Acoustics of buildings

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B.Sc Part-I
Paper-I

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Building acoustics:-

The science that deals with the design of a good ~~adiod~~ auditorium and building so as to reduce the external and internal noise and maintain the condition of sufficient loudness and clearity of the source of sound inside it is known as archetectural acoustics

The sound emitted by the source will reach the point directly along with the successive reflection from walls by travelling a greater length. These wave may interfare at the point. When the source is cut-off sound reception by the receiver will not stop instantaneously but will continue to pick-up the reflected sound waves till becomes a too weak to be recieved due to absorption.

The dying out of sound intensity after the source is ~~cut~~ cut-off is known as reverbaration. The time of reverbaration is the time for which sound remain audible after the source of sound had been cut-off. It is a measured as the time in which the intensity of sound reduces from a level 60 dB above the threshold of audibility to the threshold. This is equivalent to the time required for a sound to diminish from its initial intensity to 1 million'th of that intensity. This time depends upon the size of the room and absorption material of the sorrounding wall. The empirical formula for the time of reverbaration is

$$T = \frac{0.05V}{\Sigma a.s}$$

where V is the volume of the room in ft^3, a is absorption co-efficient and S is the area of the surface in ft^2.

So. Some reverbaration is necessary to produce enough ~~sound~~ loudness so that the clarity is ensured. The suitable value for reverbaration time for a given room is known as optimum reverbaration time.

If the absorption co-efficient of the room is small (< 0·4) the reverbaration time will be Large and the room is said to be live room. The reflected wave will not be reduce sufficiently in intencity and they will interfare with the succeding sylables comming directly from the speaker, So clarity will be destroyed. On the other hand if the absorption co-efficient of the room is too great (> 0·4) the reverbaration time will be short, the intensity of the sound will be lower such a room is said to be dead room.

The optimum reverbaration time for an auditorium of 50,000 ft^3 is T = 0·8 sec. So that the clarity is ensure.

Requirements of a good auditorium :→

1. The sound heard at every point of the room must be loud.
2. Successive sylables uttered by the speaker should be distinctly heard.
3. There must not be any distortion of the sound wave.
4. Resonance of the different part of the hall such as the wall, the space in the hall, sound boards should be avoided.
5. In order to avoid the focusing effect, curve walls, domed ceiling are to be avoided.

6. The interference effect should be minimised else it will give maximum and minimum at different places.

7. Proper design of the room and proper use of the sound absorbing materials on the walls will greatly minimised the most of the defects, the reverbaration ~~time~~ should be suitable for the purpose of music or speech for which the hall is design.

Sabine formula (reverbaration time for a live room):-

In deducing the theoritical formula for the reverberation time for a live room we assume

i) The sound energy is distributed uniformly over the entire room.

ii) In steady state the rate at which the energy is produced at the source is equal to the rate at which the energy is increased in the medium and the total rate at which the energy is absorbed by the walls and the surroundings.

We consider a hemispherical shell of radius r and thickness dr, the centre of which is taken on an area ds.

The element of volume dv is given by

$$dv = r^2 \sin\theta \, dr \, d\theta \, d\phi \quad \text{—— (1)}$$

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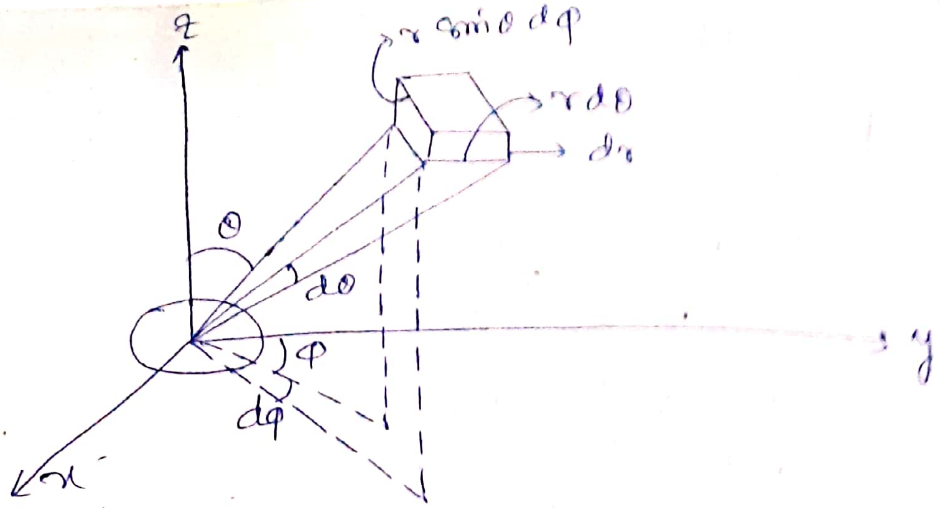


