CHAPTER 10 THE WAVES

Objectives

1. To learn about the formation of waves.
2. To learn about the physical and dynamic characteristics of waves including their size and shape, wave motion and velocity, and the interaction of waves with physical barriers and the sea floor.
3. To identify the different types of waves and their characteristics.
4. To look specifically at the interaction of waves and the shoreline in the surf zone.

Key Concepts

Major Concept (I) *Waves are created as the result of a generating force. An additional force, called the restoring force, acts to return the surface of the water to its original flat level.*

Related or supporting concepts:

- A generating force will create waves on the surface of the water that will then move away from their point of origin.
- The most common generating force is the blowing wind. Other generating forces include vessels moving in or on the water, landslides into water, submarine volcanic eruptions, and submarine earthquakes.
- There are two different restoring forces that act on water waves. These are surface tension and gravity. The size of the wave determines which one of these will be the most important restoring force.
- Most water waves begin as wind (the generating force) blows over the water and friction causes wrinkles to form on the surface. These are called ripples or capillary waves and their restoring force is surface tension.
- Small areas of capillary waves can appear and disappear rapidly giving the impression that they are jumping from point to point over the surface. These rapidly moving patches have been called cat's-paws.
- As more energy is transferred to the water, the waves will grow in size. This will increase the roughness of the surface and make it even easier for the wind to transfer energy to the water so the waves will grow in size rapidly.
- As the waves grow, gravity will become the restoring force and the waves will be called gravity waves.

Major Concept (II) *Oceanographers use specific terms to describe the shape and characteristics of waves (see fig. 10.3).*

Related or supporting concepts:

- The resting or undisturbed sea surface is called the equilibrium surface.
- The highest point on the wave is called the crest.
- The lowest point of the wave is called the trough.
- The distance between two successive crests or troughs is called the wavelength. The wavelength is the smallest section of a wave, that if reproduced multiple times, will re-create the original wave.
- The vertical distance between the crest and the trough is the wave height.
- The vertical distance between either the crest or the trough of the wave and the equilibrium surface is the wave amplitude. This is half of the wave height.
- The amount of time necessary for one wavelength to pass by a stationary point is called the period of the wave. Period is usually measured in seconds/cycle (cycle is another term that can be used for wavelength in this case).

- The number of wavelengths that pass a stationary point in a unit amount of time is the wave frequency. Frequency is usually measured in cycles/second, is the reciprocal of the wave period.

Major Concept (III)

As a deep-water wave (see Major Concept V *for a definition of deep-water waves) moves across the surface, water particles will be driven in a prograde circular orbit. The diameter of this orbit decreases with increasing depth and will disappear at a depth of one-half the wavelength (see fig. 10.4).*

Related or supporting concepts:

- The waves that we see are primarily a moving disturbance on the water's surface that transports energy.
- There is relatively little transport of water in the direction of wave propagation.
- The transport of water is related to the peaked crests and rounded troughs of the waveform. The forward velocity of the water particles at the top of their orbit is slightly greater than their backward velocity at the bottom of their orbit. Hence, there is a small net transport of water in the direction of wave propagation.
- As a wave approaches, a water particle at the surface will trace a circular path rising with the approaching crest of the wave and falling with the passing trough. The diameter of the circular orbit at the surface will equal the height of the wave.
- The diameter of the orbital motion will decrease with increasing depth until there is no motion at a depth of approximately one-half of the wavelength.

Major Concept (IV)

The speed of a wave, its wavelength, and its period are all related to one another.

Related or supporting concepts:

- Wave speed is usually represented with the symbol C which stands for *celerity* which is derived from a Latin word meaning swift.
- The speed of a wave (C) is equal to its wavelength (L) divided by its period (T).

$$C = (L / T)$$

- The period of a wave is relatively easy to measure at sea and will not change once the wave is formed.
- The wavelength of a wave is often difficult to measure directly at sea because of the lack of a stationary reference point.
- Wavelength can be calculated by a simple formula involving the period of the wave and gravity when the waves are considered to be sinusoidal in shape.

Major Concept (V)

Waves that propagate in water that is deeper than one-half their wavelength are called deep-water waves.

