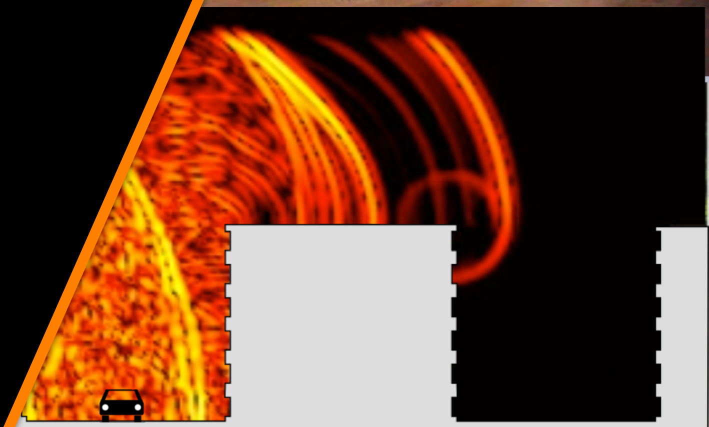
Architectural Acoustics

Week 2: Fundamentals of Acoustics
Lecture F.4



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Contents

Week 1
- Wave function (Harmonic motion)
- Complex numbers
- Impedance
- Resonance

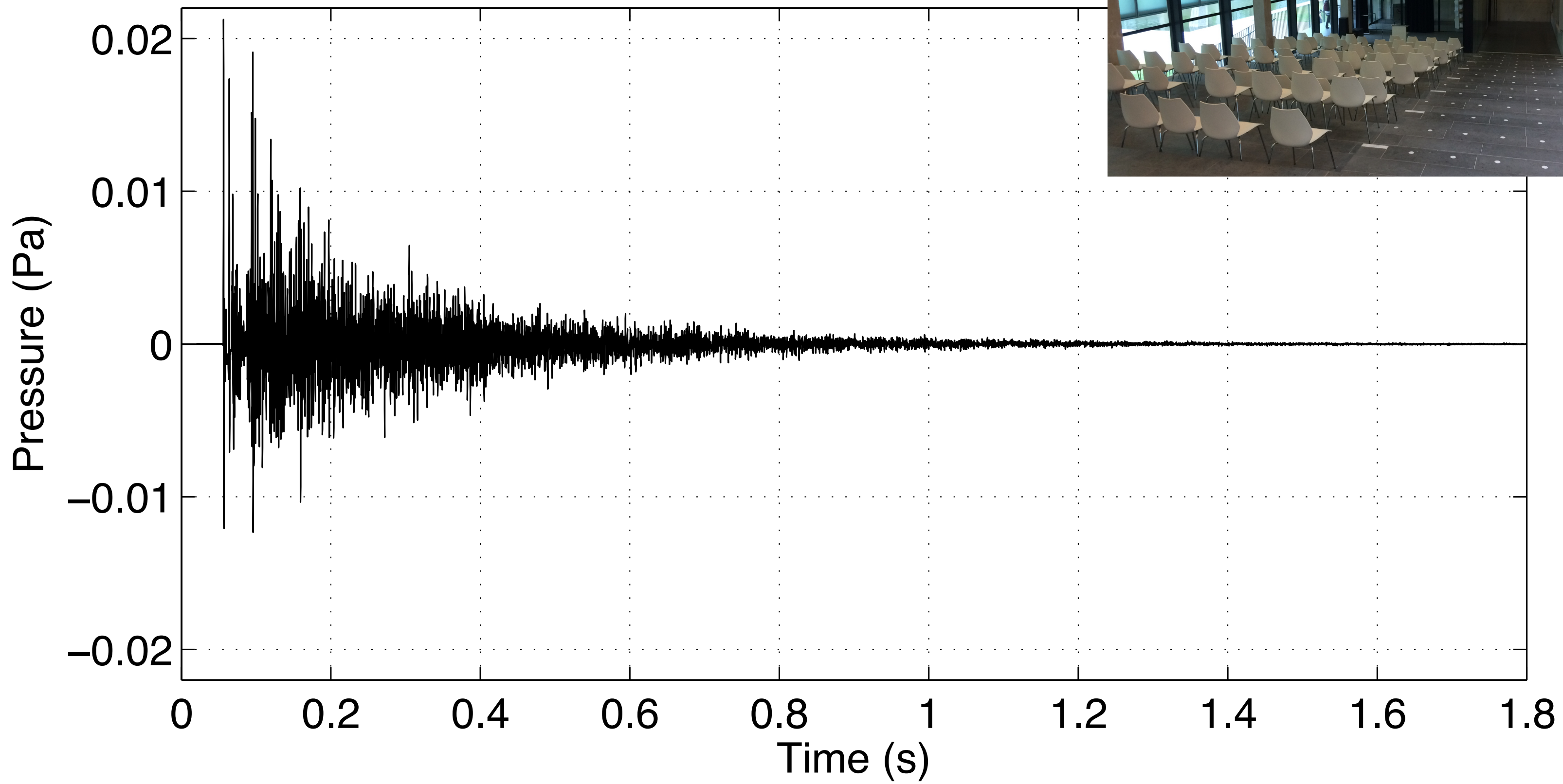
- Fourier Transform
- Impulse response and Transfer function

