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LECTURE NOTES

UNIT II ACOUSTICS

Classification of sound- decibel- Weber–Fechner law – Sabine's formula- derivation using growth and decay method – Absorption Coefficient and its determination –factors affecting acoustics of buildings and their remedies. Methods of sound absorptions - absorbing materials - noise and its measurements, sound insulation and its measurements, impact of noise in multi-storeyed buildings.

Classification of sound

Sound waves are classified into three categories on the basis of frequency.

1. Infrasonics (below 20 Hz)
2. Audible sound (between 20 Hz to 20.000 Hz)
3. Ultra sound (above 20,000 Hz)

Audible sound is further classified as

a) **Musical sound** which produces pleasing effect on the ear.
b) **Noises** which produces unpleasant effect on the ear.

Characteristics of musical sound

a) Pitch – Pitch is the characteristic of sound that distinguishes between a shrill sound and a grave sound.
b) Quality – The quality of sound is that characteristic which enables us to distinguish between two notes of the same pitch and loudness produced by two different voices.
c) Intensity of sound – It is the energy of sound wave crossing per unit time through unit area at right angles to the direction of propagation.
d) Loudness – It is the degree of sensation produced in the ear.

Weber-Fechner law

Loudness of sound is defined as the degree of sensation produced on the ear. This cannot be measured directly. So that it is measured in terms of intensity. Loudness is proportional to logarithmic value of intensity.

$$L \propto \log I; \quad L = k \log I$$

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Sound Intensity Level

It is the ratio of intensity of a sound (I) to the standard intensity of sound (I_o) .

$$(I) = \log_{10} (I/I_o)$$

Bel – 1 bel is defined as the relative intensity between two sound notes if one is 10 times more intense than the other.

Decibel – It is the smallest unit compared to Bel. It is the standard unit used to measure the loudness. One decibel is equal to one tenth of bel. An increase of sound intensity level by 1 dB would increase the intensity by 26 %.

Reverberation time

The persistence of audible sound, even after the source has stopped to emit the sound is called reverberation. The time during which the sound persists in the hall is called as reverberation time.

Reverberation time is also defined as the time taken by the sound to fall to one millionth of its original intensity, after the source of sound is stopped.

$$I = I_m / 〖10〗^{(-6)}$$

When the reverberation time is lower than the critical value, sound becomes inaudible by the observer and the sound is said to be dead and if the reverberation time is too large, echoes are produced. Therefore, the reverberation time should have some optimum value.

Absorbing Materials

The special materials used to increase the absorption of sound waves or to reduce the reflection of sound waves in a room or hall are known as sound absorbing materials. The material should have the following requirements:

The important facts in connection with absorbing materials are as follows:

An ideal absorbing material should be economical in construction and maintenance, water-proof, fire-proof, sufficiently strong and good in appearance.

- In the hall treated with absorbing materials, the speech can be heard clearly and music can be fully enjoyed.
- All the absorbing materials are found to be soft and porous. They work on the principle that the sounds waves penetrate into the pores and in this process, the sound waves are converted into other form of energy by friction
- The absorbing capacity of the absorbing materials depends on the thickness of the material, its density and frequency of sound.
- The acoustic properties of the absorbing materials are considerably changed by their modes of fixing.
- Great care should be exercised while prescribing the covering for an absorbing material so as to improve its appearance. The improper covering destroys the absorbing properties of the material It should be remembered that in a big hall, the audience is a major absorbing factor

Types of Absorbent Materials

The various types of absorbing materials are available in the market under different trade names. The value of coefficient of absorption is supplied by the manufacturer

The requirements of a good acoustical material are as follows:

- It should be durable and should not be liable to the attacked by insects, termites, etc.
- It should be easily available at a reasonable cost.
- It should be efficient over a wide range of frequencies.
- It should be fire resistant.
- It should give pleasing appearance after fixing
- It should have high coefficient of absorption.
- It should have sufficient structural strength.

Classification of sound absorbing materials

The sound absorbing materials are broadly classified into the following four categories:

(a) Porous absorbents

(b) Cavity resonators

(c) Resonant absorbing or panel absorbers

(d) Composite types of absorbents.

Have we shall discuss these materials one by one

Porous absorbents. When sound waves strike the porous material, a part of waves is reflected while the other enters the porous material. The part that enters the porous material is converted into heat energy while the reflected part is reduced in energy.

Cavity resonators A cavity resonator is a chamber or container having a small opening. When sound waves enter the resonator, due to multiple reflections.

The drawback of cavity resonator is that it is suitable for a particular frequency (single frequency) such as from individual machine, air conditioning plant, etc. for which it is constructed.

