The Boxing Day tsunami was the worst natural disaster in recent history, and Sri Lanka was one of the worst hit countries. The idea of supporting tsunami victims motivated me to write this booklet. It has been written for a non-scientific audience, so people can donate money and learn some science at the same time. All money raised through this project will be given to the Panadura Fisheries Village Rehabilitation Fund.

Teachers, students and the whole community of St Leonard's College supported me in all my efforts. On behalf of thousands of Sri Lankan tsunami victims I acknowledge this support, especially that of the Director of Community Relations Beryl McMillan, and Public Relations Coordinator Emma Reeves.

I would also like to acknowledge the support given by Sweet Design in designing the manuscripts and McKellar Renown Press Pty Ltd for printing this booklet.

A book can only reach its final state with the input of readers who give their time and effort to read through early drafts. I have been fortunate enough to have friends and family who have undertaken this task and helped me to publish this. I would like to acknowledge the special support given by Leah O'Toole, Peter Johnson, Merrin Evergreen, Dilani Fernando, Mark Byrne, Frank Augello, my wife Mala and my sons Ranga and Nilupa. Their invaluable contribution in reading manuscripts, preparing diagrams and images has brought this publication to this standard.

Ranjith Dediwalage

Sri Lanka is an island in the Indian Ocean. It is 440 km in length and 220 km in breadth. The total land area is 65610 square km and is smaller than the size of Tasmania.

Its population of 20 million people is very similar to that of Australia. The people who live along the coast line of Sri Lanka love and respect the ocean that gives life to them. 'Jala Tharanga' ('Jala' meaning water and 'Tharanga' meaning waves - 'Water Waves') has become a part of their day to day lives. During the monsoon season they tend to see a few giant waves and are well aware of their destructive power. For generations they have experienced and coped with these waves. They eventually managed to adjust their lives according to the frequency of these 'Jala Tharanga' and continued loving and respecting the ocean.

Boxing Day of 2004 was an altogether terrifying experience. A long stretch of Sri Lanka's coast was devastated by killer waves, killing more than 50,000 people and leaving a staggering 2.5 million people displaced. Survivors describe these waves as dark walls of water. The waves devastated the coastline, destroying houses, picking up cars and snapping trees in a matter of seconds.

What are these killer waves?

The waves that redrew the South East Asian coastal map. The waves that killed more than 50,000 people in Sri Lanka. The waves that killed nearly 300,000 people in total within the affected region. The waves that made millions of people homeless.

TSUNAMI! TSUNAMI! TSUNAMI!

A word the world now dreads.

Tsunami ('soo-nar-me') is a Japanese word; 'tsu' meaning harbour and 'nami' meaning wave. Tsunamis are sometimes incorrectly called tidal waves, but have nothing to do with the tides.

Waves are usually caused by the interaction of wind and the surface of the water in a constant direction. These waves join constructively and progressively to form swells that often move out of the area of origination. In a moving wave, in the open ocean, the water does not travel with the wave of energy. It actually remains relatively stationary. In most waves which are generated by wind, water flows in a circular path, as shown in figure 1.

The common occurrence of high and low tides, caused by the gravitational pull of the moon, also produce waves. The phenomenon we call a tsunami is a series of waves of extremely long wavelength and period, generated in a body of water by an impulsive disturbance of the sea floor that vertically displaces the water. Earthquakes which occur beneath or near the ocean are usually the cause of such movements in the sea floor, and sometimes these are large enough to produce a tsunami. The earthquake's magnitude, depth, fault characteristics and coincident slumping of sediments or secondary faulting, determine the size of the tsunami. A tsunami can also occur as a result of landslides, volcanic eruptions, explosions, and even meteorites.

Essentially, such waves are formed as the displaced water mass attempts to regain its equilibrium. The size of the resultant tsunami is determined by the size of the deformation of the sea floor. The greater the vertical displacement of the sea floor, the larger the waves. It must also be pointed out that not all earthquakes produce tsunamis, even when they occur at sea. The above mentioned conditions have to be present for an earthquake to cause a tsunami.

