wave energy - NOT the water particles - moves across the surface of the sea
wave form moves and with it, energy is transmitted

Wave direction

Still water level
Crest
Trough

Direction of wave motion

Frequency: Number of wave crests passing point A or point B each second
Period: Time required for wave crest at point A to reach point B

Orbital path of individual water molecule at water surface

Fig. 10-2, p. 266
Anatomy of a Wave

more like a real wave

<table>
<thead>
<tr>
<th>Surface wave</th>
<th>Wavelength</th>
<th>Crest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin wave</td>
<td>Height</td>
<td>Trough</td>
</tr>
<tr>
<td></td>
<td>Amplitude</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wavelength</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trough</td>
<td></td>
</tr>
</tbody>
</table>

more like a sine wave

Parts of a Wave

* Wavelength
* height
* Crest
* trough
* amplitude

* Frequency - # of waves passing a fixed point in a given length of time
* Period - time for successive crests or troughs (1 wavelength) to pass a fixed point

Direction of wave motion

If we had this below, then there would be no net mass transport and no contribution of waves to the surface currents

BUT in reality orbits are not exactly closed and waves DO contribute to mass transport
How do a waves form?
- Wind blowing across calm water – if gentle breeze → capillary waves. Generating force = wind; restoring force = surface tension (cohesion); grow up to a wavelength of about 2 centimeters
- As wind speed increases - wave becomes larger. Generating force = wind; restoring force → changes from surface tension to gravity

Types of waves – (1) progressive & (2) standing waves
(1) progressive = have a speed and move in a direction
- surface waves: deep-water & shallow-water waves
- big waves: large swells, tsunamis & episodic waves
- internal waves at the pycnocline
(2) standing waves or seiches - do not progress, they are progressive waves reflected back on themselves and appear as alternating troughs and crests at a fixed position called antinodes, oscillating about a fixed point called node. They occur in ocean basins, enclosed bays and seas, harbors and in estuaries.
Extra Credit Assignment - 12/05/2008

Write a 2-page essay on one of the following topics:
1. Rogue Waves
2. Tsunami

Guidelines:
1. Select one of the two topics above.
2. Do some "research" on your topic, take notes, connect the information you gather to the material of this class, make sure you can explain your notes, and only then start writing your essay.
3. Essay is due Friday Dec. 12, by the time of class (2:10 pm) - this is an ABSOLUTE deadline. Essay must be TYPED! Can be sent electronically to the class email address.

Keep in mind the key ideas in chapter 10:
• Waves transmit energy MOSTLY, not water mass, across the ocean’s surface.
• Most waves affect only the ocean’s surface layer. Movement ceases at a depth equal to about half the wave’s wavelength.
• Arranged from short to long wavelengths (and therefore from slowest to fastest), ocean waves are generated by very small disturbances (capillary waves), wind (wind waves), rocking of water in enclosed spaces (seiches), seismic and volcanic activity or other sudden displacements (tsunami), and gravitational attraction (tides).

Next:
• The speed of ocean waves usually depends on their wavelength, with long waves moving fastest.
• The behavior of a wave depends largely on the relation between the wave’s size and the depth of water through which it is moving.
• Wind strength and duration determine the wavelength and speed of wind waves.

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Wave Speed – C

Speed is equal to wavelength, L, divided by period, T. Example: the speed of a wave with a wavelength of 233 meters and a period of 12 seconds is 19.4 meters per second.

Wave propagates with C - Energy moves with V

Wave Speed is C - Group Speed is V
wave speed = wavelength / period or $C = \frac{L}{T}$

T is determined by generating force so it remain the same after the wave formed, but C changes. In general, the longer the wavelength the faster the wave energy will move through the water.