Let E be the energy density so that the amount of energy on the elementary volume dv propagating in all direction is

$$E\,dv = E r^2 \sin\theta\, dr\, d\theta\, d\phi \quad \text{——} (2)$$

The amount of energy is propagated through unit solid angle is

$$\frac{E r^2}{4\pi} \sin\theta\, dr\, d\theta\, d\phi \quad \text{——} (3)$$

The solid angle substanted by ds at the element of any volume is

$$\frac{ds \cos\theta}{r^2} \quad \text{——} (4)$$

The fraction of energy in the elementary volume propagating towards ds is

$$\frac{ds \cos\theta}{4\pi r^2} E r^2 \sin\theta\, dr\, d\theta\, d\phi \quad \text{——} (5)$$

The total energy incident on the upper face of ds from a distance between r and r+dr is obtained by integrating θ and φ between the limits θ → 0 to $\pi/2$.

and φ → 0 to 2π respectively is

$$\frac{E\,ds\,dr}{4\pi}\int_{\theta=0}^{\pi/2}\cos\theta\sin\theta\,d\theta\int_{\phi=0}^{2\pi}d\phi$$

$$= \frac{E\,ds\,dr}{4} \quad \text{——— (6)}$$

Energy received in unit time

$$= \frac{E\,ds}{4}\int_{r=0}^{c} dr$$

$$= \frac{EC}{4}\,ds \quad \text{——— (7)}$$

where, C is the velocity of propagation i.e distance travelled in one second.

If a is the absorption co-efficient of the elementary surface ds. So energy absorbed in unit time is

$$= \frac{ECa}{4}\,ds \quad \text{——— (8)}$$

The total rate of absorption of energy at any time is

$$= \frac{EC}{4}\sum a\,ds$$

$$= \frac{ECA}{4} \quad \text{——— (9)}$$

where $A = \sum a\,ds$ is the total absorption of all the surfaces exposed to sound waves.

The total rate of energy increased in the medium with in the whole volume V of the room is

$$= V\frac{dE}{dt} \quad \text{——— (10)}$$

If P be the rate at which energy is propagated by the source then form (9) and (10)

$$V\frac{dE}{dt}+\frac{AC}{4}E=P \quad \text{——— (11)}$$

or, $$\frac{dE}{dt}+\frac{AC}{4V}E=\frac{P}{V}$$

or, $$\frac{dE}{dt}+\alpha E=\frac{P}{V} \quad \left[\text{where } \alpha=\frac{AC}{4V}\right]$$

or, $$\frac{dE}{dt}+\alpha\left(E-\frac{P}{V\alpha}\right)=0.$$

put $$E-\frac{P}{V\alpha}=z.$$

$\therefore$ $$\frac{dz}{dt}+\alpha z=0$$

or. $$\frac{dz}{z}=-\alpha\, dt$$

Integrating

$$\ln z=-\alpha t+\ln C_1 \quad [C=\text{constant}].$$

or, $$z=C_1e^{-\alpha t}$$

$\therefore$ $$E=\frac{P}{V}\cdot\frac{4V}{AC}+C_1e^{-\frac{AC}{4V}t}$$

At, $t=0$, $E=0$

$\therefore$ $$C_1=-\frac{4P}{AC}$$

$\therefore$ $$E=\frac{4P}{AC}\left[1-e^{-\frac{AC}{4V}t}\right] \quad \text{——— (12)}$$

This expression shows the growth of E with time after the start of the sound.