In a tsunami, the water flows straight, as shown in Figure 2. Earthquakes can be better understood by considering the theory of plate tectonics.

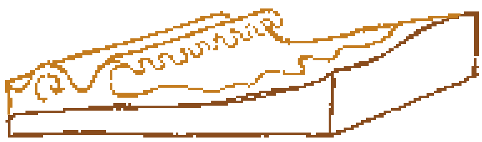


Figure 1. Water flows in a circular motion

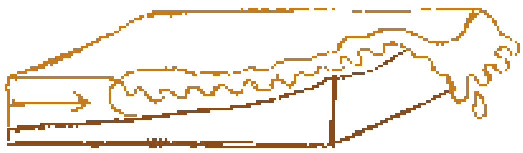


Figure 2. Water flows in a straight direction

- → Movement of Plate
- — Plate Boundary
- – – Uncertain Plate Boundary

Figure 3.

Plate Tectonics

The theory of plate tectonics suggests that the Earth's crust is divided into about 30 plates, as shown on the map in figure 3.

When two neighbouring plates slide past each other, earthquakes occur. The degree of the 'sliding' determines the effect of the earthquake, and scientists have developed a scale called the 'Ritcher Scale' to measure this. When the sliding is smooth, a small earthquake or tremors occur. Sometimes, the friction between the plates prevents them from sliding past each other, giving rise to severe earthquakes. These collisions can vibrate the plates both horizontally and vertically. The vertical oscillations that occur in the oceanic crust generate tsunamis, hence, a tsunami can be modelled as a transverse wave on the surface of the water.

Ritcher Scale

In 1925, an American seismologist called Charles Ritcher developed the first seismic magnitude scale. To honour him we call it the Ritcher Scale. The amplitude of the surface waves are measured by this scale, which is a logarithmic scale. Earthquake waves can cause ground displacements ranging from less than a millimeter to several metres in magnitude. Each successive unit of magnitude measure represents ten times the amount of the previous number (i.e. magnitude 3 on the Ritcher scale is ten times more than magnitude 2, and one hundred times more than magnitude 1).

There are also other scales used by seismologists to measure the magnitude of an earthquake. The 'Moment Magnitude Scale' is one of them. Seismologists believe that the Moment Magnitude Scale is more reliable for measuring earthquakes. This is especially true for earthquakes that measure above a 7 because other scales take into account only a fraction of the seismic waves, whereas the Moment Magnitude Scale measures the total size of the earthquake.

Waves

A wave is a way of transferring energy. Based on the type of energy involved, waves fall into two categories. Waves which involve mechanical energy are called mechanical waves, and waves which involve electric-magnetic energy are called electromagnetic waves. Sound waves, water waves and seismic (shock) waves are all mechanical waves, whereas light waves, micro waves and radio waves are all electromagnetic. Mechanical waves require a medium to travel in, but electromagnetic waves can propagate even within a vacuum.

'Up and Down' or 'Back and Forth'

There are oscillations associated with all waves. All mechanical waves carry energy without transferring matter. Matter particles oscillate about their initial position (referred to commonly as 'mean position'). If these vibrations are 'back and forth' and parallel to the direction of travel of the wave, it is called a longitudinal wave (see figure 4).

If these vibrations are 'up and down' and perpendicular to the direction of travel of the wave, it is called a transverse wave (see figure 5).

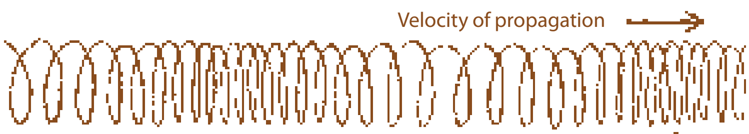


Figure 4.

