CHAPTER 8 WAVES AND TIDES

*Key Concepts*

Major Concept (I) *Two forces are involved in the creation and disappearance of waves. Waves are created by a generating force. Once the surface of the water has been disturbed a second force, called the restoring force, acts to flatten the surface once again.*

Related or supporting concepts:

- There are a variety of possible generating forces for waves including:
  a. the wind,
  b. submarine earthquakes,
  c. submarine volcanism,
  d. landslides, and
  e. ships moving through the water.

  Wind is the most common generating force for ocean waves.
- Waves are a disturbance of the surface of the water. As waves propagate they transport energy but relatively little water.
- Wind blowing over a flat water surface will create wrinkles on the surface because of friction. These wrinkles are the first stage in the generation of larger waves. They are called capillary waves and their restoring force is the surface tension of the water.
- Once capillary waves have formed, the surface has some roughness and it is able to capture the energy of the wind more efficiently. This creates larger waves whose restoring force is gravity. These are sometimes called gravity waves.

Major Concept (II) *We can approximate the shape of a wave as being similar to a simple sinusoid. There are specific terms used to indicate parts of the wave, as well as characteristics of the wave related to time.*

Related or supporting concepts:

- You can refer to figure 8.2 in your text during this discussion of the terms used to describe a wave.
- The highest point of the wave is called the crest.
- The lowest point of the wave is called the trough.
- The vertical distance between the height of the crest and the depth of the trough is the wave height. The amplitude of the wave is ½(height).
- The smallest segment of the wave form that will reproduce the shape of the wave if it is repeated is called the wavelength. A simple way to measure it is to keep in mind that the wavelength is equal to the distance between successive crests or successive troughs.

- The period of the wave is the time required for one wavelength to pass a stationary point, such as the end of a pier. The units of period are seconds/cycle or seconds/wavelength.
- The frequency of a wave is the number of wavelengths that pass a stationary point in a unit amount of time, usually one second. The units of frequency are cycles/second or wavelengths/second.
- Period and frequency are reciprocals of each other.

Major Concept (III) *Waves represent a transport of energy. The water molecules at the surface are driven in a circular orbit by passing waves. The velocity of a wave is related to its wavelength and period.*

Related or supporting concepts:

- If we trace the path taken by a single water molecule as a wave passes by we would see that it moves in a circular orbit. With the approaching crest it moves forward and up. As the crest passes and the trough approaches it will move backward and down.
- The water molecule will return very close to its original position at the end of each orbit. This is why you see objects floating in the water that do not move appreciably in the direction of the waves.
- For water molecules at the surface, the diameter of the orbit is equal to the wave height. The diameter decreases with increasing depth by a factor of about one-half for every increase in depth of one-ninth of the wavelength.
- At a depth of one-half the wavelength, motion in the water essentially stops (see fig. 8.3).
- The speed of a wave is called the wave celerity, usually abbreviated C, to distinguish it from the group speed, usually denoted V, discussed in Major Concept IV below.
- The wave speed, or celerity C, is equal to the wavelength, L, divided by the period, T.

$$C = L/T$$

- The period of a wave does not change once the wave has formed. Consequently, changes in the speed of the wave result in changes in its wavelength.
- In practice, you measure wave period directly and calculate the wavelength and speed.

Major Concept (IV) *By definition, a deep-water wave is one which propagates in water whose depth is greater than one-half the wavelength of the wave. This means that motion in the water column due to the passage of the wave does not reach the bottom.*

Related or supporting concepts:

- The wavelength of a deep-water wave is related to the acceleration of gravity, g, and its period, T. With some manipulation it can be shown that:

$$L = (g/2\pi)\,T^2 = 1.56\,T^2$$

- It can also be shown that the speed of a deep-water wave is directly proportional to its period. The relationship is:

$$C = L/T = 1.56\ T$$

where C is expressed in meters per second and T is given in seconds.
- Wind driven waves are formed either in storm centers or in regions where there are prevailing winds.
- When storms generate waves, the gusting, shifting winds will create waves of many different periods, heights, and lengths that propagate outward from the center of the storm in all directions.
- Because wave speed is directly proportional to wave period and wavelength, these chaotic waves will sort themselves out as they move away from the storm. The long period, long wavelength waves will travel most rapidly. This is a process called dispersion (see fig. 8.4).
- Groups of waves with similar wavelengths and periods will travel together across the ocean as wave trains.
- Wave trains move at a speed called the group speed, V, that is one-half the speed of the individual waves in the wave train.

$$V = C/2$$

- The group speed is the speed at which the energy in the train is propagating.
- Waves that are dispersed and are moving across the surface with very uniform lengths and periods are called swell.

Major Concept (V) *When two or more wave trains from different storms encounter one another the waves will intersect and create interference patterns. As the wave trains move away from the region of intersection they will return to their previous form.*

Related or supporting concepts:

- Intersecting waves may interfere constructively or destructively if they meet at a low angle (see fig. 8.6).
- Constructive interference occurs when the crests and troughs of the two wave trains meet at roughly the same time and place, thus doubling the wave height.
- Destructive interference occurs when the crests of one wave train coincide with the troughs of another and they cancel each other out.
- When the wave trains meet at a high angle, close to 90°, the resulting interference pattern can look like a checker board, as illustrated in figure 8.7.

Major Concept (VI) *The maximum height a wave will achieve depends on the strength of the wind, how long it blows, and the area over which it blows in a single direction.*

Related or supporting concepts:

- Large waves are produced by strong winds that blow for a long time over a long distance.
- The area over which the wind blows to create waves is called the fetch.
- The amount of energy in a wave is a function of the height of the wave squared. Consequently, as the height increases, the energy increases very rapidly (see fig. 8.8).
- In the open ocean the fetch and wind duration are seldom limiting factors. Wind speed is usually the most significant factor in wave height. Table 8.1 relates wind speed with wave height.
- The significant wave height is defined as the average wave height of the largest one-third of the waves observed. If you measured the height of 30 waves and arranged their heights in order from smallest to largest, you could break them into three groups. The first 10 waves would be the smallest one-third, the second ten would be intermediate in height, and the third set of 10 (beginning with wave number 21) would be the largest one-third. The average height of the 21st through 30th waves would be the significant wave height for the set of 30 waves.
- We can categorize the height of the waves using the Universal Sea State Code, also known as the Beaufort scale of sea state, that is given in table 8.2. This scale describes the average wave height of the sea at some given time.
- The best-documented giant wave in the open ocean was encountered by a Navy tanker, the USS *Ramapo*, in the Pacific during a severe storm. It was 34.2 m (112 ft) high. Its period was 14.8 seconds and its speed was calculated to be 27 m (90 ft)/s (roughly 65 mi/hr or 54 knots).
- Occasionally an unusually large wave called an episodic wave will form. Episodic waves have heights of 20 - 30 m, wavelengths up to a kilometer, and can move at speeds as great as 25 m/s (60 mi/hr or 50 knots).
- Episodic waves usually appear near the edge of continental shelves in water about 200 m (660 ft) deep near regions that typically have strong winds and surface currents.
- Three areas that are known to produce episodic waves are:
    a. the southeast coast of Africa where the Agulhas current meets the West Wind Drift,
    b. the North Atlantic where the Gulf Stream can flow out into strong storms, and
    c. in the North Sea.

Major Concept (VII) *For a given wavelength there is a maximum wave height that can be attained before the wave becomes unstable and breaks.*

Related or supporting concepts:

- The ratio of wave height, H, to wavelength, L, is called the steepness, S, of the wave.

$$S = H/L$$

- The maximum wave steepness for a stable wave is 1/7. If the steepness exceeds 1/7 the wave will break, lowering the height of the wave and making it stable once again.

