## II. WAVE MOTIONS

In the module "What are Waves", some general wave properties were discussed. Those properties can be determined by observing waves as they travel through space and as they vary in time. In that module, the wave amplitude was defined as the motion of an individual particle of the host medium as the wave passed a particular point in space at a particular time. It must continually be emphasized that a wave is energy in motion. Matter also move as waves interact with it, but in most cases there is no net displacement of matter. The energy in the wave causes individual particles of the material to displace briefly as the energy passes, but those particles return to their original position after passage of the wave. There are, of course, familiar exceptions. When water waves begin to break as they approach shore, water particles are obviously transported onshore. Similarly, seismic waves very near an earthquake can cause the earth to permanently deform. But, these are extreme cases. In general, water waves in open water do not result in any net displacement of particles in the water. Similarly, seismic waves that **propagate**, or travel outward from the earthquake focus, do not result in any net displacement of the Earth, especially when far from the earthquake focus.

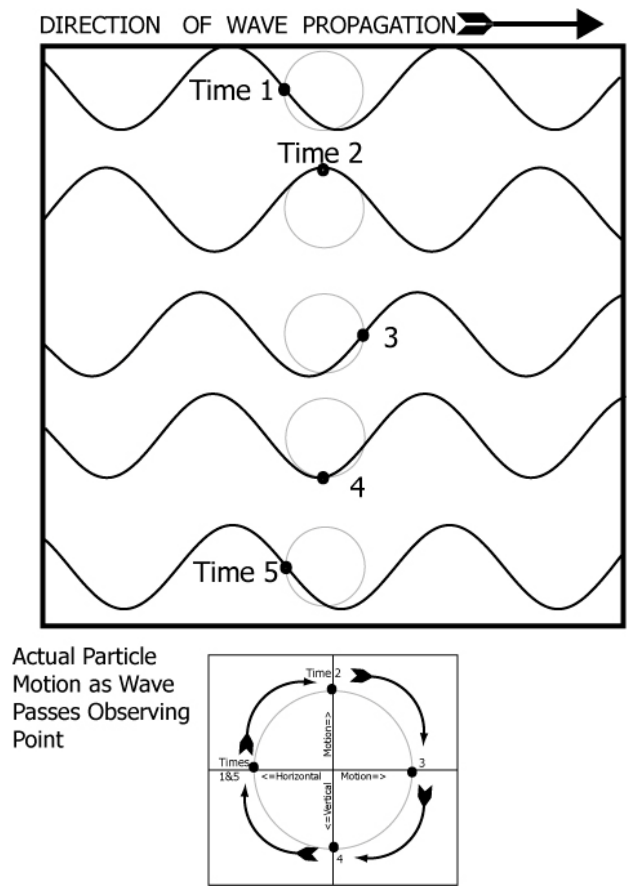


Figure II.1. Direction of propagation and particle motion in a water wave

In this module, different types of waves will be classified on the basis of the particle motion that the wave induces when it passes by an observing point. Recall that in the "What are Waves" module, the vertical axis of each graph was labeled "Amplitude". There was no discussion of the actual directional motion of particles in any detail. However, wave particle motion is an important way to classify a wave. Figure II.1 can be used to introduce this concept. In that figure, when a water wave passes, the individual particles of the water actually move in a circular pattern. So, while the energy is traveling from left to right in

Figure II.1, the passing wave causes the individual particle to move in a circle, eventually returning to its original position. The energy has moved on, but the particle remains. This effect is why it is important to be able to distinguish between the **direction of propagation** of the wave and the **particle motion** that the wave induces in the material through which it is passing.

Several different types of waves can be distinguished by the motion of the individual particles relative to the direction of propagation of the waves. Figure II.2 illustrates these waves in block diagrams. Let's begin our discussion of the direction of propagation and particle motion in various kinds of waves with one of the simplest waves.