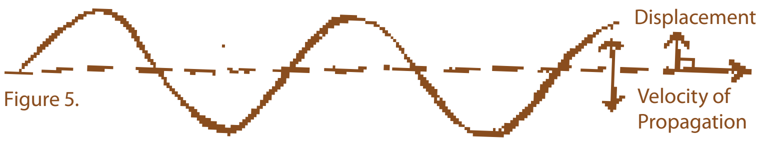
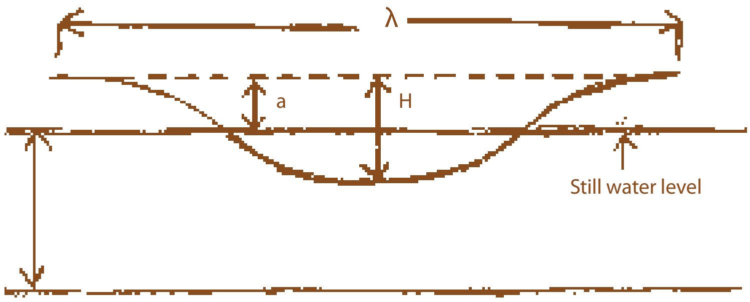


Figure 5.



Wave Jargon

To understand the phenomenon of a tsunami in detail, it is important to get familiarised with terms used to describe and measure waves. Figure 6 shows a vertical cross-section of a water wave.

Wave Crest
The highest point of a wave.

Wave Trough
The lowest point of a wave.

Wavelength (λ)
The distance measured from any adjacent in-phase points on the wave (Distance between two adjacent crests or troughs).

Wave Height (H)
The vertical distance from a crest to a trough.

Period (T)
The time it takes for one wave to pass a specific point.

Amplitude (a)
The distance, above or below the sea level, a wave displaces the water by.

Frequency (f)
The number of waves passing a specific point in a given time unit.

Velocity (V)
The distance travelled by a wave in a given time unit.

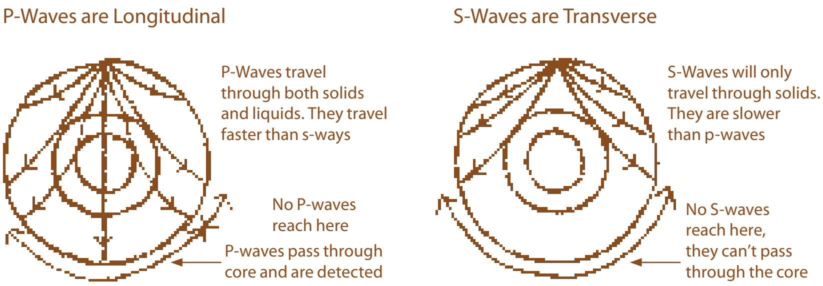


Figure 7. S-Waves and P-waves take different paths

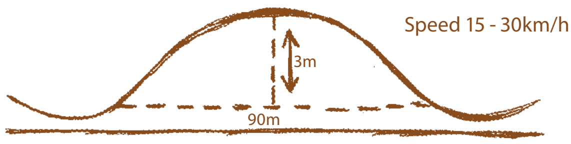


Figure 10. Regular wave generated by wind

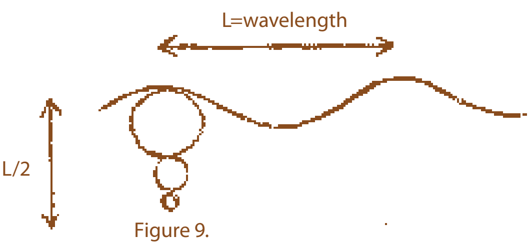


Figure 9.