Related or supporting concepts:

- The orbital motion in the water column created by deep-water waves stops before it reaches the sea floor. These waves cannot "feel" the bottom.
- The length and speed of a deep-water wave are determined by its period.
- In deep water, the wavelength of a wave is equal to the acceleration of gravity (g) divided by two pi (2π) times the period of the wave squared (T^2).

$$L = (g / 2\pi) T^2$$

or

$$L = (1.56 \text{ m/s}^2) T^2$$

or

$$(L / T) = (1.56 \text{ m/s}^2) T$$

or, remembering that $C = (L / T)$

$$C = 1.56\, T$$

where C is measured in m/s and T is measured in seconds.

Major Concept (VI) *Most open ocean waves are progressive wind waves (PWW's).*

Related or supporting concepts:

- PWW's are generated by blowing winds and restored by the force of gravity.
- PWW's may be formed either by individual storms of varying sizes or by prevailing winds.
- Individual storms occur as winds blow in a circular manner around the low-pressure system storm center.
- The turbulent, changing winds in the storm area generate confused seas with waves of different heights, lengths, and periods. These waves propagate outward from the storm center in all directions. This region of highly variable wave conditions is called a "sea."
- Waves that are actively growing because of the direct influence of the wind are called forced waves. When these waves move outward away from the direct influence of the wind and they no longer continue to grow in size, they become free waves.
- Once waves move away from the sea and become free waves their period does not change as they continue to travel through the oceans. The period of the wave will remain a constant until the wave itself is altered or destroyed by interaction with the bottom in shallow water or by breaking on the shoreline.
- Because deep-water waves travel at velocities that increase with increasing wave period and wavelength. The long period and long wavelength waves that are generated by storms will travel outward at the highest velocity. These waves will move ahead of the shorter period waves and propagate long distances with very little loss of energy. These waves are called swell.
- The dependence of wave velocity on period results in a natural sorting out of the waves with time as long period waves move ahead of short period waves. This sorting out of the waves into groups of similar waves with nearly the same period and speed, or wave trains, is called dispersion.
- Deep-water waves are dispersive waves.
- The wave train is a group of waves. As the wave train moves forward, individual waves will form on the rear of the wave train and travel towards the leading edge of the group where they will disappear. Thus, the individual waves move faster than the group but the group velocity is the speed at which the energy moves through the water.
- Group velocity is one-half of the wave velocity within the group for deep-water waves. Group velocity is usually represented with the symbol V to distinguish it from the wave velocity C.

$$V = C / 2$$

- Multiple storms in the ocean basins may each generate swell that propagates away from the storm centers. These wave trains can intersect, and if they do, their waveforms will add to each other when they meet and then they will pass on out of the region where they have met and continue once more as individual wave trains.
- Waves can add constructively to produce waveforms with greater height or they may add destructively and cancel each other out.

Major Concept (VII) *The potential height of a wind-generated wave is a function of three dependant factors. It is only when none of these factors is limited that maximum wave heights can be achieved.*

Related or supporting concepts:

- The maximum height that a wave can reach increases with increasing wavelength and period. This is shown in table 10.1 in the text. The actual wave height for any given period and wavelength depends on a number of other factors as well.
- The three most important factors controlling wave height are:
    a. the speed of the wind,
    b. how long the wind blows, and
    c. the size of the fetch, or the area the wind blows over in one direction.
- The maximum possible wave height increases as these three factors increase.
- If any one of these factors is small, the wave height will be small.
- The significant wave height is defined as the average wave height of the highest one-third of the waves in a long record of measured wave heights.
- Significant wave heights are forecast from wind data and then the maximum likely wave heights are calculated from them.
- Larger waves will be produced on the side of a storm where the winds are blowing in the same direction as the storm is moving. On this side of the storm both the fetch and the duration of the wind will be increased.
- Unusually large waves can occasionally be produced as a result of constructive interference between intersecting wave trains, changing depths, and currents. These are called episodic waves. These occur most often near the edge of the continental shelf (typically along the southeast coast of Africa where the Agulhas Current meets storm waves from the Antarctic).
- Episodic waves can have a height equal to a 7 or 8-story building (20–30 m, or 70–100 ft). They have speeds as high as 50 knots and wavelengths of nearly a half-mile (0.9 km).
- Researchers have calculated maximum potential heights of episodic waves of 33.8 m (111 ft) in the North Sea and 57.9 m (190 ft) in the area of the Agulhas Current. The maximum observed height of an episodic wave in the North Sea is 22.9 m (75 ft).