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Deep Water Waves

* surface waves progressing in waters of D larger than 1/2 L
* as the wave moves through, water particles move in circular orbit
* diameter of orbits decrease with depth, orbits do not reach bottom, particles do not move below a depth $D = \frac{L}{2}$

Period of up to about 20 seconds
Wavelength of up to at most 600 meters (extreme)
Speed can be up to 100 km/hr (70 mi/hr) (extreme)

* The wave speed can be calculated from knowing either the wavelength or the wave period:

$$C = 1.56 \text{ m/s}^2 T \quad \text{or} \quad C^2 = 1.56 \text{ m/s}^2 L$$

Example: a 300 meters wave with a 14 sec period, propagated at 22 meters per second

* Group Speed (which really transport the energy) is half of the wave speed for deep-water waves: $V = \frac{C}{2}$
**Shallow-Water Waves**

- Surface waves generated by wind and progressing in waters of depth less than $(1/20) L$.
- Wave motion: as the wave moves through, water particles move in elliptical orbits.
- Diameter of orbits remains the same with depth; orbits do reach the bottom where they flatten to just an oscillating motion back and forth along the bottom.

- The wave speed and the wavelength are controlled by the depth $D$ of the waters only:
  
  \[ C = \sqrt{gD} = \sqrt{3.4L} \]

  Example: a 300 meters wave propagating in a 10 meter-deep channel has a speed of 9 meters per second.

- Group Speed (which transport the energy) is the same as the wave speed for shallow-water waves: $V = C$

**Wind Blowing over the Ocean Generates Waves**

Waves development and growth are affected by:

**Wind Speed**: velocity at which the wind is blowing

**Fetch**: distance over which the wind is blowing

**Duration**: length of time wind blows over a given area

**Interference Produces Irregular Wave Motions**

When waves meet up, they interfere with one another.

Wave interference can be:

- **Destructive interference** - two waves that cancel each other out, resulting in reduced or no wave.

- **Constructive interference** - additive interference that results in waves larger than the original waves.

**Rogue waves** - these freak waves occur due to interference and result in a wave crest higher than the theoretical maximum.
Constructive and destructive interference.

Two waves of different wavelength (different storms) overlapping, one in blue and one in green. The blue wave has a slightly longer wavelength.

(a) The waves will interfere with each other to form a composite wave with (1) a very large crests and troughs if the interfere CONSTRUCTIVELY, or (2) the two waves will destructively interfere, and the crests and troughs will be very small.

**Wave Height, Wavelength & Wave Steepness**

Typical ratio wave height to wavelength in open ocean = 1:7 = wave steepness - angle of the crest = 120°

Exceed these conditions and wave will break at sea → whitecaps

Wave Height is controlled by (1) wind speed, (2) wind duration and (3) fetch (= the distance over water that the wind blows in the same direction and waves are generated)

Significant Wave Height - average wave height of the highest one-third of the waves measured over a long time

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Deep-water waves change to shallow-water waves as they approach the shore and they break

1. The swell "feels" bottom when the water is shallower than half the wavelength.
2. The wave crests become peaked because the wave's energy is packed into less water depth.
3. Water's circular motion due to wave is constrained by interaction with the ocean floor and slows the wave, while waves behind it maintain their original rate.
4. The wave approaches the critical 1:7 ratio of a wave height to wavelength.
5. The wave breaks when the ratio of wave height to water depth is about 3:4. The movement of water particles is shown in red. Note the transition from a deep-water wave to a shallow-water wave.

**The Surf Zone - Breakers**

Wave Breaking: wave becomes unstable as water particles at the crest travel much faster/farther than water particles in the trough

Breaker type is determined by slope, composition and contours of the bottom
**Tsunami**

- Vertical sea floor displacement
- Shallow water waves
  - Long wavelength
  - Relatively long period (compared to wind waves)
- Wave height changes (quite dramatically!)
  - At point of origin
  - Close to shore where depth decreases

Landslides, Icebergs falling from glaciers, Volcanic eruptions, Asteroid impacts, Other direct displacements of the water surface CAN also generate tsunami

Read sections 10.24 through 10.29 and review questions 24 through 30 (page 291 of current textbook)

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The great Indian Ocean tsunami of 26 December 2004 began when a rupture along a plate junction lifted the sea surface above. The wave moved outward at speeds of 212 meters per second (472 miles per hour).