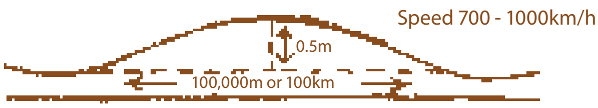


Figure 11. Tsunami in Deep water

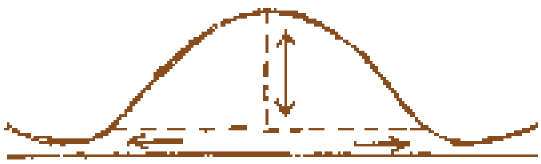



Figure 8.

Seismic Waves

When there is an earthquake the shock waves travel outwards from the epicentre, and these waves are called seismic waves. There are two types of seismic waves, Primary waves (P-Waves) that travel through both solids and liquids, and Secondary waves (S-Waves) that only travel through solids. S-Waves travel slower than P-Waves. The speed of these waves depends on the density of the medium. When the density changes, the speed changes as well, and the wave changes direction abruptly. The curvature of their paths, as shown in figure 7, is due to the change in density of the medium.

Water Waves

Water waves are created when a disturbance occurs on the surface of the water. For example, when a stone is dropped into a pond, ripples travel outwards across the water's surface, as shown in figure 8.

While the energy of the disturbance transfers across the water (ripples spreading outwards), the water particles oscillate up and down perpendicular to the wave direction. Hence, these waves are transverse in nature. Waves occurring deep in a lake or ocean are longitudinal in nature, and the water particles oscillate back and forth parallel to the wave motion. However, when wind causes waves at the surface of the water, the particles move in a direction that is both parallel and perpendicular to the direction of wave motion. In these waves the particle motion is somewhat circular, as shown in figure 9. These types of waves are known as surface waves, which have characteristics of both transverse and longitudinal waves.

The velocity of the water waves on the surface depends on the depth of the water. These waves travel faster in deep water and slower in shallow areas.

Tsunami

A tsunami can be most aptly described as a series of waves of extremely long wavelength and period. Wind generated waves usually have periods of five to twenty seconds and a wavelength of about 100 to 200m (300 to 600 ft). Tsunamis can have a period anywhere between ten minutes and two hours, and a wavelength in excess of 500km. It is because of their long wavelength that tsunamis behave similarly to shallow-water waves. As the tsunami crosses the deep ocean, its wavelength may be 100km or more and its amplitude in the order of a few feet. They cannot be felt aboard ships, nor can they be seen from the air whilst in the open sea. Figures 10, 11 and 12 are a comparison between wind generated waves, deep ocean tsunamis and shallow water tsunamis.