Major Concept (VIII) *The energy in a deep-water wave is nearly equally divided between potential and kinetic energy.*

Related or supporting concepts:

- The energy in a wave is measured in terms of energy averaged over one wavelength, per unit width of the crest, down to a depth of one-half the wavelength.
- The energy in a wave extends to a depth of one-half the wavelength because this is approximately the depth at which orbital motion in a deep-water wave ceases.
- The potential energy in a wave is the result of the elevation of the sea surface in the waveform above the resting level of the water.
- The kinetic energy in the wave is present because of the orbital motion of water particles as the wave passes.
- The energy in the wave increases as the wave height increases because the diameter of the orbits of water particles becomes greater and the water is lifted to a higher elevation (fig. 10.10).
- In 1933 a Navy tanker en route from Manila to San Diego was overtaken by a giant wave with a height of 34.2 m (112 ft), a period of 14.8 s, and a wavelength of 329 m (1100 ft). Its speed was calculated to be 27 m (90 ft) per second.

Major Concept (IX) *There is a maximum possible wave height for any given wavelength of a wave. The Universal Sea State Code describes wave heights and corresponding wind speeds.*

Related or supporting concepts:

- The ratio of a wave's height to its length is called the steepness of the wave.
- If the steepness of a wave exceeds 1:7, it will be too steep and the crest of the wave will break as it becomes unstable.

- This maximum steepness corresponds to a waveform whose crest angle reaches 120 degrees (see fig. 10.11).
- Small waves with short wavelengths (generally about 1 meter) are frequently built up in height rapidly by the wind and will break, creating whitecaps.
- Long waves at sea usually are very stable with wave heights well below their maximum.
- Large, open-ocean waves can reach a critical steepness when:
    a. intersecting wave trains combine constructively to build large heights, or
    b. if a wave runs into an opposing current that slows the wave's speed (C) and builds its height (H) since the period of the wave (T) remains constant after the wave is formed (recall that $C = L / T$ or $T = L / C$).
- In 1806, Admiral Sir Francis Beaufort of the British navy created a wind speed estimation system based on the height of waves. This is called the Beaufort Scale. It consists of a 0–12 wind scale that ranges from calm to hurricane force winds.
- The Beaufort Scale has been adapted to create the Universal Sea State code from 0–9 that is summarized in table 10.2.

Major Concept (X) *Waves change in a variety of ways when they propagate into water whose depth is less than one-half the wavelength of the wave and they stop being deep-water waves.*

Related or supporting concepts:
- We need to keep in mind two facts:
    a. that the speed of all waves is equal to the wavelength divided by the period, and
    b. that the period of a wave does not change after the wave has formed.
- As a wave passes into water that is shallower than $L/2$, the orbital motion in the water will extend to the bottom and the orbital circles will flatten out into ellipses. On the bottom there will be a back-and-forth motion of the water across the sea floor.
- The wave speed will decrease as a result of friction with the bottom.
- Since the period of the wave will remain constant, the decrease in velocity will result in a shortening of the wavelength and an increase in both the wave height and its steepness.
- At water depths less than $L/2$ and greater than $L/20$ the wave's characteristics will be changing. These are called intermediate or transitional waves.
- At water depths less than $L/20$ the wave will become a shallow-water wave.
- The length and speed of a shallow-water wave are determined by the water depth.
- The speed of a shallow-water wave (C) is related to the acceleration of gravity (g) and the depth of the water (D) by the following formula:

$$C = \sqrt{gD} \quad \text{or} \quad C\,(\text{m/s}) = 3.13\sqrt{D(\text{m})} \quad \text{or} \quad L(\text{m}) = 3.13\,T\sqrt{D(\text{m})}$$

Major Concept (XI) *As waves move into shallow water or encounter obstacles in their path, they may be refracted, reflected, or diffracted.*

Related or supporting concepts:
- As waves enter shallow water and feel the bottom, their direction of movement will change. Their paths will be bent or refracted.
- In general, it is unlikely that an approaching wave crest will be parallel to the shoreline. Consequently, one end of the wave will encounter shallow water and slow down sooner than the other end. In this way, the end of the wave in deep water will move ahead of the shallow, slow moving end and the entire crest of the wave will bend and become more parallel to the shoreline. This is the process of refraction.
- We can draw wave rays that are perpendicular to a wave crest that show us the direction in which the wave crest is moving.
- Along irregular coastlines there are often submerged extensions of headlands that create shallower water while the water depth typically remains relatively deep in front of bays. As a result, wave rays drawn for wave crests approaching irregular coastlines curve inwards and together to concentrate

energy on headlands and spread apart, dispersing energy over a wider area, in bays. Look at figures 10.15 and 10.16 in the text to see this.