- When the maximum steepness is attained, the angle between the sides of the wave crest will be about 120° (see fig. 8.10).
- The whitecaps often seen on water are waves with short wavelengths on the order of 1 m.
- In the open ocean it is rare to have wind speeds high enough to build waves to unstable heights.  The spray seen in the open ocean is more frequently the result of water blowing off the very top of the crest.

Major Concept (VIII) *Shallow-water waves propagate in water whose depth is less than L/20 (see fig. 8.11).  These waves cause motion in the water column that extends to the bottom.  The interaction of the waves with the bottom gives these waves unique characteristics.*

Related or supporting concepts:

- As deep-water waves propagate into shallower water and become shallow-water waves the following things happen:
  a. circular orbital paths become flattened and form ellipses,
  b. there is a frictional drag on the wave as it feels the bottom, and
  c. the speed of the wave is reduced because of the drag on the bottom.
- The speed of a wave is equal to the wavelength divided by the period:

  $$C = L/T$$

  Since the speed of shallow-water waves decreases and since the period of a wave does not change once it has formed, we can see from the equation for speed that the wavelength will decrease when a deep-water wave becomes a shallow-water wave.
- As the wavelength decreases, the wave height must increase to conserve the energy in the wave.
- With increasing height and decreasing wavelength the steepness of the wave increases rapidly.  This is what eventually causes the wave to break near shore.
- The velocity of a shallow-water wave is a function of the depth of the water, not the wavelength.  Since all shallow-water waves travel at the same speed in a given water depth, they are non-dispersive waves.
- The speed of a shallow-water wave, C, and its wavelength, L, are controlled by the acceleration of gravity, g (9.81 $m/s^2$), and the depth of the water, D:

  $$C = \partial(gD) = 3.13\ \partial(D)$$
  $$L = \partial(gD)\ T = 3.13\ \partial(D)\ T$$

  where the units of C are m/s,  and L and D are measured in meters.
- The group speed, V, of shallow-water waves is equal to the wave speed, C.
- On the bottom, the elliptical orbits will be flattened and the water will simply wash back and forth against the sea floor.
- Waves can be:
  a. refracted,

b. reflected, or
c. diffracted.

- Because waves seldom approach land parallel to the shore, one end of the wave will usually encounter shallower water first and begin to slow down while the other end continues at a higher speed. This causes the wave to bend, or refract, to become more nearly parallel with the shore (see fig. 8.13).
- Along irregular coastlines the water will usually become shallow quicker off of headlands and will remain relatively deep longer in bays. The net effect of this is to concentrate breaking wave energy on headlands and disperse the energy in bays. You can see this in figures 8.14 and 8.15.
- Waves can also be reflected if they hit barriers, creating interference patterns as they pass back through the incoming waves.
- Wave diffraction is the passage of wave energy around and behind barriers, as shown in figure 8.16.
- Wave diffraction often results in reduced wave heights behind barriers.
- In the open ocean, deep-water waves typically remain unchanged for long distances. When a change in the nature of the waves occurs, such as a change in:
  a. the direction of travel,
  b. the speed,
  c. the height, or
  d. the wave's shape,

  it may be due to changing depth because of the presence of shoals or the proximity of an island. Subtle changes such as these allowed the Polynesians to complete long voyages in canoes across vast distances of open water centuries ago.

Major Concept (IX) *Waves steepen rapidly and break in a region near the shoreline called the surf zone.*

Related or supporting concepts:

- The width of the surf zone is a function of the:
  a. height of the approaching waves,
  b. wavelength of the waves, and
  c. the slope of the bottom.
- Waves with longer wavelengths and greater heights will break farther from shore.
- The width of the surf zone increases as the steepness of the bottom slope decreases.
- Plunging breakers curl over rapidly and crash with a sudden loss of energy (see fig. 8.17a). They form where the surf zone is narrow due to a steeply sloping bottom.
- On some plunging breakers the crest will slowly curl over and the curl will propagate along the crest of the wave forming a "tube" popular with surfers (see fig. 8.18).
- Spilling breakers are found where the bottom slopes gently. Water will slow down the face of the wave, bubbling and mixing with a gradual loss of energy over a longer distance (see fig. 8.17b).