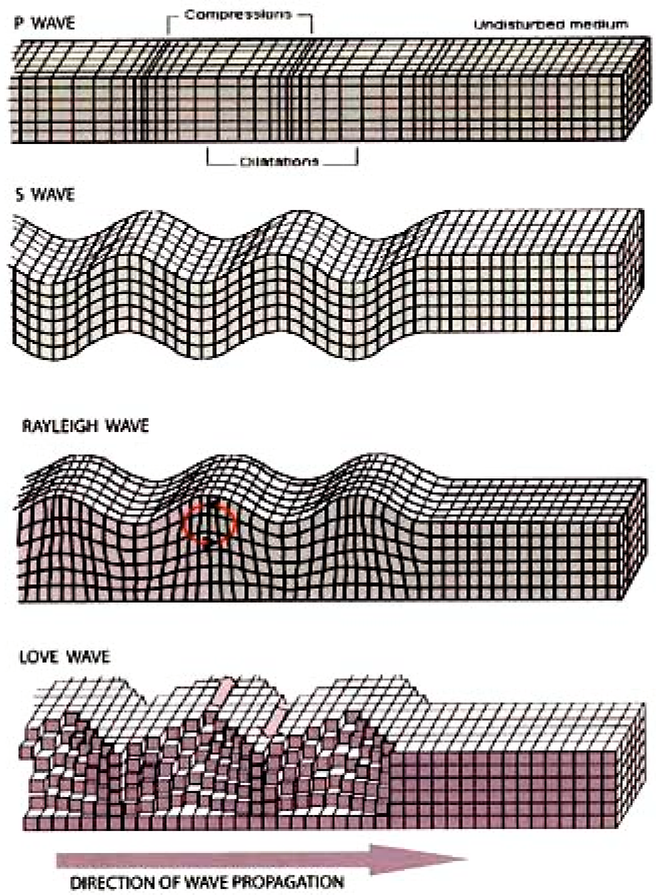

Figure II.2 Particle Motion of Seismic Waves

**Longitudinal waves**, such as sound and seismic P waves, are characterized by particle motion that is parallel to the direction of propagation of the wave. In other words, an individual particle vibrates back and forth along the same line as the wave is traveling when the wave energy passes. After the wave passes, there has been no net displacement of the particle.

**Transverse waves**, such as seismic S waves and certain types of electromagnetic waves, have particle motion perpendicular to the direction of wave propagation. When a seismic S wave passes, say, from south to north, the particles in the ground will either move up/down or east/west (or some combination of these directions), but there will be no motion in the north/south direction! These differences in particle motion are a valuable way to distinguish between types of waves. In the following module, we discuss seismic waves in particular in a little more detail.

Water waves are an example of **Surface waves.** Earthquakes also generate seismic surface waves. The circular pattern of water wave particle motion is similar to the pattern of ground motion when a seismic surface wave passes. Two types of seismic surface waves will be discussed later in this module. For now, suffice to say that seismic surface waves are the large waves that arrive later than P waves and S waves. Surface waves are complex, or composite, waves that are characterized by both longitudinal and transverse motions. Just like waves on the ocean, the seismic waves traveling past a given point vibrate particles according to their wave type, but do not actually cause the particles to be permanently displaced.

## WAVES IN THE EARTH

Earthquakes generate enormous amounts of energy, which travel radially outward in all directions from the focus of the earthquake along a fault. The bigger the earthquake, the greater is the amount of energy that is released. Some seismic waves that travel through the earth, such as P waves and S waves are referred to as **body waves**. Other seismic waves travel only at or near the earth's surface and they are referred to as **surface waves**. Some earthquakes in coastal areas can generate another type of seismic wave, a **Tsunami.** Tsunami, a Japanese term, describes seismic waves that move through the oceans and often cause extensive coastal destruction hundreds or thousands of kilometers from where the earthquake occurred. In ancient times, a tsunami could strike without warning because the earthquake that generated it was too far away to be felt. Today, an earthquake-generated tsunami can be tracked across the ocean and early warnings can be provided to distant coastal residents.
(http://www.geophys.washington.edu/tsunami/intro.html)

To study the energy released from earthquakes, scientists use instruments called **seismographs.** These instruments measure the motion of the ground at the point where the instrument is located. They sense the complex motion of earthquakes, even those that are far away! Earthquake or seismic waves that cause the ground to move cause that motion. Waves that are generated by an earthquake are complex for several reasons. First, the faults that move and cause them are large features that often extend from the earth's surface to great depths and have many irregularities. Second, the rocks through which faults cut are equally complex from the microscopic scale to the scale of mountain ranges or deep sea trenches. Third, several types of waves can be generated by a single earthquake and can be modified by the earth materials through which they travel.

Body waves can be either longitudinal or transverse waves that travel through the interior and, in some cases, even through the center of the earth. Seismographs within a few tens to hundreds of miles of an earthquake record both P and S waves that travel more or less directly to the instrument or may be reflected off of shallow rock boundaries.

Near an earthquake, seismic surface waves tend to cause more damage. At distant locations they can sometimes induce motion that can be felt in tall buildings. These waves, which are confined to traveling near the earth's surface, have characteristics of both longitudinal and transverse energy waves. Each type of seismic wave travels at speeds and in directions that are dependent both on the manner in which the particles of the wave vibrate and on the types of rock through which they pass.