- Headlands are high-energy environments subjected to a lot of erosion and bays are lower-energy environments somewhat protected from the energy of the waves.
- When waves encounter barriers in their path, they can be reflected. The efficiency of the reflection depends on the properties of the barrier and its geometry. We can easily imagine a wave being reflected from a hard, vertical seawall, while a soft, very gently sloping beach would not reflect as much energy.
- The wave will be reflected off the barrier at the same angle at which it hit the barrier.
- Reflected waves will interfere with the incoming waves and often result in choppy water.
- Waves may also be diffracted. This causes the wave to be bent so that it travels sideways at right angles to the direction of the incoming wave.
- Small openings in barriers such as breakwaters cause successive parallel approaching wave crests to move through the opening and then behind it in a semicircular pattern of expanding wave crests. Take a look at figure 10.18 in the text to see a good illustration of this. Interference patterns can be produced behind barriers if there is more than one opening in the barrier and waves are diffracted through openings close to one another.
- Diffraction may also occur around a barrier without an opening that extends into the water. In this case the diffraction will produce a pattern of wave crests that is half of a semi-circle (see fig. 10.19).
- In areas where the winds blow steadily and from one direction, waves are very regular in their direction of motion. This is common in the trade wind belts. Under these conditions a vessel can easily maintain a constant course with respect to the waves.
- Careful observation can often reveal subtle changes in wave patterns many miles from shore. Recognition of these changes can be used to pilot a vessel to shore when no landmarks are visible.
- The Polynesians were able to use their knowledge of wave patterns and their association with winds and islands to navigate across hundreds, and even thousands of miles of open ocean.

Major Concept (XII) *In the surf zone, waves undergo a number of fundamental changes as they move into shallow water and interact with the bottom.*

Related or supporting concepts:

- The surf zone is the nearshore region where waves begin to slow down, increase in steepness, and eventually break as the steepness grows and exceeds 1:7.
- The width of the surf zone is a function of the depth of the water and the wavelength of the approaching waves. Long wavelength waves will feel the bottom sooner, or in deeper water, so the surf zone will extend further offshore than for short wavelength waves.
- Breakers form when orbital particle motion at the trough of the wave slows more rapidly than at the crest. The water at the crest of the wave will move forward and outrun the base of the wave.
- There are different types of breakers including plungers and spillers. These are distinguished from one another by the speed and amount of turbulence with which they expend their energy.
- Plunging breakers:
    a. form on steep beach slopes,
    b. break suddenly, and
    c. expend their energy with a crash.
- Spilling breakers:
    a. are found over gently sloping beaches,
    b. are characterized by turbulent water flowing down the face of the wave,
    c. last longer than plunging breakers, and
    d. occur more frequently than plunging breakers.
- Waves typically approach the coast at an angle so they begin to break at the end closest to shore and the breaking will progress along the length of the wave crest as it continues to move toward the beach.
- Distant storms will produce swell, consisting of waves with nearly constant wavelengths, heights, and periods. These waves will result in a well-defined surf zone with breakers that appear at a constant distance from shore.

- Local storms will produce highly variable waves that will break at different distances from the beach.

Major Concept (XIII) *Waves transport water onto and along the beach. The water then will often return seaward in a relatively narrow, concentrated flow called a rip current.*

Related or supporting concepts:

- Because waves generally approach the shore at an angle, there is a net movement of water along the beach in the direction of wave travel within the surf zone.
- The water driven onto the beach in the surf zone will flow along it until it reaches an area where it can easily return seaward.
- The return flow occurs where the surf zone is the least turbulent and wave heights are relatively small. This is often the result of locally deeper water close to shore due to a trough or depression in the sea floor extending seaward from the beach.
- The return flow seaward must be quite rapid to carry the large volume of water that was driven onto the beach back off of it in a much narrower current. This rapid flow is the rip current.
- It is often possible to spot an area where rip currents either have, or may, form by looking for:
    a. turbid, muddy water or floating debris moving seaward through the surf zone,
    b. areas of smaller wave heights in the surf zone, or
    c. depressions in the beach face that appear to extend offshore.