Resonant absorbents or Panel absorbers. In this system, the absorbent materials is fixed on a framing (usually timber) with an air space between the framing and the wall. It acts as a panel absorber. When sound waves strike the panel, then due to flexural vibration of panel, a certain amount energy is absorbed.

(Ex) The common examples are: gypsum boards, wood and hard-board panels, suspended plaster ceilings, rigid plastic boards, windows, doors, etc.

Composite absorbers. When the functions of all the three types described above is combined in a single unit, then it is known as composite absorber. The composite absorbers consist of a perforated panel fixed over an air space containing porous absorbent. When sound waves strike the panel, they pass through it and dampled by resonance of the air in the cavity.

Following are some of the common types of absorbing materials:

1.Hairfelt

The average value of coefficient of absorption of 25 mm thick hairfelt is 0.60.

2.Acoustic plaster

This is also known as the *fibrous plaster* and it includes granulated insulation material mixed with cement. The acoustic plaster boards are also available. They can be fixed on the wall and their coefficient of absorption varies from 0.15 to 0.30.

3.Acoustical tiles

These are made in factory and sold under different trade names. The absorption of sound is uniform from tile to tile and they can be fixed easily.

4.Strawboard

This material can be also used as absorbent material.

5.Pulp boards

These are the soft boards which are prepared from the compressed pulp. They are cheap and can be fixed by ordinary panelling. The average value of coefficient of absorption is 0.17.

6.Compressed fiberboard

This material may be perforated or unperforated. The average coefficient of absorption for the former is 0.30.

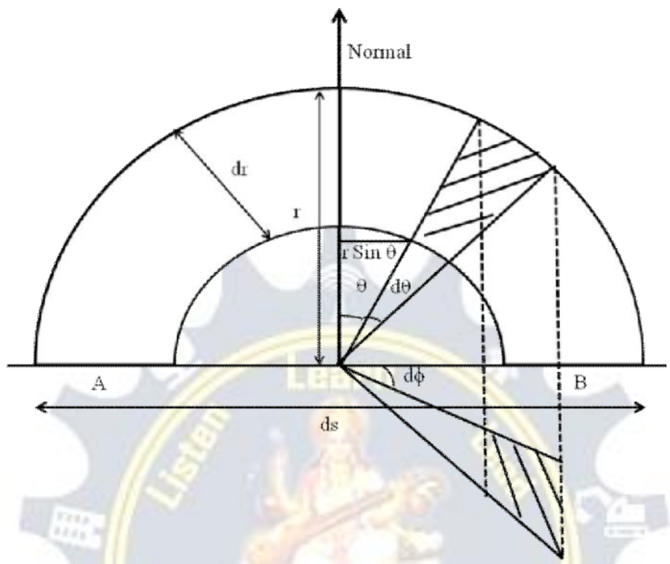
Sabine’s law

If V is the volume of the hall, a is the average absorption coefficient and S is the total surface area, the reverberation time can be related as

$$T = (0.167V)/(\sum as)$$

Derivation of Sabine's law

Let us consider small element *ds* on a plane wall AB as shown in fig.



Assume that this element *ds* receives sound energy. Taking O as a mid-point on ds, two semicircles are drawn with radii r and r+dr. Consider a small shaded portion between the circles lying between two radii drawn at angles θ and θ+dθ.

Radial length of the shaded portion = dr

Arc length of the shaded portion = r dθ

Area of the shaded portion = r dθ dr

Imagine the whole figure is rotated about the normal through an angle dϕ and shaded portion travels through a small distance dx and thus traces a elemental volume dV.

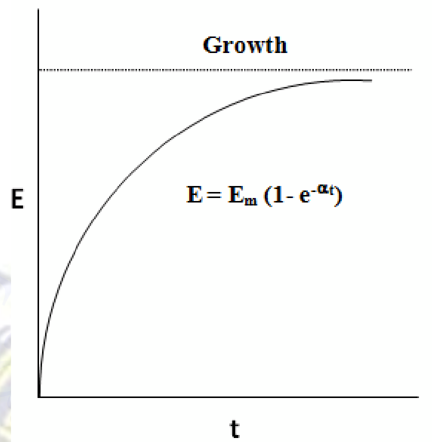
Distance travelled by this shaded portion, dx = r sin θ dϕ Volume
traced by the shaded portion, dV = r dθ dr .r sin θ dϕ

If E is the sound energy density, then sound energy present within the volume element dV,

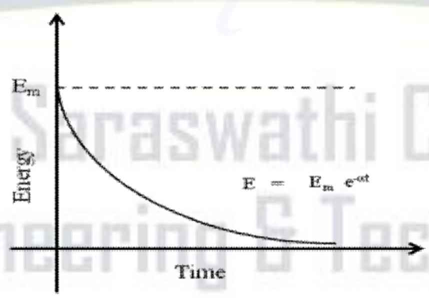
= E . dV

$= E.\ r^2 \sin\theta\ d\theta\ dr\ d\phi$

This equation expresses the growth of sound energy density 'E' with time 't'. This indicated that E increases with t, and when $t \to \infty$, $E = E_m$.