Energy of a tsunami

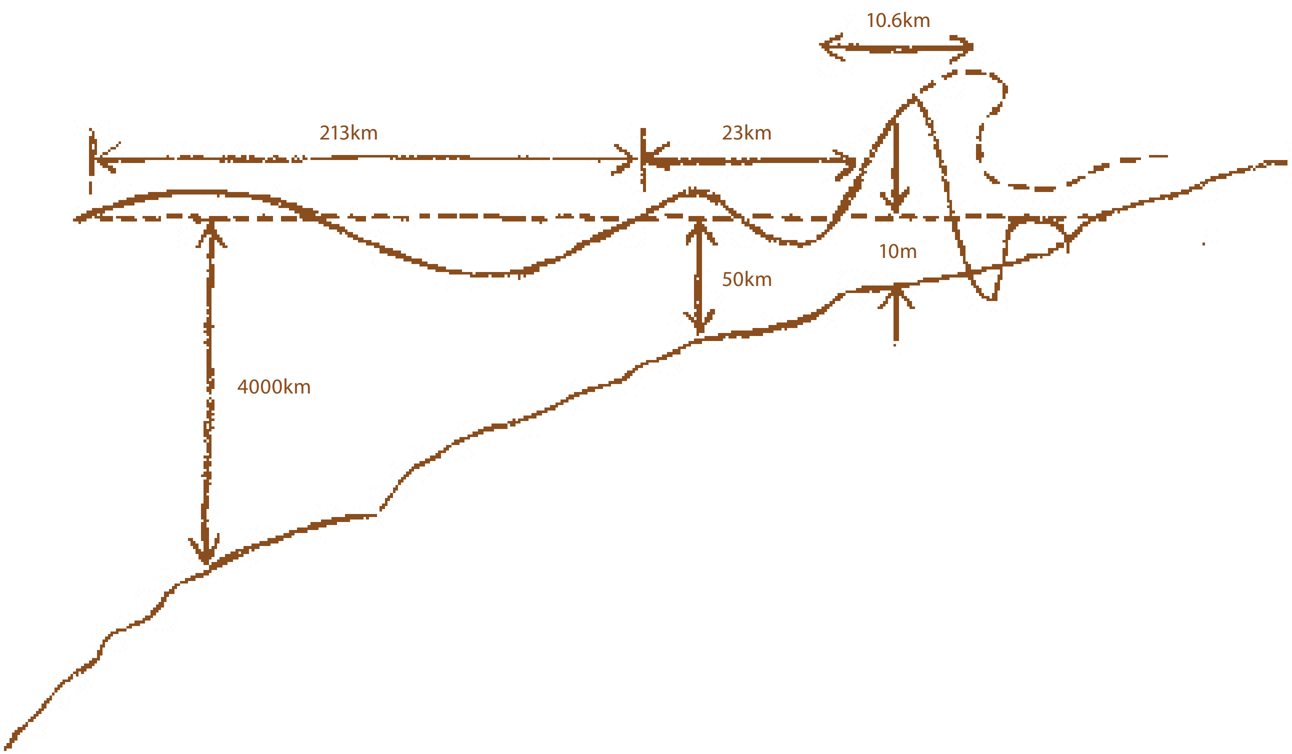
The rate at which a wave loses its energy is inversely proportional to its wavelength. Since a tsunami has a very large wavelength, it will only lose a little energy as it propagates.

Hence, in very deep water a tsunami will travel great distances at high speed with limited energy loss. For example, when the ocean is more than 5000m deep, an unnoticed tsunami will travel at about 800 to 900km/h, the speed of a jet airplane. However, the speed of a tsunami is still much slower than the seismic waves. This is the reason that earthquake information is often available hours before the tsunamis are able to travel across the ocean. Tremors were felt in Chennai more than two hours before the 2004 boxing Day tsunami reached the shore.

Speed of a tsunami

A tsunami is different to normal waves in the ocean. Wind generated ocean waves cause the water to move downwards about 150m at most. In contrast, the passage of a tsunami involves the movement of water all the way to the seafloor. This means that the speed of a tsunami is controlled by water depth. As the wave approaches land, it reaches increasingly shallow water and slows down. Compared to the front of the wave, the rear is still in slightly deeper water (so it is going slightly faster) and eventually catches up to the front. The result is that the wave quickly 'bunches up' and becomes much higher in amplitude, like a rug crumpled against a wall creating a wave.

This then results in decreasing the distance between individual waves, in a process called 'shoaling' (see figure 13). The theory of 'conservation of energy' requires that the amplitude grows larger as the waves slow down. Hence, the height of the wave rises up to about 30 feet or more, keeping the total energy of the tsunami constant. The highest tsunamis occur if they encounter a long and gradual shallowing of the water, and this allows enough time for the wave to interact with its surroundings and cause extensive damage to low-lying areas.



Movement of Plate
Plate Boundary
Uncertain Plate Boundary

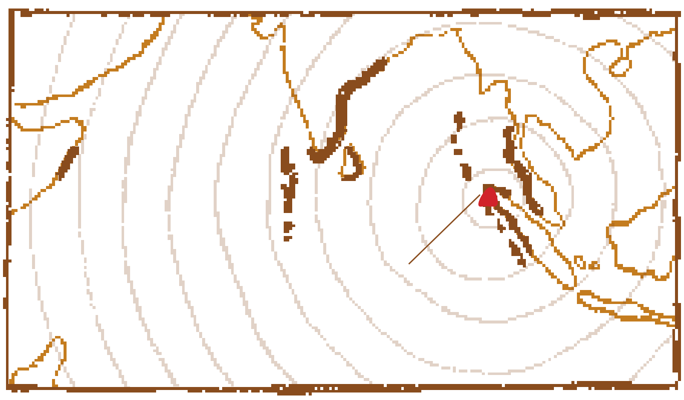
Figure 14.