Major Concept (XIV) *Waves carry large amounts of energy with them and the release of that energy in the coastal environment can pose significant hazards for unsuspecting people.*

Related or supporting concepts:

- The breaking of very large waves in a narrow surf zone can concentrate the release of energy and result in very dangerous conditions. Breaking waves can throw rocks and other debris far up onto the shore away from the water line.
- Large breaking waves offshore can occur when the water suddenly shoals because of the presence of a submerged sandbar. Sandbars are often associated with the mouths of large rivers and estuaries. These breaking waves can be very hazardous for vessels.
- Massive waves with heights up to 20 m (66 ft) with the ebbing (falling) tide at the bar at the mouth of the Columbia River. The Coast Guard uses this area to train its crews to operate roll-over, or self-righting, rescue boats. These amazing vessels are used during storms and heavy surf conditions.

Major Concept (XV) *Submarine earthquakes that cause vertical displacements of the sea floor can generate massive waves on the sea surface called tsunamis.*

Related or supporting concepts:

- Tsunamis, or seismic sea waves, are also frequently called tidal waves. This is a fundamental mistake since they are not related to the tides in any manner.
- Tsunamis are enormous waves compared to typical wind-generated waves. They have wavelengths that are often 100–200 km (60–120 mi) and periods of 10–20 minutes.
- Because of their long wavelength, tsunamis travel as shallow-water waves even in the deepest oceans, and orbital motion in the water column extends to the sea floor.
- Their velocity of propagation depends on water depth and is approximately 200 m/s (400 mi/hr) in the open ocean.
- Because they travel as shallow-water waves, they can be reflected, refracted, or diffracted in the open ocean.
- The average height of a tsunami in mid-ocean is 1–2 m (3–6 ft) but they can pass by a vessel undetected since this height is distributed over their extraordinarily long wavelength.

- As the wave passes into shallow water, the height will grow very rapidly, its velocity will decrease to about 80 km (50 mi) per hour, and its wavelength will decrease.
- Tsunamis can cause great devastation in coastal regions by producing waves over 30 m (100 ft) high.
- If the initial motion of the sea floor is upward, the resultant tsunami will have a wave crest at its leading edge and when it reaches shore there will be a rush of water inland. If the initial motion of the sea floor is downward, the resultant tsunami will have a wave trough at its leading edge and when it reaches shore there will be a rush of water away from the beach that will expose the sea floor.
- If a trough arrives first, the water level can drop by as much as 3–4 m (10–13 ft) within 2–3 minutes. This is followed 4–5 minutes later by a rise in water level of 6–8 m (20–26 ft), which is followed a few minutes later by an equivalent drop in water level.
- Tsunami typically arrive as a series of wave crests rather than one single giant wave.
- The severity of a tsunami is related to the amount of vertical displacement of the sea floor caused by faulting. It is not possible to accurately relate vertical displacement to earthquake magnitude, hence we cannot predict the severity of a tsunami from the magnitude of the earthquake that produced it.
- Tsunamis occur most often in the Pacific Ocean.
- Devastating historic tsunamis include:
    a. An earthquake in the Aleutian Islands on April 1, 1946 created a series of tsunamis that struck Hilo Hawaii killing 150 people.
    b. Hawaii was struck again in 1957 but early warnings prevented any loss of life.
    c. The great 1964 Alaska earthquake created tsunamis that struck the west coast of Vancouver Island and the northern coast of California.
    d. A large earthquake off the coast of Nicaragua on Sept. 1, 1992 created a tsunami that killed 170 people, injured 500 more, and destroyed 1500 homes.
    e. On Dec. 12, 1992 a major earthquake in the Sunda and Banda island arc systems reportedly killed 2080 people and injured 2144 others.
    f. The magnitude 7.8 earthquake that occurred in the Sea of Japan on July 12, 1993 resulted in 185 deaths and an estimated property loss of $600 million.
    g. A devastating tsunami struck the northwest coast of Papua New Guinea on July 17, 1998, destroying four fishing villages. More than 2000 people were reported killed or missing. The earthquake that generated the tsunami created a 2 m (6 ft) vertical drop along a 40 km (24 mi) fault in the sea floor.

