Even taller waves have likely been experienced, but without accurate measurement devices, in the chaos of the storm, we can't be sure. We can certainly take stock of the damage done, however.

Another way to get tall waves it to have waves from different storm systems approach an area and interfere with each other. Waves are additive, so when the crest of one appears in phase with the crest of another, they will join up to create a much larger crest. We call this kind of interference constructive, because the addition results in a larger wave. When the waves interfere out of phase, the crest of one arriving with the trough of another, they diminish the height of the wave, and we call this destructive inference. Ironically, it's the constructive, not the destructive interference that causes the most damage. When many large waves constructively interfere in the same location, they can create a really large wave known as a **rogue or episodic wave**. These are the waves that Hollywood likes to immortalize in their movies, where you see a giant wall of water approaching a ravaged boat or coastline. It is also the type of wave that causes the most damage, because it has the potential to be the largest.

This image shows the waves that result in an area when six different wave trains approach from six different areas. You can see the result of combined interference is a chaotic jumble of waves of varying sizes with little consistency. Here you have the makings of a "perfect storm" where giant rogue waves can develop, and shipwrecks are common. How are so many different wave trains created? Some come from different storm systems. But others come from waves from the same storm system colliding with land and reflecting back in a new direction or having their wave base collide with the seafloor and then refracting, or bending around underwater banks and changing direction. This image of the Georges Bank off of Cape Cod Massachusettes, a very popular and productive fishing area, shows this type of refraction. Waves advancing towards the Georges bank will slow down when they feel bottom. This can cause the waves to bend almost 90 degrees and cross in front of the waves that are approaching further south. Interference results, and the water in this area can be quite erratic and challenging to navigate.

You can see this type of refraction when waves collide with beaches. The side of the wave front that feels bottom first will slow down – the side in deeper water keeps it speed forward. The net result is a bending inward toward the beach. You see this spectacularly on coastlines that have rocky peninsulas – the waves bend in toward anything that sticks out from the coastline – focusing wave energy on attacking and eroding these areas. The coves between have waves diffracting outwards, creating much gentler defocussed waves inside these areas. So the rocky protusions have high wave energy – the coves much lower energy waves. This image taken from above some rocky islands shows the waves refracting around the rocks and diffracting through the slot between the two. Another thing waves can do is reflect off objects. This is especially true where there are hard rocks underwater or human-made walls, like jetties. The jetty at the harbor entrance in Newport Beach, California, is well known for its wave reflection. Combined with constructive interference with incoming waves, it creates a large wave called the "wedge," which is popular for body boarders. This image of a tombolo along the California coastline also demonstrates the refractive power of waves. The waves bend in to attack the rocks that stick out of the coastline and a shadow forms behind it where sand piles up protected from the high waves that are focused on the island.

How tall can a wave get before it becomes unstable? And what happens when it becomes too steep? It breaks. We measure wave steepness as wave height divided by wavelength. It's maximum value is 1 over 7. Another way to say that is the height must be $1/7^{th}$ the value of the wavelength or else the wave will break. Or the wavelength must be at least 7 times the value of the wave height. Let's apply that to this idealized wave shape. Is a wave that looks like this really possible? Is its wavelength at least 7 times its wave height? Not at all. The wave height is almost equal to the wavelength – at best it's ½ of the value. It must be shrunk to one seventh before it reflects the maximum steepness a wave can be. Why use the unreal images of waves for teaching? Because it becomes very difficult to show crest, trough, height, and other characteristics of a wave if it's squashed down to more realistic proportions.

Pause now.

Most of our conversation so far has been about wind-generated waves. But there's another kind of wave we've mentioned a few times – **tsunami**. These waves are also referred to as splash waves that result from a large displacement of seawater, either due to a landslide into or under the ocean or by vertical displacement of the seafloor during earthquakes. If an earthquake doesn't cause vertical displacement, it will not produce a tsunami. For this reason, the San Andreas Fault, a mostly transform motion fault, is not associated with producing tsunami, even though parts of it are under water. But seafloor spreading center earthquakes and subduction zone earthquakes can produce vertical displacement – and subduction zones are the biggest culprits, as they are associated with the largest displacements.

The average wavelength of a tsunami is 200 km. The height in the open ocean is only 1 meter. That means the height of the wave should be $1/200{,}000^{th}$ the wavelength. It wouldn't even appear in this image – it would look totally flat. The height will grow as it approaches the land, as all waves do. But it will still look flat to the observer. This image of a tsunami in Hilo Hawaii shows the rising water as an advancing large mass that extends as far as the horizon. It's more like watching a bathtub fill up in front of you – but much faster than expected. In fact, tsunami look a lot like the rise and fall of the tides. Only intead of the rising and falling happening over 12 hours, it happens within 15 minutes. Vertical heights of these waves on land can be anywhere from 1 to 30 meters. For flat land that doesn't have a lot of vertical relief, that means the ocean can penetrate many tens to hundreds of kilometers inland, alternately flooding and exposing the land in cyclic pulses of fast-moving currents of water.

The Pacific Ocean, with all its subduction zones, experiences a number of tsunami every decade. There is a robust warning system in place to monitor earthquake activity and warn local residents to stay off the beaches. However, not every earthquake will produce a tsunami, and not every shoreline will be affected the same way. It depends very much where the tsunami happened and the geometry of the continental slope and shelf off a particular section of coast. For example, the tsunami that hit Japan in 2011 caused significant damage in Japan and its surrounding islands. The wave arrived at beaches throughout the Pacific Ocean and reached different heights in different locations. In California, there was damage in harbors in Crescent City and Santa Cruz. Remember, it was the energy that transferred across the ocean as waves – not the water. In fact, it takes 1 to 2 years for the debris produced by that tsunami to wash up onto the beaches of North America carried by ocean currents. In the 2004 tsunami in the Indian Ocean there was no way to warn the residents of the impending tsunami because there were no warning systems in place on the beaches. The Pacific Tsunami Warning Center had an alert to provide, but there was no way to transmit that information to those who would be affected.

These two images show the propogation of tsunami waves outward from the Japan 2011 earthquake and the Sumatra 2004 earthquakes. You can see the effects of refraction as well as the fact that sometimes the crest of the tsunami arrives first (red) and sometimes the trough arrives first (blue). When the trough arrives first, folks see water removed from the beach – and often that causes people to move out into the intertidal area to explore. They then get caught in the crest when it arrives. Typically there are about 4 to 8 individual waves in the tsunami train. Height can vary throughout. Often it's the 2nd or 3rd wave to hit that has the highest amplitude. Education on tsunami lasts only as long as local memory of the last one. If you plan to travel to or live in an area prone to tsunami, it's good to pay attention to signs from the ocean and know your escape route. If you see water rising or falling quickly, head to high ground right away!

Pause now.

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

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Waves Series:
Part 1: Wave Basics
Part 2: Big Waves
Part 3: Rip Currents

Big Waves
Geoscience Video Tutorial
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