The Boxing Day disaster

Look at the map in figure 14. On Boxing Day of 2004, the Eurasian Plate (in beige) and Indo-Australian Plate (in brown) collided under the Indian Ocean, near the west coast of the island of Sumatra (indicated by a circle on the map). This location is called the epicentre of the resulting earthquake.

This collision of tectonic plates caused the most powerful earthquake in 40 years, and its magnitude was recorded at 9.8 on the Ritcher Scale. It caused giant waves to crash ashore in nearly a dozen countries, killing approximately 300,000 people. A long stretch of Sri Lanka's coast was devastated by these killer waves, with more than 50,000 people dead and a staggering 2.5 million people displaced. Although Sri Lanka is about 1,600km from the epicentre (see figure 15), the waves struck with tremendous force and swept as far as 5km inland. The towering waves crashed into coastal villages, washing away houses, vehicles, people and even a train with 1,700 passengers. The tsunami took almost two hours to travel from the epicentre to the shores of Sri Lanka, bringing with it the worst devastation the small island nation had ever seen.

Coastlines severely hit by tsunamis



Reflection

Any type of wave can be reflected. Reflection best occurs from flat, hard surfaces.

After reflection, a wave has the same speed, frequency and wavelength; it is only the direction of the wave that has changed.

Wave reflection is a very useful phenomenon that has many practical applications. Sonar, ultrasound scanning and the use of radar, are some of these applications. Engineers used the reflective theory behind radar technology to develop Stealth Bombers, using very poor reflective materials to render them undetectable by radar.

Refraction

Any type of wave can be refracted, meaning a change in direction. Refraction can occur when the speed of a wave changes, as it moves from one environment to another. After refraction, the wave has the same frequency but a different speed, wavelength and direction. When a wave enters a new environment, its change in speed will also change its wavelength. If the wave enters the new environment at any angle other than normal to the boundary, then the change in the wave's speed will also change its direction. This can be easily shown with water waves.

Water waves travel faster on the surface of deep water than they do on shallow water.

The change in speed of the wave will cause refraction.

As you can see in figure 16, the change in speed has changed the direction of the wave. The slower wave in the shallow water has a smaller wavelength. The amount of refraction increases as the speed increases.

Diffraction

Any type of wave can be diffracted. A diffracted wave will "spread out". Diffraction occurs when the wavelength of a wave is of a similar size to an obstacle or a gap in a barrier, as shown on figure 17. After diffraction, a wave will have the same speed, frequency and wavelength.

The region where there are no waves is called a shadow. The amount of diffraction that occurs depends on the ratio of wavelength (λ) to the size of the gap or obstacle (d). When the λ/d ratio is > 1, the diffraction is significant. When waves diffract around an obstacle, the larger the wavelength, the more diffraction there will be. Figure 18a and b shows this relationship.

Tsunami waves, like all transverse and longitudinal waves, can exhibit reflection, refraction, and diffraction as they approach the shoreline.

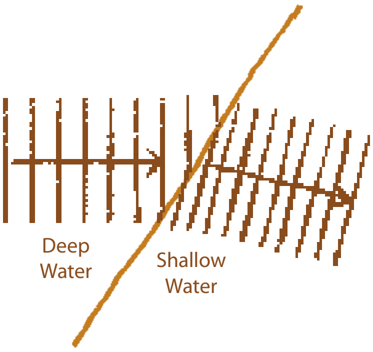


Figure 16.