Major Concept (XVI) *Waves can also form along the subsurface boundaries that separate different water masses. These waves are called internal waves.*

Related or supporting concepts:

- Because the density difference across boundaries between water masses is so small, both the generating and restoring forces for internal waves can be small. In other words, it doesn't take much energy to create a wave along an internal boundary.
- Internal waves have large heights and wavelengths but propagate at slow velocities.
- The height of an internal wave is limited by the thickness of the surface layer above them.
- Internal waves are thought to act like shallow-water waves, with the depth of the water corresponding to the thickness of the underlying water mass rather than the distance to the sea floor.
- If the water mass above the boundary is relatively thin, the internal wave may reach to the surface. When the crest of the wave reaches the surface, it will create a band of water with ripples that moves across the surface. A band of smooth water called a slick marks the trough of the internal wave. These usually occur in nearshore regions where freshwater runoff creates a relatively thin surface water layer.
- Generating forces for internal waves include:
    a. tilting of the sea surface caused by variations in atmospheric pressure, upward doming under low pressure systems and the reverse under high-pressure cells, and wind stress,
    b. earthquakes,
    c. tidal forces, and
    d. long-term wind changes.

- The velocity of an internal wave (C) is related to the density of the water layer above (d'), the density of the water layer below (d), its wavelength (L), and the acceleration of gravity (g):

$$C^2 = (g / 2\pi) L [(d-d') / (d+d')]$$

Major Concept (XVII) *Waveforms that do not propagate from one location to another and do not have a velocity are called standing waves.*

Related or supporting concepts:

- Standing waves appear as alternating crests and troughs at the same location separated by points where the water surface does not change elevation.
- Areas that alternate between a crest and a trough are called antinodes, while the intervening points where there is no change in elevation are called nodes.
- Standing waves can also be thought of as progressive waves that have been reflected back on themselves.
- The period of oscillation of a standing wave increases as you increase either the depth or length of the basin it is in.
- In a closed basin, a standing wave with one node will have a wavelength twice the length of the basin. A wave with two nodes will have a wavelength equal to the length of the basin and a period that is one-half that of the single-node wave.
- In an open basin (such as a bay or inlet), a node is usually positioned at the opening of the basin. In this way, there is only one-quarter of a wavelength of the wave inside of the basin, with the largest variation in water level at the end of the basin, and no change in level at the opening of the basin. It is also possible to have multiple nodes in open-ended basins.
- Standing waves in natural basins are called seiches.
- Tectonic movements or winds can generate seiches.
- The period of oscillation T of a standing wave with n nodes is related to the acceleration of gravity, g, the depth of the basin D, and the wavelength of the wave L by the following version of the shallow-water wave equation:

$$T = (1/n)(L / \sqrt{gD})$$

L is twice the length of the basin in a closed basin and four times the length of an open basin.

Major Concept (XVIII) *While there is a tremendous amount of power available in ocean waves, there are a variety of reasons why the harnessing of this power is not a trivial task.*

Related or supporting concepts:

- Wave energy is dispersed over large areas and is always changing in response to changes in driving forces and the sea state.
- Wave energy can be captured in three different ways:
  a. allowing the water to lift an object, and thus produce potential energy,
  b. rocking an object back and forth either by the orbital motion of water particles or changes in the tilt of the sea surface, and
  c. using rising water to compress air in a chamber.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XVIII) of the appropriate major concept identified in this section:

forced wave	ripple	seiche
trough	fetch	storm center
spiller	refraction	crest
tsunami	wave period	surface tension
reflection	shallow-water wave	standing wave
restoring force	slick	capillary wave
internal wave	generating force	deep-water wave
dispersion	group speed	wavelength
episodic wave	rip current	node
diffraction	plunger	breaker
water particle orbit	gravity wave	

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. Waves are created by an initial ____________________________ force.
2. The restoring force for gravity waves is _______________________.
3. The restoring force for capillary waves is ___________________ ___________________.
4. The height of a wave is twice the wave's ___________________________.
5. The undisturbed sea surface is sometimes called the ______________________________ surface.
6. Deep-water waves cause water particles to move in a ______________________ orbit.
7. When waves are being generated, they receive additional energy from the wind and are known as _________________ waves.
8. Waves that move independently of the wind are called ______________ waves.
9. The velocity of propagation of a wave is related to the wave's ________________________ and ____________________________.
10. Once a wave has been created, its ___________________ does not change.
11. Long period, uniform waves propagating away from the storm center are called ______________.
12. Groups of fast moving waves traveling in packets are called _____________ _________________.
13. Group speed is the speed of _________________ transport.
14. The distance over which wind blows in a single direction is the _______________.
15. Two wave trains can approach from different directions, intersect, and produce _________________________________ patterns.
16. Energy in a wave comes in two forms, _________________________ energy due to changes in elevation and ___________________ energy due to motion of water particles.
17. __________________________ is the ratio between height and wavelength.
18. Wind speeds and sea surface conditions are described by use of the ____________________________ _________ _______________ code.
19. Wave crests are bent as they move into shallow water in a process called ____________________________.
20. Waves that move through narrow openings in barriers will be _________________________________.

