Waves and Oscillations

Lecture No. 10

Topic: Architectural acoustics

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Architectural acoustics

- Before the Beginning of 20th century constructions (rooms or buildings or halls) were designed without any consideration for their suitability from the acoustic point of view. That is why most of the constructions had bad sound quality.
- In the year 1910, Wallace Clement Sabine (an American physicist) stated that the building materials are poor absorber of sound. As a result, a large fraction of sound energy in a room is reflected possibly about some hundreds of times before being completely absorbed. The consequence of these repeated reflections is that appreciable amount of sound intensity persists even after the source stops emitting sound.

❑ **Reverberation:**

“The persistence of sound in the audible range after the sound source has ceased is called **reverberation** and it is responsible mainly for the bad acoustics of a room or a hall.”

❑ **Reverberation time:**

The **time of reverberation** or **reverberation time** is defined as the time taken by the sound intensity to fall from its value called threshold of audibility.” It is also known as the time taken by the sound intensity to fall through one-millionth of its value or 60 dB of intensity.

- **Things those affects the acoustics of a building:** 1. Un-optimized reverberation time, 2. Very low sound or very high loudness, 3. Interference of sound caused by improper focusing to a particular area, 4. Echoes produced inside the buildings, 5. Resonance caused due to matching of sound waves, 6. Noise roaming outside or inside the building.

- **Reduction of Reverberation:** Reverberation can be reduced by covering the walls, ceiling and floors with suitable absorbent materials. The absorbing power of an absorbent is measured by the fraction of the total sound energy which it can absorb in a single incidence. It depends somewhat on the frequency of the source.

Table: Absorption co-efficient of various materials determined by Sabine for the source of frequency 500 Hz

Materials	Absorption co-efficient (Sabines)
Brick, Plaster, Marble, etc.	0.01 to 0.03
Carpets and curtains	0.15 to 1.00
Felt	0.7
Person	0.2
Open window	1.00

Open window behaves as a perfect absorber of sound

- The **absorption coefficient of a surface** is defined as the ratio of sound energy absorbed by a certain area of the surface to that of an open window of same area. The absorption coefficient is measured in open window unit (O.W.U) or Sabines.

- Optimization of reverberation time is very important. If it is longer it will reduce the intelligibility while if it is lower it will make the sound level of the room very low.

Sabine's Reverberation Formula

Sabine developed the reverberation formula to express rise and fall of sound in a auditorium. The basic assumptions are-

- The average energy per unit volume is uniform.
- The energy is not lost in the auditorium except due to the absorption of the materials of the walls, ceiling, open windows and ventilators.

Analytical treatment of reverberation:-

Let E be the energy supplied by the source per second to a room having volume V. Then the energy supplied per unit volume is E/V. If I be the intensity, a the absorption co-efficient and n the number of reflection per unit second, then the energy absorbed per unit second is Ian.

The rate of change of energy per unit volume is given by,

$$\frac{dI}{dt} = \frac{E}{V} - Ian \qquad (12.10)$$

(a) Growth of intensity: The equation (12.10) can be written as, $\frac{dI}{\frac{E}{V} - Ian} = dt$

$$\int \frac{dI}{\frac{E}{V} - Ian} = \int dt$$

Or, $-\frac{1}{an} \log_e\left(\frac{E}{V} - Ian\right) = t + k$ [k= constant of integration]

Choosing initial conditions: At t=0, I=0 from equation (12.10) we get, $-\frac{1}{an} \log_e\left(\frac{E}{V}\right) = k$

So, $-\frac{1}{an} \log_e\left(\frac{E}{V} - Ian\right) = t - \frac{1}{an} \log_e\left(\frac{E}{V}\right) \Rightarrow -\frac{1}{an} \log_e\left(\frac{E}{V} - Ian\right) + \frac{1}{an} \log_e\left(\frac{E}{V}\right) = t$

Or, $-\frac{1}{an}\left[\log_e\left(\frac{E}{V} - Ian\right) - \log_e\left(\frac{E}{V}\right)\right] = t$

Or, $-\frac{1}{an}\left[\log_e\left\{\left(\frac{E}{V} - Ian\right) / \left(\frac{E}{V}\right)\right\}\right] = t$

Or, $-\frac{1}{an}\left[\log_e\left(1 - \frac{Ian}{E/V}\right)\right] = t \qquad \Rightarrow \log_e\left(1 - \frac{Ian}{E/V}\right) = -ant$

Or, $1 - \frac{Ian}{E/V} = e^{-ant} \qquad \Rightarrow \frac{Ian}{E/V} = 1 - e^{-ant}$

$$\therefore I = \frac{E}{anV}(1 - e^{-ant}) \qquad (12.11)$$

The equation (12.11) shows that I attains its maximum value (I_o) when t is infinity.

So, $I_o = \frac{E}{anV}$ (12.12)

(b) **Decay of intensity:** When the source ceases to emit sound, $E=0$ and hence equation (12.10) reduces to,

$$\frac{dI}{dt} = -Ian \qquad (12.13)$$

Or, $\frac{dI}{I} = -andt$

Or, $\int \frac{dI}{I} = -an \int dt$

Or, $log_e I = -ant + k'$ (12.14)

Here, k'= constant of integration

Counting the time from just when the source ceases, we have $t=0, I=I_o$

Putting these values in equation (12.14),

$log_e I_o = k'$

Therefore, equation (12.14) can be written as

$log_e I = -ant + log_e I_o$

Or, $log_e I - log_e I_o = -ant \quad \Rightarrow log_e \frac{I}{I_o} = -ant$

Or, $\frac{I}{I_o} = e^{-ant} \Rightarrow I = I_o e^{-ant}$ (12.15)

Equation (12.15) shows theoretically I will be zero after an infinite time.

Jaeger shows by statistical methods that

n=cS/4V

Where, c = velocity of sound, S= Surface area of the room.

Substituting n in the equation (12.15),

$$I = I_o e^{-acSt/4V} \qquad (12.16)$$

If T= reverberation time, putting $I/I_o = 10^{-6}$ in equation (12.16) we get,

$10^{-6} = e^{-acST/4V}$; Now, taking log_{10} on both sides

$$6 = \frac{acS}{4V} T \log_{10} e$$

$$\therefore T = \frac{24V}{340 \times \log_{10} e \times aS} = 0.16 \frac{V}{aS} \text{ (SI unit) } [c=340 \text{ m/s}]$$

$$\therefore T = \frac{24V}{1100 \times \log_{10} e \times aS} = 0.05 \frac{V}{aS} \text{ (CGS unit) } [c=1100 \text{ ft/s}]$$

When, different portion of the room has different absorption coefficient, aS in the equation should be replaced by ΣaS.

So, $T = 0.16 \frac{V}{\Sigma aS}$ (SI unit) or, $T = 0.05 \frac{V}{\Sigma aS}$ (CGS unit)