Figure 17.
Diffraction of waves around an obstacle

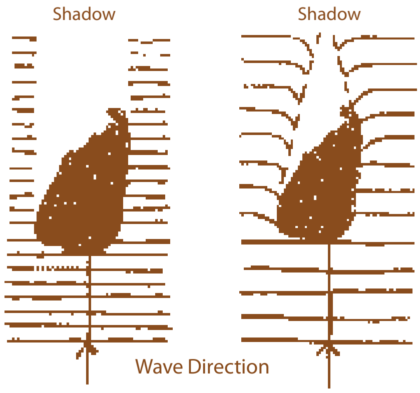


Figure 18a. Figure 18b.

As shown in figure 19, the waves approached Sri Lanka from the south-east and wrapped around the island. The tsunami left about an eighth of the coast line untouched, from Chilaw to Poonerya on the north western coast.

This can be easily explained by the refraction and diffraction of waves. When waves approach a relatively straight shoreline at an angle, the part of the wave crest closest to the shore is in shallower water and thus moves slower than the part in deeper water. The crests in deeper water catch up to make the wave more parallel to the shore.

The wave will wrap around the island so that it can hit the beach almost parallel on all sides, as shown in figure 20. Diffraction usually happens when waves encounter surface piercing obstacles, such as a breakwater or an island. One would assume that on the lee side of the island, the water would be perfectly calm, but this is not the case.

After passing the island as shown in figure 21, the waves turn toward the region behind the island, and carry wave energy and the wave crest into this so-called 'shadow zone'.

The maximum width of the island is 440 km and the effective obstacle size perpendicular to the wave direction is less than 440 km. As the wavelength λ of the tsunami wave was about 500 km, it easily diffracted, leaving only a small shadow region of about one eighth of the coast line.

Interference of Tsunami Waves

The tsunami wave even reached as far as Somalia, and was still strong enough to cause damage. Yet there have been no reports of significant damage in either Bangladesh or North-West Australia. This can be explained by considering another wave phenomenon called interference of waves.

When there are two sources creating waves on the surface of the water, the waves from each source interfere with each other as they travel from their respective sources. If the two sources are in phase (providing crests and troughs simultaneously), a pattern consisting of constructive and destructive interference would occur, as shown in figure 22.

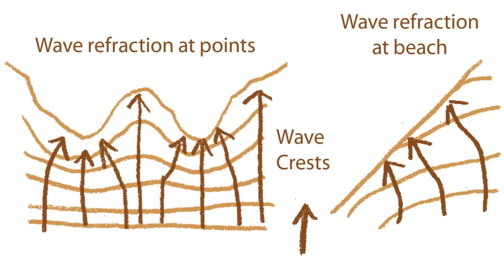


Figure 20.

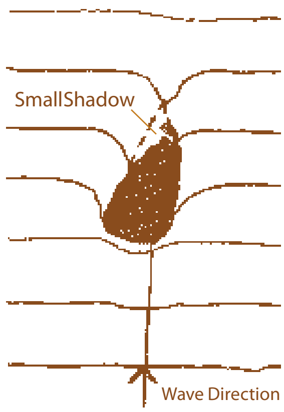
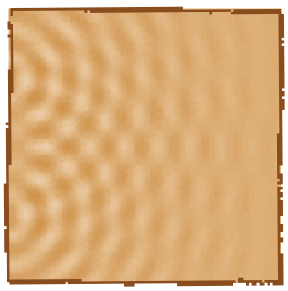


Figure 21.



Constructive Interference

When two waves overlap in phase to each other (crests fall on crests and troughs fall on troughs), they add up to produce waves with relatively large amplitude (amplitude doubles), as shown in figure 23. This is called constructive interference.