TRUE - FALSE

1. Most open-ocean waves are restored by the water's surface tension.
2. Capillary waves grow into gravity waves as more energy is added by the wind.
3. The low point of a wave is the trough.
4. The horizontal distance between adjacent crests and troughs is one-half the wavelength.
5. The vertical distance from the equilibrium surface to the top of the wave crest is the wave height.
6. The period is the time required for a wavelength to pass a stationary point.
7. Shallow-water waves create circular orbital motion in the water all the way to the sea floor.
8. Water particles at the top of a wave crest are moving in the direction of propagation of the wave.
9. The period of a wave will change with distance from the storm center because of dispersion.
10. Most progressive wind waves are capillary waves.
11. The group speed is exactly twice the wave speed in deep water.
12. Wind wave speeds in the oceans are typically 100's of m/s.
13. Tsunamis are unrelated to the tides.
14. Tsunamis travel as shallow-water waves in the open ocean.
15. Waves transport large volumes of water across great distances.
16. Intersecting waves always cancel each other out.
17. The crests of internal waves can occasionally break the sea surface.
18. Internal waves generally can have greater wave heights than surface waves.
19. Standing waves can form in both closed and open-ended basins.
20. The period of a standing wave is related to the physical dimensions of the basin.

MULTIPLE CHOICE

1. The speed of a wave is equal to
   a. the height divided by the frequency.
   b. the wavelength divided by the amplitude.
   c. the period divided by the wavelength.
   d. the amplitude divided by the period.
   e. the wavelength divided by the period.
2. The restoring force for ________ is surface tension.
   a. capillary waves
   b. progressive wind waves
   c. ripples
   d. tsunamis
   e. a and c above
3. The most common generating force for ocean waves is
   a. tidal forces.
   b. the wind.
   c. tectonic forces.
   d. submarine earthquakes.
   e. disruptive schools of fish.
4. The horizontal distance between two successive crests or troughs is the
   a. height.
   b. period.
   c. wavelength.
   d. amplitude.
   e. frequency.
5. As a wave trough approaches, surface water particles
   a. fall and move backward.
   b. fall and move forward.
   c. rise above the equilibrium surface level.
   d. a and c above.
   e. b and c above.
6. At a depth of _________ , the orbital motion in a deep-water wave has decreased to almost zero.

a. twice the amplitude
b. half the height
c. one-quarter the wavelength
d. half the wavelength
e. one-third the height

7. Shallow-water waves travel in water whose depth is less than _______ of the wavelength of the wave.
   a. 1/2
   b. 1/20
   c. 1/3
   d. 1/30
   e. 1/10
8. In the storm area, the surface is a jumble of confused waves called a _______.
   a. storm center
   b. interference pattern
   c. swell
   d. surf zone
   e. sea
9. Far from a storm center, the first waves to arrive at some location will be
   a. short-period waves, because of dispersion.
   b. long-period waves, because of diffraction.
   c. long-period waves, because of dispersion.
   d. short-period waves, because of diffraction.
   e. long-period waves, because of refraction.
10. In a wave train
    a. the individual wave crests move toward the back of the group.
    b. the individual wave crests move toward the front of the group.
    c. the train carries the energy of the waves.
    d. b and c above.
    e. a and c above.
11. The most important factors controlling the height of a wave are
    a. how long the wind blows in a given direction.
    b. the distance over which the wind blows.
    c. how fast the wind blows.
    d. the latitude of the blowing wind.
    e. a, b, and c above.
12. The area of the oceans that is best for producing high waves is
    a. between 40–50 degrees south.
    b. between 40–50 degrees north.
    c. between 40–50 degrees west.
    d. between 40–50 degrees east.
    e. there is no single best location.
13. Episodic waves are related to
    a. changing water depths.
    b. strong currents.
    c. intersecting wave trains.
    d. all of the above.
    e. none of the above.
14. When the steepness of a wave exceeds _______, it will break.
    a. 1:2
    b. 1:7
    c. 1:20
    d. 1:5
    e. 1:10
15. As a wave enters shallow water
    a. it will slow down.

b. its steepness will increase.
c. its wavelength will decrease.
d. its period will remain the same.
e. all of the above.