At this speed, it took only about 15 minutes to reach the nearest Sumatran coast and 28 minutes to travel to the city of Banda Aceh.

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**Tsunami Move at High Speed**

The speed of a tsunami can be calculated using the same formula used for other shallow-water waves:

\[ C = \sqrt{gd} \]

- \( g = 9.8 \) meters per second (the acceleration due to gravity)
- \( d = \) depth (a typical Pacific abyssal depth is 4,600 meters)
Eleven destructive tsunami have claimed more than 180,000 lives since 1990.

More Key ideas to keep in mind:

- Waves can interfere with one another, resulting in larger or smaller waves.
- Most waves change shape and speed as they approach shore. They may plunge or spill at the surf zone and bend to break nearly parallel to shore.
- A storm surge is a short-lived, abrupt bulge of water driven on shore by a tropical cyclone or a frontal storm (from Ch. 8). Although storm surges are sometimes called storm tides or storm waves, storm surges consist of only a crest, so they cannot be assigned a period or wavelength, and cannot be called a wave.
- Tsunami are always shallow-water waves. No ocean basin is deeper than one-half their wavelength. Tsunami have been responsible for large losses of life and property.
- Tsunami are caused when water is displaced by the forces that cause earthquakes or by landslides, eruptions, or asteroid impacts. Typically tsunami resemble a fast-onrushing tide, not a breaking wave. They are not dangerous in the open sea.

And there is more:

Even greater waves exist: the tides. Yes, two "tidal waves" move along most coasts each day: the crests are the day's high tides; and the troughs, the day's low tides. Tides are shallow-water waves no matter how deep the ocean they're moving through. Tides can be destructive, but among all waves their ability to cause damage is fortunately not proportional to their wavelengths.
Review

1. Wavelength is the Most Useful Measure of Wave Size
2. The Behavior of Waves is Influenced by the Depth of Water through Which They Are Moving
3. Wind Blowing over the Ocean Generates Waves – we call these 'wind waves'
4. Storm Surges are NOT waves
5. Tsunami are long-wavelength, shallow-water, progressive waves Caused by Water Displacement
6. Tsunami Are Always Shallow-Water Waves

Chapter 11 – Tides

Tide - rhythmic oscillation of the ocean surface due to gravitational & centrifugal forces ('inertia') between the Earth, Moon, and Sun.

Tidal Patterns - regular, cyclic patterns of low water-high water

Tidal cycle – one low tide and one high tide consecutively

diurnal tide - one low tide, one high tide a day;
semidiurnal tide - high water-low water sequence twice a day; 2 high, 2 low, about the same level
semidiurnal mixed tide - same as semidiurnal but 2 highs and 2 lows do not reach/drop to the same level; may be the result of a combination of tide types

Tide Patterns - regular, cyclic patterns of low water-high water
Tides Are the Longest of All Ocean Waves

Characteristics and Causes of Tides:
Tides are caused by the gravitational force of the moon and sun and the motion of Earth.

The wavelength of tides can be half the circumference of Earth.
Tides are the longest of all waves.

Tides are forced waves because they are never free of the forces that cause them.

Study of Tides:
Equilibrium Tidal Theory - ideal approach to understand basic principles, assumes an earth covered with water and an infinitely deep basin.

Dynamical Tidal Analysis - realistic approach, studying the tides as they occur on earth, accounts for modification due to landmasses, geometry of ocean basins, earth's rotation.

Flood Tide: tide wave is propagating (onto shore) onshore –
water level is rising

High Tide: water level reaches highest point

Ebb Tide: tide is moving out to sea – water level is dropping

Low Tide: water level reaches lowest point

Slack tide: period when tide wave is reversing –
low current velocity

Water currents are generated by the tides, the speed of the incoming tide is about the same but in the opposite direction of the outgoing tide. Moving waters have to slow down and reverse, from flood to ebb and vice versa (slack tide). This is a good time for navigation through narrow places, particularly those characterized by strong tides (East River, for example).