Destructive Interference

When two waves overlap out of phase to each other (crests fall on troughs), they cancel out, as shown in figure 24. This is called destructive interference

The earthquake which resulted in the 'killer tsunami' was caused by a major inter-plate shift, running the entire length of the Andaman and Nicobar Island chain, with three separate, noticeable epicentres. This caused 'differential propagation' of the tsunami wave - strong to the east and west, but much weaker to the north and south. The propagation of the wave created a pattern similar to a three source interference pattern, and hence did not reach either Bangladesh or Australia.

The deadly ways of the TSUNAMI

Tsunamis can be local, regional, or ocean-wide, depending on the size of the waves and the area affected. Ocean-wide tsunamis are by far the most destructive, because of their power and the area they encompass. The bar chart in figure 25 can be used to compare the damage caused by tsunamis.

The death toll caused by the 2004 Boxing Day tsunami stands at 300,000 at the time of publication of this document, and is the highest ever caused by a natural disaster.

Complete constructive interference

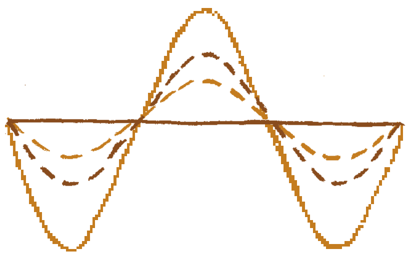
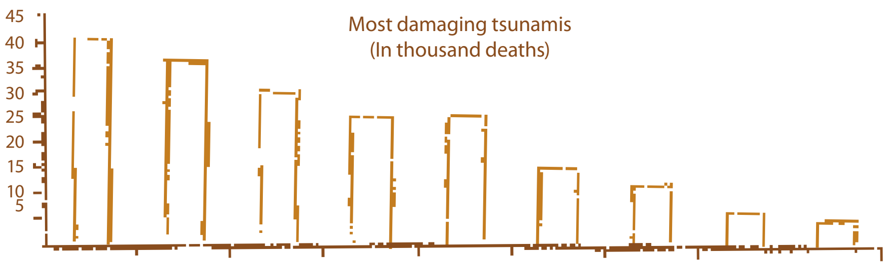


Figure 23.

Complete destructive interference

Figure 24.



6100 BC North Atlantic Ocean, the Storegga Slides

1650 BC Greek island Santorini

200BC Sri Lanka

1524 Near Dabhol, Maharashtra

1605 Nankaido, Japan

20 January 1607 Bristol Channel

1703 Awa, Japan

1703 Tokaido-Kashima, Japan

1707 Tokaido-Nankaido, Japan

1 November 1755 Lisbon, Portugal

02 April 1762 Arakan Coast, Myanmar

1771 Ryukyu Trench

1782 South China Sea, Taiwan

1792 Southwest Kyushu, Japan

16 June 1819 Rann of Kachchh, Gujarat

1826 Japan

31 October 1847 Great Nicobar Island

1868 Chile

31 December 1881 Car Nicobar Island

26 August 1883 Krakatoa volcanic eruption, Indonesia

1896 Sanriku, Japan

1908 Messina, Italy

1929 Canada

1933 Sanriku, Japan

28 November 1945 Mekran coast, Balochistan

1946 Pacific Tsunami, Hawaii

1958 Lituya Bay, Alaska

1960 Chilean Tsunami

1964 Good Friday Tsunami, Alaska, British Columbia, California

16 August 1976 Moro Gulf, Philippines

1983 Japan

17 July 1998 Papua New Guinea

This booklet was written by
Ranjith Dediwalage, Head of Science
at St Leonard's College.

Proceeds raised by this booklet, through donations, will be forwarded to Panadura Fisheries Fund which is providing relief to Sri Lankan victims of the 2004 Boxing Day tsunami.

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The design of this booklet was inspired by the ancient art form of henna.

Traditionally henna art has been used by Sri Lankan women to mark significant events in their lives.

Knowing this we were able to create a device that not only conveyed the details of the tsunami disaster, but also expressed the beauty of what is Sri Lanka.

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