16. A wave with a period of 10 s and a wavelength of 130 m will travel at a velocity of
    a. 1300 m/s.
    b. 130 m/s.
    c. 13 m/s.
    d. 1.3 m/s.
    e. you can't tell from this information.
17. The velocity of shallow-water waves is a function of
    a. water depth.
    b. wave height.
    c. wavelength.
    d. wave period.
    e. wave frequency.
18. Tsunamis
    a. generally have small heights at sea.
    b. usually travel as a series of crests and troughs.
    c. have periods from 10 to 20 minutes.
    d. have wavelengths of 100 to 200 km.
    e. all of the above.
19. Areas susceptible to rip currents can be recognized by
    a. regions of smaller wave heights in the surf zone.
    b. turbid water moving rapidly away from shore.
    c. ridges of sand perpendicular to the beach.
    d. all of the above.
    e. a and b above.
20. The wavelength of a standing wave having one node in an open basin is
    a. 1/2 the length of the basin.
    b. 4 times the length of the basin.
    c. equal to the length of the basin.
    d. twice the width of the basin.
    e. 1/4 the width of the basin.

Visual Aids: Test Your Understanding of the Figures

1. Water waves are often approximated by sine waves. The difference between an actual wave and a sine wave is illustrated in figure 10.3. Notice how the trough of an actual wave is rounded in the same manner as a sine wave, while the crest of an actual wave is peaked. This allows us to think of measuring the angle of the crest in a manner shown in figure 10.10. Remember that if this angle approaches 120 degrees, the wave will be unstable and break.
2. Study the arrows along the sea surface in figure 10.4. If you follow the surface from *right to left,* the arrows will give you a good idea of the motion of a surface water particle as a wave approaches and passes. This type of movement where motion at the crest is in the direction of propagation of the wave is called prograde motion.
3. Take a look at figures 10.14 and 10.15. The wave rays drawn here give you an idea of where the energy of the approaching waves will be directed. Would you choose to anchor a boat off a headland or in a bay?
4. Figures 10.27a and b are particularly good illustrations of how the sea level remains constant at the nodes of stationary waves and has its greatest oscillations at the antinodes. It's relatively simple to create a single node standing wave in a sink, bathtub, or even a round coffee cup; you should try it.

Study Problems

1. After taking another look at section 10.5, calculate the wavelength in meters of a deep-water wave whose period is 12.5 seconds. What would its velocity be?

2. At what depth of water will the wave in problem one become a shallow-water wave?
3. What height can the wave in problem one grow to before becoming unstable?
4. What is the natural period of a standing wave with two nodes in a closed basin 650 meters long and 83 meters deep? Check section 10.11.

Answer Key for Key Terms and Test Your Recall

KEY TERMS

forced wave (VI)	ripple (I)	seiche (XVII)
trough (II)	fetch (VII)	storm center (VI)
spiller (XII)	refraction (XI)	crest (II)
tsunami (XV)	wave period (II)	surface tension (I)
reflection (XI)	shallow-water wave (X)	standing wave (XVII)
restoring force (I)	slick (XVI)	capillary wave (I)
internal wave (XVI)	generating force (I)	deep-water wave (V)
dispersion (VI)	group speed (VI)	wavelength (II)
episodic wave (VII)	rip current (XIII)	node (XVIII)
diffraction (XI)	plunger (XII)	breaker (XII)
water particle orbit (III)	gravity wave (I)	

FILL IN THE BLANK

1. generating	2. gravity	3. surface tension
4. amplitude	5. equilibrium	6. circular
7. forced	8. free	9. period, wavelength
10. period	11. swell	12. wave trains
13. energy	14. fetch	15. interference
16. potential, kinetic	17. steepness	18. Universal Sea State
19. refraction	20. diffraction	

TRUE-FALSE

1.F 2.T 3.T 4.T 5.F 6.T 7.F 8.T 9.F 10.F 11.F 12.F 13.T 14.T 15.F 16.F 17.T 18.T 19.T 20.T

MULTIPLE CHOICE

1.e 2.e 3.b (if you answered 'e,' see your instructor immediately!) 4.c 5.a 6.d 7.b 8.e 9.c 10.d 11.e 12.a 13.d 14.b 15.e 16.c 17.a 18.e 19.e 20.b

STUDY PROBLEMS

1. 244 m, 19.5 m/s
2. 12.2 m
3. about 35 m
4. 22.8 s