Architectural Acoustics

Exercises Building Acoustics: answers

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Question 1

In solid media, we can distinguish various wave types, whereas in air, we only have longitudinal waves as regards sound propagation.

a) Why do we not have more than one wave type in air?

Compared to solid media, elastic stresses are not relevant for air. The force (pressure) exerted in a certain direction will only cause a wave motion in the same direction, i.e. a longitudinal wave.

b) Describe, in words, the difference between longitudinal waves and transverse waves.

In a longitudinal wave, the direction of wave propagation is the same direction as the motion of the particle displacement (and particle velocity). In a transverse wave, the direction of wave propagation is perpendicular to the motion of the particle displacement (and particle velocity).

Question 2

You are standing in a long corridor and at the far end of the corridor, a person slams a door. Assume that the walls of the corridor (which are connected to the door) are made of 0.1 thick lightweight concrete with a bending stiffness 2.85 10^5 N.m^2, Youngs modulus 3.42 10^9 N/m^2 and Poisson ratio 0.5.

What is the first sound you hear from the slammed door: the sound from the wave that has travelled through the corridor, the sound radiated from the bending waves in the wall close to you or the sound radiated from the extensional waves in the wall close to you. Explain your answer.

Sound from a wall is radiated from bending waves and not from extensional waves, as the latter does not have a component of the particle displacement perpendicular to the wall. The wave speed in air indoors is around 343 m/s. The bending wave speed can be computed as:

$$c_B = \sqrt{\omega}\sqrt[4]{\frac{B}{m'}} = \sqrt{\omega}\sqrt[4]{\frac{2.85 \cdot 10^5}{1300 * 0.1}} \approx 17.2 * \sqrt{f}$$

where we have assumed a density of 1300 kg/m^3*. For* $f < 398$ *Hz,* $c_B < c$*. You will thus first hear the high frequencies radiated from the bending waves.*

Question 3

You live in an old a flat, and the façade consists of a single window pane with a thickness d = 20 mm, a density of 2500 kg/m^3 and a bending stiffness 3.33 10^4 N.m^2.

A road is situated parallel to the façade with a distance of 20 m from the center of the façade.

a) When a single car passes by, at what position of the car is the sound insulation of the window best regarding the noise of the car?

At the position of the car in front of the window. For this position, no dip in the insulation due to the coincidence phenomenon will be observed (see Fig. 14.7 in the book). For very high frequencies however, the insulation at other angles (i.e. position of the car), could be better.

b) The car produces most noise at 1000 Hz. For what position of the car is this noise best audible in your flat?

We will compute the incident angle for which this occurs (14.15):

$$\omega_\theta = \frac{\omega_c}{sin^2\theta}$$

with ω_c= 713 Hz (using 10.27), we find θ = 57 deg., which means that the car is about 31 m away from the position in front of the window.

c) What thickness should the glass pane to avoid the 1000 Hz to be above its critical frequency?

Using equation 10.27 and the fact that m' is proportional to d, and that B is proportional to d^3 (equation 10.10), we find d < 14 mm. Note however that the sound reduction will be lower due to a lower mass.

Question 4

With lightweight building techniques, several options exist to improve sound insulation, which is in particular critical for the low frequencies.

a) Why is it difficult to obtain a high sound insulation for low frequencies with lightweight building techniques.

The sound insulation at low frequencies depends on the mass of the construction (6 dB increase for doubling the mass).

b) If you are to design a lightweight double leaf partition and a minimum requirement is set for R_A at and above 100 Hz, what would be your design suggestion if the both masses of the leafs are known? (describe in words)

Design the spacing between the leafs such that the mass-spring frequency is below 100 Hz.

c) A colleague designs a lightweight single leaf partition wall and he suggests to improve the insulation by increasing the internal loss in the material (this reduces the amplitudes of the bending wave vibrations). The critical frequency of the wall is 2000 Hz. Does this suggestion improve R_A at 100 Hz?

Reducing the bending waves only effects radiation of sound above the critical frequency, i.e. above 2000 Hz in this case. The answer is no!

Question 5

Two adjacent student rooms are built with concrete floor, wall and ceiling elements. All floor and ceiling elements have a thickness of 0.2 m and all walls have a thickness of 0.1 m. The rooms have a dimension of LxWxH = 5m x 3m x 2.5m, with 3m the width of the partition wall between the rooms. For the frequency of 500 Hz, which is above the critical frequency of both elementss, the sound reduction index is 42 dB for the 0.1 m elements and 51 dB for the 0.2 m element.

a) Why is the sound reduction index of the 0.2 m elements higher?

The sound reduction index above the critical frequency (equations (14.14) and (14.16)) increases with an increased mass per square meter of the wall. Also, as the thickness increases, the bending stiffness increases and thereby the critical frequency shifts to a lower frequency, leading to a higher sound reduction index for 500 Hz.

b) How many first order flanking sound transmission paths should be included in the calculation of the total sound reduction index *R'* between the two rooms? (Consider all sound paths that cross a junction between two elements as flanking sound transmission path)

The total number of flanking paths is 12:

1. *2 paths via wall to wall*
2. *2 paths via wall to partition wall*
3. *2 paths via partition wall to wall*
4. *1 path via ceiling to ceiling*
5. *1 path via floor to floor*
6. *1 path via ceiling to partition wall*
7. *1 path via floor to partition wall*
8. *1 path via partition wall to ceiling*
9. *1 path via partition wall to floor*

c) Compute *R'* between the student rooms. How much do the flanking paths influence the sound reduction index (compared to R from the partition wall alone)?

The sound reduction index is computed with equation (9.47) from Vigran.

- *The total sound reduction index is computed from equation (9.21) or (9.23)*
- K_{ij} is computed with equations (9.43) and (9.44). This means for the flanking contributions from question b)

1. *R = 42+8.7+10log10(3) = 55.5 dB*
2. *R = 42+8.7+10log10(3) = 55.5 dB*
3. *R = 42+8.7+10log10(3) = 55.5 dB*
4. *R = 51+4.1+10log10(2.5) = 59.1 dB*
5. *R = 51+4.1+10log10(2.5) = 59.1 dB*
6. *R = 46.5+9.2+10log10(2.5) = 59.7 dB*
7. *R = 46.5+9.2+10log10(2.5) = 59.7 dB*
8. *R = 46.5+9.2+10log10(2.5) = 59.7 dB*
9. *R = 46.5+9.2+10log10(2.5) = 59.7 dB*

- *The total value now is R' = 40.5 dB. Thus, the flanking paths have reduced the total sound reduction by 1.5 dB compared to the sound reduction of the partition wall alone.*