Major Concept (X) *Tsunamis are waves that propagate as shallow-water waves even in the open ocean due to very long wavelengths. They are produced most frequently by submarine earthquakes and faulting.*

Related or supporting concepts:

- The word tsunami is Japanese. Translated it means harbor wave. Tsunamis cause the most damage in shallow water areas with high population or building density, like a harbor.
- There are few things that will indicate a person's ignorance of physical oceanography more quickly than if you hear them referring to tsunamis as tidal waves (please do not make this mistake). These waves are totally unrelated to the tides. They may be caused by:
  - a. earthquakes and faulting on the sea floor,
  - b. submarine volcanic explosions, and
  - c. landslides that send large amounts of material into the water.
- Faulting on the sea floor that results in vertical displacement will cause a similar displacement in the water's surface. This will generate a wave, or tsunami, with the following characteristics:
  - a. long wavelength (100 - 200 km, or 54 -108 nmi),
  - b. long period (10 - 20 minutes commonly and sometimes as long as an hour), and
  - c. very high speeds (generally about 200 m/s or 400 mi/hr).
- Because tsunamis are shallow-water waves they can be refracted, reflected, or diffracted if they encounter islands or significant changes in depth as they propagate across the ocean.
- In the open ocean in deep water the height of a typical tsunami will be on the order of 1 - 2 meters (3 - 6 ft). Despite this, there is enormous energy in the wave because of its very long wavelength.
- When a tsunami enters shallow water its height can grow to as much as 30 m (roughly 100 ft) and create great damage by crashing on shore and running some distance inland along low-lying coasts.
- Tsunamis are not single waves; they travel as wave trains and there may be several crests in the train. The leading edge of the wave train may be either some portion of the crest above normal sea level or a portion of the trough below normal sea level.
- If the crest of the tsunami is the first to arrive at the shoreline it can inundate the shore with little or no warning.
- If the trough of the tsunami is the first to arrive, the water will appear to rush away from the shore, exposing the sea floor.
- Since tsunamis are caused most frequently by submarine earthquakes, they are usually formed in the Pacific Ocean basin. They may also be formed in the Caribbean Sea and the Mediterranean Sea.
- In 1946 a tsunami caused major damage in Hilo, Hawaii and killed more than 150

people.

- Hawaii was hit by another tsunami in 1957 but no lives were lost due to early warning and evacuation (see fig. 8.19).
- The 1964 Alaska earthquake produced a tsunami that did extensive damage in Alaska, along the west coast of Vancouver Island, and the northern coast of California.
- In 1992 a tsunami killed 170 people in Nicaragua and a second one reached a height of 25 m (82 ft) and killed 1000 people in Indonesia.
- In 1993 more than 185 people died and $600 million in damages were caused by a tsunami in Japan (see fig. 8.20).
- A region along the northwest coast of Papua, New Guinea was devastated by a series of large waves 7 to 15 m in height (22 - 50 ft) that destroyed four fishing villages killing more than 2000 people (See fig. 8.21).

Major Concept (XI) *When waves reflect and travel back on themselves, they can create standing waves with nodes having no motion and antinodes with oscillating water height between the level of the trough and the level of the crest.*

Related or supporting concepts:

- Standing waves may have one node or many.
- Standing waves can form in ocean basins or partially isolated bodies of water such as bays and estuaries.
- Take a look at figure 8.22 to get a feeling for the motion of the water surface in a standing wave.
- The nodes of the wave correspond to areas where there is no change in the elevation of the water surface.
- The antinodes are located where the water level alternates between the level of the trough and the level of the crest.
- In closed basins where a standing wave with one node develops in the center of the basin, the wavelength of the wave is twice the length of the basin.
- In open basins the node usually develops at the entrance to the basin so the wavelength of the wave is four times the length of the basin. This means that the water level remains fairly stable at the entrance but at the closed end of the basin it may rise and fall a considerable distance, if the natural period of the oscillation of the basin is close to the tidal period.
- Multiple nodes may also be present in open-ended basins.
- The dimensions of each individual basin determine the wavelength and period of its standing wave.
- Standing waves can be produced by:
    a. earthquakes that may tilt basins,
    b. strong winds that may pile water up on one side of a basin and then stop

blowing, and

c. the tides, if the natural period of oscillation of the basin is a multiple of the period of the tide.