P WAVES

As we discussed above, P waves, or primary waves, are longitudinal waves. P waves are the first body waves to be detected from an earthquake. They travel faster with a higher frequency (remember that frequency is the inverse of period, so P waves have a shorter period) than other types of seismic waves. P waves reflect volume changes as particles oscillate back and forth in the direction that the wave is traveling (Figure 2). P waves are equivalent to sound waves and behave like "pings" emitted by dolphins or submarine sonar to detect objects underwater. As the P wave moves, it actually compresses the rock through which it is traveling thus causing a change in the shape and volume of the rock. Of course, in between successive compressions the rock expands by a process known as **rarefaction**. Thus during the passages of P waves, the rock shrinks and swells by small amounts. The volume of solids, liquids, and gases can all be changed, hence longitudinal waves can travel through any of them.

S WAVES

S Waves, or secondary waves, are transverse waves. S waves travel slower than P waves, hence they arrive a given place later than P waves. S waves travel slower in part because the particle motion is different. S waves do not change the volume of the rock through which they pass. They are typical of Transverse Waves, which change the shape of the material but not its volume (Figure II.2). How can they do that? S waves shear the rock! During passage of S waves, particles behave much like a deck of cards. Cards can slide (or shear) past one another and change the shape of the card deck into various forms. However, no changes occur in the volume of each card, hence no change occurs in the total volume of the deck regardless of how the cards slide past one another. The shearing motion of S waves takes place in the plane perpendicular to the direction that the wave is traveling. Also, because no volume change occurs, S waves can only travel through solids, they can not pass through a liquid or gas (since you cannot shear these!). Thus, longitudinal waves can travel through the ocean or air, but transverse waves can not.

## SURFACE WAVES

Surface waves, called **Rayleigh waves** and **Love waves**, were recognized more than a century ago and are named for the men that discovered them. Rayleigh and Love waves are produced by interaction of P and/or S waves with the earth's surface. Hence they occur only at or near that surface, which is what distinguishes them from body waves that travel through the earth's interior. Thus, like ripples from a stone, surface waves are obvious at surface, but diminish rapidly downward into the earth. The periods of surface waves are generally much greater than those of body waves. Rayleigh waves have characteristics of both longitudinal and transverse waves. Particles oscillate back and forth in the direction that the wave is traveling analogous to longitudinal (P) waves. But, they also are characterized by shearing in the vertical plane perpendicular to the direction that the wave is traveling, like transverse (S), thus producing an overall elliptical particle

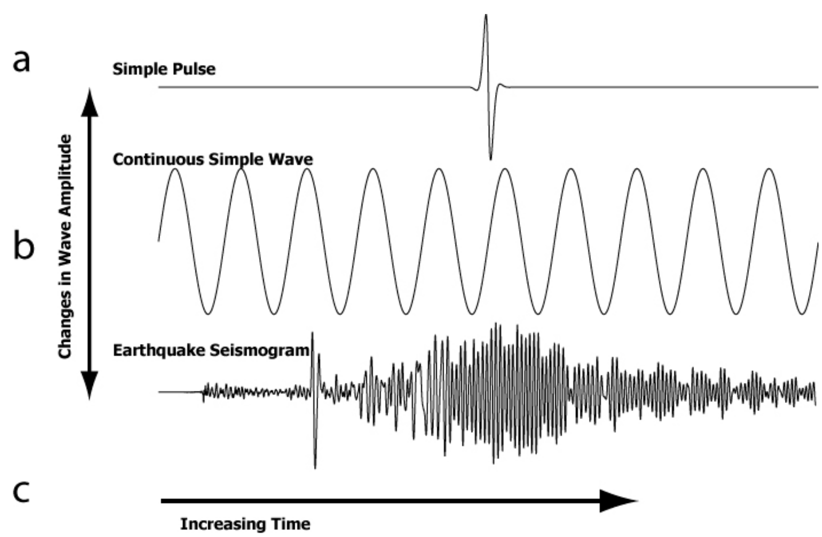


Figure II.3 Different Types of Waves

path. Love waves involve shape changes due to shearing in the horizontal direction perpendicular to the direction of propagation and are most similar to transverse waves (Figure II.2).