Week 2
- Wave equation in fluids
- Harmonic waves
- Intensity

- Sound pressure level
- Wave equation in solids
- Quiz!

Sound pressure level

Time average of a sound signal is almost zero, how to calculate the time-averaged level?



Sound pressure level

Sound pressure level L in dB

$$L \quad = \quad 20 \cdot \log_{10}\left(\frac{\tilde{p}}{p_b}\right)$$

p_b Reference sound pressure, $2 \cdot 10^{-5}$ Pa

$$\tilde{p} \quad = \quad \sqrt{\frac{1}{t_0}\int_0^{t_0} p(t)^2 dt} = \frac{\hat{p}}{\sqrt{2}}$$

Sound pressure level difference between two signals

$$\Delta L \quad = \quad 20 \cdot \log_{10}\left(\frac{\tilde{p}_1}{\tilde{p}_2}\right) dB$$

Elastic stresses on a solid element

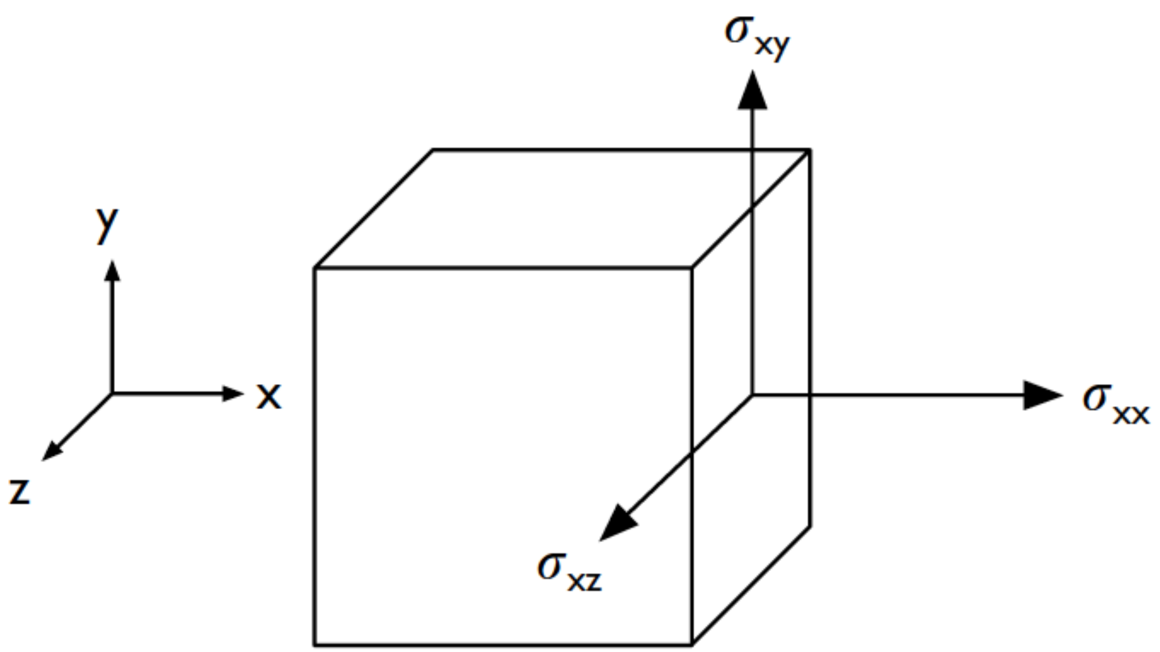


Figure 3.1 Tensile and shear stresses in a square volume element of a solid body.

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

Wave equation for solids

- Homogeneous and isotropic solid
- Equation for 3 variables (displacements)
- Supports multiple wave types (longitudinal and transverse waves)

$$\mu \Delta \xi + (\mu + \lambda) \frac{\partial (\mathrm{div}\, \vec{s})}{\partial x} = \rho_0 \frac{\partial^2 \xi}{\partial t^2}$$

$$\mu \Delta \eta + (\mu + \lambda) \frac{\partial (\mathrm{div}\, \vec{s})}{\partial y} = \rho_0 \frac{\partial^2 \eta}{\partial t^2}$$

$$\mu \Delta \zeta + (\mu + \lambda) \frac{\partial (\mathrm{div}\, \vec{s})}{\partial z} = \rho_0 \frac{\partial^2 \zeta}{\partial t^2}$$

Formulas week 2