- A standing wave occurring in a natural basin is called a seiche.

Major Concept (XII) *The tides involve a regular rise and fall of the water along the coasts. The period of the tides can vary with location, and the height of successive low and successive high tides may not always be equal.*

Related or supporting concepts:

- There are two fundamental tidal periods that are observed (see fig. 8.23):
  a. the diurnal tide with one high and one low water level each tidal day, and
  b. the semidiurnal tide with two high and two low water levels each tidal day.
- A semidiurnal tide with high tides of unequal height and low tides of unequal height is called a mixed tide or a mixed semidiurnal tide.
- In a diurnal and semidiurnal tide the height of the crest of the tide is called high water and the level of the trough is called low water.
- In a mixed tide we use the following terms:
  a. higher high water and lower high water for the two high tide levels, and
  b. higher low water and lower low water for the two low tide levels.
- The zero depth used for reference on marine charts corresponds to:
  a. mean low water in regions of diurnal and semidiurnal tides, and
  b. mean lower low water in areas that experience mixed tides.
- Minus tides occur infrequently when the water level falls below the mean low tide level for a given area.
- A rising tide is called a flood tide.
- A falling tide is called an ebb tide.

Major Concept (XIII) *There are two ways we can study the tides. We can study them mathematically using what are called equilibrium tides or we can study them by direct observation of actual, or dynamic, tides.*

Related or supporting concepts:

- Equilibrium tides are often modeled using a planet that is covered with a uniform depth of water in order to simplify the problem.
- As a first approximation we consider the earth and the moon to be revolving around their common center of mass. The center of mass of the earth-moon system is located at a point beneath the surface of the earth. We will also begin by assuming that the moon's orbit is in the plane of the earth's equator.
- The rotation of the earth-moon system involves two forces:
  a. gravity acts to pull the bodies together, and

b. centrifugal force acts to move them apart.

The gravitational attraction and centrifugal force balance to keep the two bodies at a constant distance (see fig. 8.24).

- On the side of the earth away from the moon the centrifugal force is a little greater than the gravitational force and the water envelope tends to bulge outward away from the axis of rotation of the system.
- On the side of the earth closest to the moon, the gravitational attraction of the moon is a little greater than the centrifugal force and the water envelope is pulled away from the surface by the moon.
- The magnitude of the difference between these forces, or the lunar tide-generating force, on the two opposite sides of the planet is the same, so the water envelope will be displaced outward by the same amount on both sides.
- Figure 8.25 shows how this situation produces a diurnal tide with a wavelength of one-half the circumference of the earth.
- Another way to understand the tide-generating force is to think of the Sun and the moon exerting a gravitational, or centripetal force on the earth that keeps it in its orbit. In the case of the Sun this is the earth's orbit around the Sun. In the case of the moon this is the earth's orbit around the common center of mass of the earth and the moon.
- In each case the gravitational or centripetal force is constant and equal to the average gravitational force at the earth's center. The difference between the average gravitational attraction at the earth's center and the attraction at individual points on the earth's surface produces the tide-generating force.
- The lunar tide-generating force, $F_T$, is proportional to:

$$F_T \propto Mr/R^3$$

where M is the mass of the moon, r is the radius of the earth, and R is the distance between the centers of the earth and the moon.