Let's look in more detail at the surface waves in the seismogram shown in Figure II.3.c in the **<u>"What are Waves"</u>** module (redrawn at the right). A single seismogram can only display ground motion in one direction. However, as we saw in the case of the water wave, particles can move in more than one direction when a wave passes. For this reason, earthquake recording instruments, or **seismographs**, often have the capability of recording motion in three dimensions. Most often, these three directions define a coordinate system aligned with geographic orientations. One element of the system can detect only vertical motion (ground motion up or down). Another can only detect motion parallel to the east-west geographic direction (ground motion in the eastward or westward directions). A third element can only detect motion in the north-south direction (ground motion northward or southward only). Thus, to completely describe the ground motion during the passage of the seismic waves shown in Figure II.3.c we would need three seismograms. Figure II.4.a is another way to visualize the seismograms, but

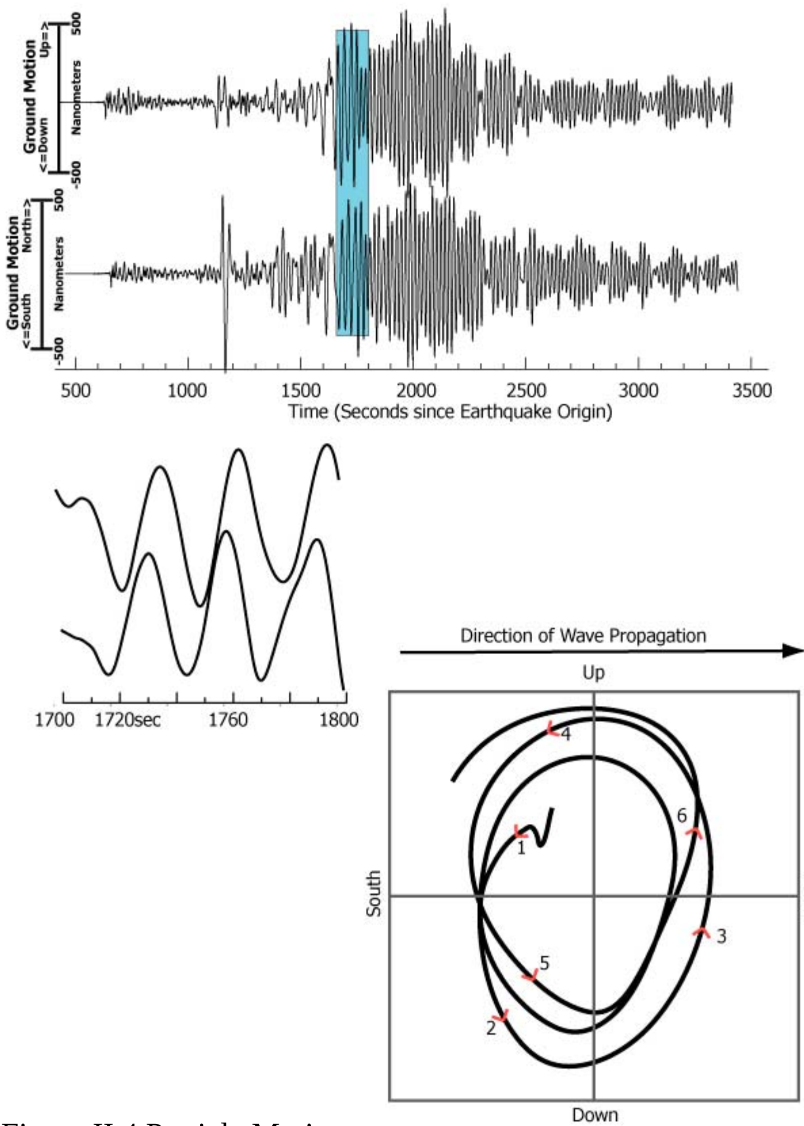


Figure II.4 Particle Motion

it is not a very practical way to look at the graphs, so we normally don't plot seismograms this way! We plot each seismogram in the same wave, but the amplitude axis for each represents ground motion in a different direction.

The earthquake in Figure II.3.c is located due south of our seismograph station. This is fortunate because this means that the north-south component also represents motion that is parallel to the direction of wave propagation. This allows us to use the north-south seismogram and the vertical (up-down) seismogram to create a particle motion diagram for these seismic waves that is similar to Figure II.1, the diagram that we made for water waves.

The energy traveling as seismic surface waves also induce a complex particle motion pattern as it passes this observing station. In this case, the individual particle seems to be moving in the opposite direction from the direction of wave propagation! Figure II.4 shows this diagram.

Analyses of particle motion diagrams such as this one are an important means of classifying waves. Complex particle motions seen in our water wave and seismic surface wave examples can be easily compared to simpler patterns that result from seismic P waves, S waves, and sound waves. In the accompanying computer exercise, "Longitudinal and Transverse Waves", we saw that seismic P waves were characterized by particle motion parallel to the direction of wave propagation and are examples of **longitudinal** waves. Seismic S waves, in contrast, display only motion perpendicular to the direction of wave propagation and are in a class of waves termed **transverse** waves.