Decay of sound energy



Assume that, when sound energy has reached its steady (maximum value) state Em, sound energy is cut off. Then the rate of emission of sound energy, P = 0.

Therefore, equation (2) can be written as $Ee^{\alpha t} = K$

Substituting the boundary conditions $E = E_m$ at t = 0 and P = 0, we get

$E_m e^0 = 0 + K$

$K = E_m$

Therefore, we get

$Ee^{\alpha t} = E_m$

$E = E_m/e^{\alpha t}$

Therefore, $\mathbf{E = E_m \cdot e^{-\alpha t}}$

This equation represents the decay of sound energy density with time after the source is cut off.

Expression for reverberation time

The standard reverberation time is the time taken by the

sound to fall of its intensity to one-millionth of its initial value after the source is cut off. Now, the value of sound energy density before cut off is E_m, at standard reverberation time, it reduces to

$$E = E_m/10^6$$

To calculate T, we put $E = E_m.10^{-6}$ and $t = T$,

$E_m.10^{-6} = E_m.\ e^{-\alpha T}$

$e^{-\alpha T} = 10^{-6}$

$e^{\alpha T} = 10^6$

Taking log on both sides, we have

$\alpha T = 6\log_e 10$

$T = (6\times2.3026\times1)/\alpha$

$T = (6\times2.3026\times1) / (vA/4V)$

By using velocity of sound, v = 340 m/s

T = 0.165 V / A

or

T = 0.165 V / Σas

This equation is in agreement with the experimental values obtained by Sabine.

Absorption Co-efficient

All the sound waves when pass through an open window, the open window behaves as a perfect absorber of sound and hence the absorption coefficient can be defined as the rate of sound energy absorbed by a certain area of the surface to that of an open window of same area.

Definition:

The absorption coefficient of a surface is defined as the reciprocal of its area which absorbs the same amount of sound energy as absorbed by a unit area of an open window.

For ex, if $2m^2$ of a carpet absorbs the same amount of sound energy as absorbed by $1m^2$ of an open window, then the absorption coefficient of the carpet is ½=0.5. The absorption coefficient is measured in open window unit sabines.

In general, the absorption coefficient of a material is defined as the ratio of the sound energy absorbed by the surface to that of the total sound energy incident on the surface.

Absorption coefficient (a) = Sound energy absorbed by the surface/Total sound energy incident on the surface

Average Absorption coefficient

The average absorption coefficient is the defined as the ratio between the total absorption in the hall to the total surface area of the hall.

i.e., $\bar{a} = A/S = \Sigma as/\Sigma s$

Determination of Absorption Coefficient

Let us consider a sample for which the absorption coefficient is to be measured. Initially without this material the reverberation time in a room is measured and let it be T1. Now the given sample is kept inside the room and again the reverberation time is measured and let it be T2.

Then from sabine's formula

For case (i) (i.e) without the sample

$T_1 = 0.167V/\Sigma as$ .... (1)

Where Total absorption = $\Sigma as = a_1s_1+a_2s_2+$……….[for all the materials such as doors, windows, etc.]

For case (ii) (i.e.) Including the sample material

$T_2 = 0.167V/ \Sigma as+a_ms_m$..(2)

Where a_m = absorption coefficient of the material to be found

s_m = surface area of the material.

Therefore from equ. (1) we have

$\Sigma as = 0.167V/T_1$ ....(3)

From equ. (2) we have $\Sigma as+a_ms_m = 0.167V/T_2$

Sub eqn (3) from eqn (4)

$a_ms_m = 0.167V(1/T_2-1/T_1)$ (or)

$a_m = 0.167V/s_m[T_1-T_2/T_1T_2]$

Hence, by knowing the terms on the right hand side the absorption coefficient of the given sample can be determined.

Factors affecting acoustics of buildings and their remedies

1. **Optimum reverberation time:**

(i) Heavy contains folds are used to reduce reverberation time by increasing absorption of sound

ii) Floor is covered with carpets to absorb sound.

iii) Windows and openings are provided in the hall which can be opened or closed to control the reverberation time.

iv) Walls and ceilings are covered with sound absorbing materials.

v) If the hall is filled to its maximum capacity of audience, reverberation time is less.