- The earth rotates on its axis once every 24 hours. As it rotates the moon progresses in its orbit around the earth, moving in the same direction. Consequently, it will take 24 hours and 50 minutes for a point on the surface of the earth that is directly beneath the moon to rotate and be directly beneath the moon again (see fig. 8.26). We call this period of 24 hours and 50 minutes the length of a lunar or tidal day.
- The period of the lunar diurnal tide is 24 hours and 50 minutes, while the period of the lunar semidiurnal or mixed tide is 12 hours and 25 minutes.
- The sun also produces a tide called the solar tide.
- Because of the great distance between the sun and the earth, the amplitude of the solar tide is only about 46 percent of the lunar tide.
- The period of the diurnal solar tide is 24 hours and the period of the semidiurnal and mixed solar tides is 12 hours.

Major Concept (XIV) *The earth, moon, and sun are in different positions with respect to one* *another throughout the month. This creates solar and lunar tide interference patterns that produce abnormally high and low tides at regular intervals.*

Related or supporting concepts:

- Figure 8.27 illustrates the different relative positions between the earth, moon, and sun on a monthly cycle.
- Relative to a point on the surface of the earth it takes the moon 29½ days to complete one orbit. During this length of time the moon will pass from being directly between the earth and the sun, to being on the opposite side of the earth from the sun, and then returning to a point between them once again.
- When the earth, moon, and sun are aligned, approximately every two weeks, the solar and lunar tides will interfere constructively and the high tide will reach a maximum height and the low tide will be at its lowest level. These maximum range (the vertical distance between the crest and the trough of the tide) tides are called spring tides. Spring tides occur with the full and new moons.
- When the moon is in its first or third quarter and the moon-earth-sun form a right angle, the solar and lunar tides will interfere destructively and produce the lowest tidal range. These tides are called neap tides.
- Figure 8.28 illustrates this alternation between spring and neap tides.

Major Concept (XV) *Because of the tilt of the earth's axis and the orbital plane of the moon with respect to the earth's orbital plane around the sun, there are some regions that experience diurnal tides and others that have semidiurnal tides.*

Related or supporting concepts:

- The earth's axis of rotation is tilted by 23½° with respect to its orbital plane around the sun. The result of this tilt is that through the year the sun will be directly overhead at some point on the surface of the earth that varies between 23½°N and S.
- The moon's orbit is tilted by an additional 5° so the moon will move between 28½°N and S with, a period of 18.6 years.
- When the sun and moon are both directly over the equator (a rare occasion given the previous statement) there will be diurnal tides at all latitudes.
- You can see from figure 8.29 that when either body, especially the moon, is not directly over the equator you will have diurnal, semidiurnal, and mixed tides depending on location.
- In general, tides are more diurnal during the summer and winter solstices.
- When the earth is closest to the sun during the Northern Hemisphere winter, the tides have a greater range. The tides are also more extreme when the moon's orbit brings it closer to the earth.

Major Concept (XVI) *A better understanding of the tides requires the direct observation of real, or dynamic, tides.*

Related or supporting concepts:

- The oceans are separated into basins by the presence of the continents. Consequently, the tide wave is not continuous except around Antarctica.
- Tides are the ultimate example of shallow-water waves.
- Because they are shallow-water waves the tides can be:
  a. reflected from continental margins and oceanic ridges,
  b. refracted by shallow water, and
  c. diffracted as they pass through comparatively narrow straits or gaps between continents.
- The reflection of the tide from continental margins creates a standing wave in some parts of the oceans. The period of the tide is so long that as the water in this standing tide flows from crest to trough, the Coriolis effect will deflect it. This makes these standing waves rotate around a central node.
- In general, the real tides can be extremely complex.
- Standing waves in narrow bays that have natural periods close to the tidal period can have very large oscillations at the antinode or closed end of the bay. An excellent example is illustrated in figure 8.31, where the Bay of Fundy has a tidal range of about 2 m at the mouth of the bay and 10.7 m at the head of the bay.
- Flood and ebb tides create tidal currents that range from sluggish to very strong.
- During the change in current direction at the peak of the flood or ebb tide, there is a period of little or no current flow called slack water.
- At the entrances to harbors or embayments that experience strong tidal currents, vessels may have to wait for slack water to safely enter.
- In theory, the shallow-water tide wave should move at a speed of about 200m/s. This is complicated by friction between the sea floor and the wave.
- At the equator the earth rotates eastward under the tide wave at a speed more than twice the predicted speed of 200m/s. Friction between the wave and the sea floor drags the wave crest to the east of its expected position beneath the moon (see fig. 8.30).

