Longitudinal Waves

Speed of propagation

Sound Waves

Air, Liquid (Tsunami)

Solid (Earthquakes)

Longitudinal + Transverse

Hear 20Hz ⇔ 20kHz

Below Audible infrasonic

Above Audible Ultrasonic

For each type of wave

Speed $C = \sqrt{\frac{\text{Elastic Modulus}}{\text{density}}}$

see Serway 12.4

COMPRESSION WAVES

B = Bulk Modulus, ρ = density

$$C = \sqrt{\frac{B}{\rho}}$$

Primary Wave of earthquake

Secondary earthquake waves involve Shear = transverse waves

⇒ use shear modulus

$$C = \sqrt{\frac{S}{\rho}} \quad = S$$

Sound Waves

Bulk Modulus for Gas has different values depending on Compression type

Compression at Constant Temperature (isothermal) or without heat transfer (Adiabatic). For Sound Adiabatic

$$C = \sqrt{\frac{B(\text{adiabatic})}{\rho}} = \sqrt{\frac{\gamma B(\text{isothermal})}{\rho}}$$

$$\gamma = \frac{C_p}{C_v}$$ (Serway 21.2)

C_p = Specific Heat at Const. Press.

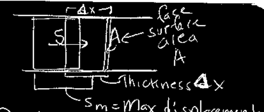
C_v = Specific Heat at Constant Volume

Air: $\gamma = 1.4$ P = Pressure

$$C = \sqrt{\frac{\gamma P}{\rho}}$$

$V = 344\ m/s = 1139\ ft/s$

Sound Waves in air: element of air



Bulk Modulus

$$B = \frac{-\Delta P}{\Delta V / V}$$

Distance btw front and back Changes from Δx by ΔS Due to Compression.

Volume was $V = A\Delta x$

$\Delta V = A\Delta S \Rightarrow$

$\Delta P = -B\frac{\Delta V}{V} =$

$-B\frac{A\Delta S}{A\Delta X} = -B\frac{\Delta S}{\Delta X}$

$\lim_{x\to 0} \Rightarrow dP = -B\frac{\partial S}{\partial X}$

Oscillating Displacement

A = Amplitude = S_m

$S = S_m \cos(kx - \omega t)$

$dP = -B\frac{\partial}{\partial X}(S_m \cos(kx-\omega t))$

$= +BkS_m \sin(kx-\omega t)$

$\Delta P_m = BkS_m, C = \sqrt{\frac{B}{\rho}}$

$C^2 = \frac{B}{\rho} \Rightarrow B = C^2\rho$

$\Delta P_m = (C^2\rho k)S_m$

$C = \frac{\omega}{k} \Rightarrow Ck = \omega$

$\Delta P_m = (C\rho\omega)S_m$

Thin Slice of air thickness dx, mass dm, area A oscillates as sound passes

Kinetic Energy = $dK = \frac{1}{2}dm V_s^2$

V_s = speed of oscillating air element, not wave speed

$V_s = \frac{\partial S}{\partial t} = -\omega S_m \sin(kx-\omega t)$

$d_m = \rho A dx \Rightarrow dK = \frac{1}{2}dm V_s^2$

$dk = \frac{1}{2}(\rho A dx)(-\omega S_m)^2 \sin^2(kx - \omega t)$

Power is dk/dt, $C = \frac{dx}{dt}$

$\frac{dk}{dt} = \frac{1}{2}\rho A C \omega^2 S_m^2 \sin^2(kx - \omega t)$

Average over time: $\overline{\left(\frac{dk}{dt}\right)} = \frac{1}{2}\rho A C \omega^2 S_m^2 \overline{\sin^2(kx - \omega t)}$ ($= \frac{1}{2}$)

$= \frac{1}{4}\rho A C \omega^2 S_m^2$

Like a spring on average, energy is 1/2 potential + 1/2 kinetic energy

$\overline{\frac{dE}{dt}} = 2\overline{\frac{dk}{dt}} = \frac{1}{2}\rho A C \omega^2 S_m^2$

Intensity = $\frac{\text{Power}_{Avg}}{\text{Area}} = \frac{\overline{dE/dt}}{A = \text{area}} = \frac{1}{2}\rho C \omega^2 S_m^2$

($S_m = A$ = amplitude)

($I = \frac{1}{2}\rho \omega^2 A^2 C$ where A = amplitude)

$\Delta P_m = \rho C \omega S_m \Rightarrow I = \frac{1}{2}\frac{\rho^2 C^2 \omega^2 S_m^2}{\rho C}$

Can be written: $I = \frac{\Delta P_m^2}{2\rho C}$

Sounds vary in intensity by factor of 10^{12}

Decibel = db = $10 \log \frac{I}{I_0}$, $I_0 = 10^{-12} \frac{\text{watts}}{m^2}$

Sound from moving Sources

Doppler Effect

Detector moves towards stationary source at V_D

If V_D were zero in time t Ct/λ waves pass

Because detector moves additional $V_D t/\lambda$ waves pass. So instead of hearing $f = \frac{c}{\lambda} = \frac{Ct/\lambda}{t}$

hear $f' = \frac{Ct/\lambda + V_D t/\lambda}{t}$

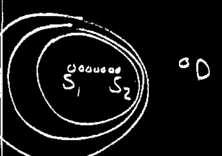
$= \frac{C + V_D}{\lambda} = \frac{C + V_D}{c/f} =$

$f' = f\left(\frac{C + V_D}{C}\right)$

If moving away, waves chase detector, fewer arrive:

$f' = f\left(\frac{C - V_D}{C}\right)$

Suppose detector at rest. $V_D = 0$ Source moves at V_S



Let $T = 1/f$ = Period

During one Period T

Source moves $V_s T = V_s/f$

Towards Detector

Wavelength & f arriving Sound is not

$\lambda = \frac{c}{f}$ but it's

$$\lambda' = \frac{c}{f} - \frac{V_s}{f}$$

We hear

$$f' = \frac{c}{\lambda'} = \frac{c}{\frac{c}{f} - \frac{V_s}{f}}$$

$$f' = f\left(\frac{c}{c - V_s}\right)$$

Move away: $V_s \to -V_s$

$$f' = f\left(\frac{c}{c + V_s}\right)$$

If both Source + detector move

$$f' = f\left(\frac{c \pm V_D}{c \mp V_s}\right)$$

Towards

away