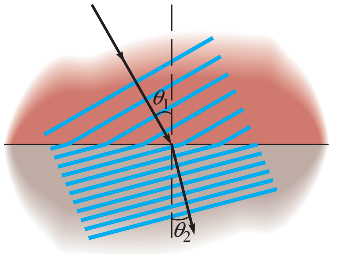

Figure 11.16 Wave crests for a seismic wave incident on a boundary between two different kinds of rock. Not only does the wavelength (distance between wave crests) change at the boundary, the wave also refracts (changes its direction of propagation). The reflected wave is omitted for clarity.

CHAPTER 11

Refraction

The law of refraction is derived in Chapter 23 for light waves but applies equally to mechanical waves. It relates the directions of propagation of a wave on the two sides of a boundary to the speeds of wave propagation in the two wave media.

Law of Refraction

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} \tag{11-14}$$

The angles in Eq. (11-14) are called the *angle of incidence* and the *angle of refraction*. Note that these angles are measured between the propagation direction of the wave and the *normal* (a line perpendicular to the boundary between media).

Example 11.8

Refraction of an S Wave During an Earthquake

An earthquake emits seismic waves of two types, called P waves (longitudinal waves) and S waves (transverse waves), which travel at different speeds through the Earth. Suppose an S wave passes through a boundary in rock where its speed decreases from 5.0 km/s to 4.0 km/s. If the angle of incidence at the boundary is 40.0°, what is the angle of refraction?

Strategy We know the speed of the S wave in the two materials and we know the angle of incidence. From the law of refraction, we can find the angle of refraction. We let the subscript 1 represent the first material and 2 the second. Then $\theta_1 = 40.0°$, $v_1 = 5.0$ km/s, and $v_2 = 4.0$ km/s; we want to find θ_2.

Solution The law of refraction is

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

Solving for $\sin\theta_2$ yields

$$\sin\theta_2 = \frac{v_1}{v_2}\sin\theta_1$$

Now we substitute numerical values:

$$\sin\theta_2 = \frac{4.0\ \text{km/s}}{5.0\ \text{km/s}}\sin 40.0° = 0.514$$

Solving for θ_2,

$$\theta_2 = \sin^{-1} 0.514 = 31°$$

Discussion The wave speed is slower in the second material, so we expect the angle of refraction to be smaller than the angle of incidence; the wave is bent toward the normal.

Practice Problem 11.8 Refraction of a P Wave

A P wave from an earthquake is traveling at 8.0 km/s. It is incident on a boundary between materials at an angle of incidence of 45°; the angle of refraction is 34°. What is the speed of the P wave in the other material?

Conceptual Question

12. Water waves can travel in any direction when far offshore, but they always arrive at the beach nearly head on. Explain.

Answers to Practice Problems

11.8 6.3 km/s

Problem

78. An S wave crosses the boundary between two different types of rock. The angle of incidence is 22° and the angle of refraction is 34°. If the speed of the S wave before the boundary is 3.2 m/s, what is the speed past the boundary?