Major Concept (XVII) *Accurate tidal predictions require a detailed, long-term knowledge of the local tidal pattern. This relies on astronomical data and actual measurements of the tidal variation locally.*

Related or supporting concepts:

- Water levels are routinely measured in many locations. In some areas these measurements have been taken over periods of years.
- At primary tide stations, measurements are taken for at least 19 years to get a

reasonably complete picture of tidal variation. Remember that the moon's declinational variation has a period of 18.6 years.

- Annual tide tables were routinely produced for North and South America, Alaska, Hawaii, and Asia by the National Oceanic and Atmospheric Administration (NOAA). This information is now available in the Internet and public companies have taken over the job of publishing tide tables.
- Tide tables give the dates, times, and water levels for high and low tides at primary stations around the world. There are also corrections to these values given for many other cities and locations along coastlines.

Major Concept (XVIII) *Some coastal regions experience a rapid rise of sea level in the form of a moving wave called the tidal bore.*

Related or supporting concepts:

- The tidal bore often forms in rivers or narrow embayments when the water level rises faster than the tide wave, or crest of the tide, would normally move (see fig. 8.32).
- The tidal bore takes the form of a breaking wave that is usually less than a meter (3 ft) high but can be as much as 8 meters (26 ft) in height.
- Tidal bores are dangerous because they can flood regions very quickly with little or no warning.

Major Concept (XIX) *Although there is an enormous amount of energy in ocean waves, it is dispersed over 71 percent of the planet's surface and is not always present in the same location at any given time.*

Related or supporting concepts:

- There are three ways to capture wave energy:
    a. lifting floating objects by changes in water level,
    b. rocking an object, much like a rocking chair, by the orbital motion of the water or the changing slope of the water's surface with the passage of waves, and
    c. compressing the air in a chamber with rising water.
- The intent in all of these methods is to ultimately turn a generator that will then produce electricity.
- Air compression by rising water is being used to generate energy along the coast of northern Norway.
- Both France and Canada have power stations located in coastal regions with large tidal ranges. Dams are built across the mouths of embayments or estuaries to trap the water that flows in during flood tide. This water is then used to drive turbines when it is released during ebb tide. The process is similar to a conventional hydroelectric power dam. In order to be cost effective the tidal range needs to be as much as 7 m (23 ft).
- There are many problems that need to be addressed in harnessing the energy in waves

and tides. At present there are relatively few areas where this can be done effectively.

*Key Terms and Related Major Concepts*

At the back of the chapter in your book there are a number of key terms. You should be able to find the following terms referenced in the major concept indicated in parentheses.

| | | |
|---|---|---|
| surface tension(I) | episodic wave(VI) | lower high water(XII) |
| crest(II) | wave steepness(VII) | higher low water(XII) |
| trough(II) | shallow-water wave(VIII) | lower low water(XII) |
| wavelength(II) | refract(VIII) | minus tide(XII) |
| wave height(II) | diffraction(VIII) | flood tide(XII) |
| amplitude(II) | tsunami(X) | ebb tide(XII) |
| wave period(II) | standing wave(XI) | equilibrium tide(XIII) |
| orbit(III) | node(XI) | dynamic tide(XIII) |
| deep-water wave(IV) | antinode(XI) | centrifugal force(XIII) |
| storm center(IV) | diurnal tide(XII) | tidal day(XIII) |
| swell(IV) | semidiurnal tide(XII) | spring tide(XIV) |
| dispersion(IV) | mixed tide(XII) | neap tide(XIV) |
| wave train(IV) | high water(XII) | tidal current(XVI) |
| group speed(IV) | low water(XII) | slack water(XVI) |
| fetch(VI) | higher high water(XII) | tidal bore(XVIII) |