The source is cut-off when E has reached the maximum value so that $t=0$, $P=0$ and

$$E=E_{max}=\frac{4P}{AC} \quad \text{——— (13)}$$

Eq^n (11) Then becomes

$$V\frac{dE}{dt} + \frac{AC}{4}E = 0$$

or, $$\frac{dE}{E} + \frac{AC}{4V}dt = 0.$$

Integrating

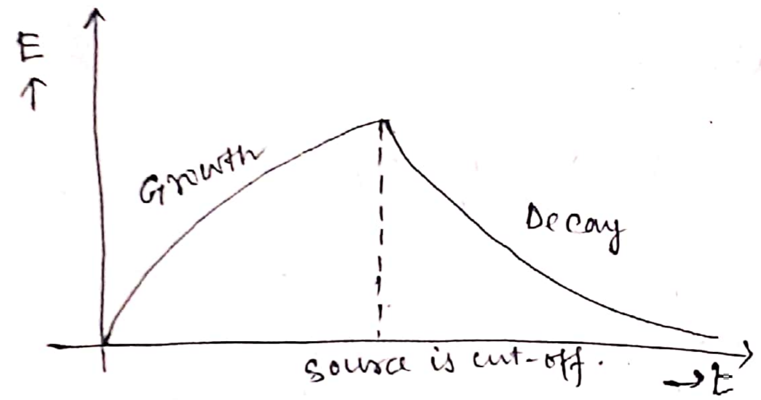
$$E = C_2 e^{-\frac{AC}{4V}t} \quad [C_2 = \text{constant}].$$

At, $t=0$, $E = E_{max}$.

$$\therefore C_2 = \frac{4P}{AC}.$$

$$\therefore E = \frac{4P}{AC} e^{-\frac{AC}{4V}t} \qquad (14)$$

This expression represent the decay of energy. The fig represent the growth and decay of sound energy.



Let T be time taken to reduce the energy density and therefore intensity to decay by 60 dB i.e. 1 millionth part of the value just before cut-off. Therefore.

$$\frac{E}{E_{max}} = e^{-\frac{AC}{4V}T}$$

$$= 10^{-6}$$

or, $$\frac{AC}{4V}T = -\ln 10^{-6} = 6 \times 2.303$$

$$\therefore T = 6 \times 2.303 \times \frac{4V}{AC}.$$

or, $$T = 0.16\frac{V}{A} \; (\text{M.K.S.}) \qquad (15)$$

where. $C = 340$ m/s.

Again $T = 0.05 \frac{V}{A}$ (F.P.S) ——— (16)

where $C = 1120$ ft/s.

Eqⁿ (15) and (16) are known as Sabine formula.

Measurement of absorption co-efficient :-

Let the reverbaration time T_1 and T_2 for two sources emitting power P_1 and P_2. The steady energy density maintained by two sources are

$$E_{max}\Big|_1 = \frac{4P_1}{AC}$$

$$E_{max}\Big|_2 = \frac{4P_2}{AC}.$$

During decay in time T_1 and T_2 are repectively, we have

$$\frac{4P_1}{AC} e^{-\frac{AC}{4V}T_1} = \frac{4P_2}{AC} e^{-\frac{AC}{4V}T_2}$$

Hence, $$\frac{P_1}{P_2} e^{\frac{AC}{4V}(T_2 - T_1)} = 1.$$

or. $$e^{\frac{AC}{4V}(T_2 - T_1)} = \frac{P_2}{P_1}$$

or, $$\frac{AC}{4V}(T_2 - T_1) = \ln(P_2/P_1)$$

or, $$A = \frac{4V}{C(T_2 - T_1)} \ln(P_2/P_1).$$

where A is the total absorption by the area of the room is given by aS, a being the mean absorption co-efficient and S be the surface area.