2. **Loudness:** There should be adequate loudness in all parts of the hall.
   Remedies:
   i) Large sounding boards are used behind the speaker facing the audience.
   ii) Loudspeakers are used to increase the loudness.
   iii) Low ceilings help to reflect the sound towards the audience.
   iv) Sound absorbing materials are used in those parts of the hall where sound intensity is large.
3. **Echo:** The reflection of sound from a distant reflecting surface is known as echo. If the echo reaches the listener about $1/17^{th}$ of a second after the direct sound, the listener hears two sounds instead of one which causes confusion. Such echoes mush be eliminated in halls.
   Remedy: High ceilings and distant walls are covered with second absorbing materials.
4. **Echelon effect:** Succession of echoes produced by a set of regularly spaced reflecting surfaces like staircase causes confusion in original sound. This effect is known as echelon effect. **Remedy:** The regularly spaced reflecting surfaces like stairs are covered with sound absorbing materials like carpets.
5. **Focusing:** Concave and parabolic surfaces in the hall focus sound. This causes concentration of sound in certain regions of the hall which is not desirable.
   Remedies: Curved surfaces are avoided, If there are curved surfaces, they are covered with sound absorbing materials.
6. **Resonance:** Loose fitting window panels and some other objects resonate at some audible frequencies creating more sound of these frequencies. This distorts the original sound. **Remedies:** Window panels are fixed properly, Vibrating objects are placed on sound absorbing materials.
7. **Noise:** Noise from different sources adversely affects the quality of sound in a hall. The noise can be air borne, structure borne or inside noise.
   a) ***Air borne noise:*** the external noise, for example of traffic, which enters the halls through doors, windows and ventilators is known as external noise.
      Remedies:
      i) Openings for ventilators inside the hall are avoided.
      ii) Doors and windows are provided with rubber covering on frames so that they shut without any gaps.
      iii) Double doors and windows having separate frames enclosing sound absorbing materials are used
      iv)

b) ***Structure borne noise:*** Noise produced by activities like drilling and hammering or the vibrations of heavy machinery is transmitted through the structure of the building. This is known as structure borne noise.

Remedies:

i) Heavy machinery is mounted on sound absorbing materials like wood or rubber.

ii) Double walls are used with space between them.

c) ***Inside noise:*** It is the noise produced inside the hall by machinery, fans, air conditioners etc.

Remedies:

i) Sound absorbing materials and curtains are provided near the sources of noise.

The sources of noise are mounted on sound absorbing materials

Methods of sound absorption

When a sound wave strikes one of the surfaces of a room, a part of the sound energy is reflected back into the room and others are penetrating through the surface. The parts of the sound energy are absorbed by the conversion to heat energy in the material, while the rest is transmitted through it. The level of energy conversion to heat energy depends upon sound absorbing properties of the material.

The listener and the sound source are in the same room, if the room has no sound absorbing surfaces, the sound energy is bounced back between the surfaces and it takes long time before dies out.

The listener will have a problem registering the speaker because listener hears both direct and repeated reflected sound waves. If the surfaces are covered with absorbing material, the reflected sound will decrease, also sound level of the room is decreased.

Noise measurement

The logarithms scale provides comparing the sound pressure of one sound with another. To avoid a scale which is too compressed a factor 10 is introduced, giving rise to the decibel unit.

1 decibel = 10 $\log_{10}$(intensity measured/reference intensity)

Where reference intensity 2 x 10^{-5} Newtons per sq.meter or 10^{-12} watts per sq. meter.

Sound pressure level(LP or SPL) = $10 \log 10(P^2 - P^2 ref)$ (unit-db)

$= 20 \log 10 P - 20 \log 10 P ref$ (unit-db)

Sound insulation and its measurements

It is a measure used to reduce the level of sound when it passes through the insulating building component. It is also called sound proofing

Methods of sound insulation

By avoiding opening of pipes and ventilators.

By allotting proper places for doors and windows.

i) When noise is structured-borne Using double walls with air space between them. Insulating of machinery.

Impact of noise in multi-storeyed buildings

It is defined as the structure whose usage levels are regular in distribution and which correspond roughly to the required for human habitation. There are four main actions which causes impact of noise in multistoried buildings.

(i) Speech privacy

It is an issue within office buildings, including individual work space, inside conference halls and between offices. It mainly affects the quality of work in the adjacent buildings.

(ii) Back ground noise

It can adversely impact the work space too little background noise and speech privacy is reduced.

(iii) Sound masking

It can blend the building systems noise levels within electronic noise systems in the middle. Traditional sound masking systems are located in loud speakers above the ceiling.

(iv) Orientation of buildings

The noise impact may also be great for rooms perpendicular to road ways because, a noise pattern can be more annoying in perpendicular rooms. Windows on perpendicular walls do not reduce noise as effectively as those on parallel walls became at the angle of sound.