*Test Your Understanding With The Following Questions:*

FILL IN THE BLANK

1. The highest tides during the month are called ___________________ tides.
2. A long wavelength wave created by submarine earthquakes is called a ______________________.
3. The part of a standing wave that does not change elevation is called the _____________.
4. A period of calm water at the peak of the flood or ebb tide is called _____________ water.
5. A tide that falls below the average low water is called a ________________ tide.
6. The area over which the wind blows to create waves is called the _________________.
7. The ratio between the height of a wave and its wavelength is called the _____________________________.
8. The wave ____________________________ is one-half of the wave height.
9. The highest point of the wave is called the ________________.
10. The lowest point of the wave is called the ___________________.

TRUE - FALSE

1. A lunar day is longer than a solar day.
2. The group speed of deep-water waves is one-half the speed of the individual waves.
3. The most common generating force for ocean waves is the wind.
4. The period of a wave will change with changing water depth.
5. The speed of a deep-water wave is equal to a constant times its period.
6. Waves in the open ocean seldom break.
7. Water motion extends all the way to the bottom in shallow-water waves.
8. The orbital paths of water molecules in deep-water waves are elliptical.
9. In the open ocean a tsunami may reach a height of 30 m.
10. The wavelength of a diurnal tide is equal to the circumference of the earth.

MULTIPLE CHOICE

1. The velocity of shallow-water waves:
   a. generally decreases closer to shore
   b. is a function of the wave period
   c. is a function of the depth of the water
   d. all of the above
   e. a and c
2. The period of a lunar diurnal tide is:
   a. 24 hours
   b. 24 hours and 50 minutes
   c. 12 hours
   d. 12 hours and 25 minutes
   e. it depends on the location
3. The first waves formed by the wind on a previously flat water surface are ____________ waves.
   a. capillary
   b. shallow-water
   c. tsunami
   d. tidal
   e. standing
4. The time required for one wavelength to pass a stationary point:
   a. is the period of the wave
   b. is the frequency of the wave
   c. depends on wave speed
   d. may depend on the depth of the water
   e. all of the above
5. Shallow-water waves:
   a. refract as they move toward the shore
   b. concentrate their energy on headlands

c. may be diffracted and move behind barriers
d. include the tides and tsunamis
e. all of the above

6. The process that can lead to the formation of standing waves is:
   a. refraction
   b. reflection
   c. diffraction
   d. desalination
   e. none of the above
7. The height that a wave will eventually achieve is a function of:
   a. the period of the wave
   b. the fetch
   c. the wind velocity
   d. the duration of the wind
   e. b, c, and d
8. The period of a tsunami is usually on the order of:
   a. 10 - 20 seconds
   b. 1 - 2 hours
   c. 10 - 20 minutes
   d. 5 - 10 minutes
   e. 45 - 60 seconds
9. The wavelength of a standing wave in an open basin is ________ the length of the basin.
   a. ½
   b. ⅓
   c. ¾
   d. ¼
   e. ⅔
10. The amplitude of the solar tide is about _______ percent of the amplitude of the lunar tide.
   a. 46
   b. 120
   c. 58
   d. 14
   e. 76

*Answer Key for 'Key Terms' and 'Test Your Understanding'*

FILL IN THE BLANK

| | |
|---|---|
| 1. spring | 6. fetch |
| 2. tsunami | 7. steepness |
| 3. node | 8. amplitude |
| 4. slack | 9. crest |
| 5. minus | 10. trough |

TRUE - FALSE
1.T 2.T 3.T 4.F 5.T 6.T 7.T 8.F 9.F 10.T

MULTIPLE CHOICE
1.e 2.b 3.a 4.a 5.e 6.b 7.e 8.c 9.d 10.a