Acoustic variables and basic relations (chapter 3)

$$
\begin{aligned}
\vec{v} &= \frac{\partial \vec{s}}{\partial t} \\
p &= \left(\frac{dp_t}{d\rho_t}\right)_{\rho_0} \cdot \rho = c^2 \rho \\
\frac{\partial p}{\partial x} &= -\rho_0 \frac{\partial v_x}{\partial t} \\
\rho_0 \frac{\partial v_x}{\partial x} &= -\frac{1}{c^2} \frac{\partial p}{\partial t} \\
\frac{\partial^2 p}{\partial x^2} &= \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} \qquad \text{One-dimensional wave equation} \\
\frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} &= \Delta p \equiv \frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} \qquad \text{Three-dimensional wave equation} \qquad (8) \\
P_a &= \iint_S \vec{I}_n dS \\
\vec{I} &= \frac{1}{4}(p\vec{v}^* + p^*\vec{v}) = \overline{p\vec{v}} = \frac{1}{2} Re\{p\vec{v}^*\} \qquad (9) \\
L &= 20 \cdot \log_{10}\left(\frac{\tilde{p}}{p_b}\right) dB \qquad (10) \\
\Delta L &= 20 \cdot \log_{10}\left(\frac{\tilde{p}_1}{\tilde{p}_2}\right) dB
\end{aligned}
$$

Formulas week 2

Plane waves, attenuation (chapter 4)

$$Z_0 = \rho_0 c = \frac{p}{v_x} \quad \text{Characteristic impedance of air} \tag{11}$$

$$v_x(x,t) = \hat{v}_x e^{j(\omega t - kx)} \quad \text{One-dimenstional plane wave}$$

$$p(x,t) = \hat{p} e^{j(\omega t - kx)} \quad \text{One-dimenstional plane wave}$$

$$p(x,y,z,t) = \hat{p} e^{j[\omega t - k(x cos\alpha + y cos\beta + z cos\gamma)]} = \hat{p} e^{j(\omega t - \vec{k}\vec{r})} \quad \text{Three-dimenstional plane wave} \tag{12}$$