BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE, INDIA

ACOUSTICAL DESIGNING AND SPEECH COMMUNICATION

There is a demand for concise information on the acoustic design of halls and auditoria and on the corrective measures required when the acoustics of an auditorium prove unsatisfactory. This digest aims at enumerating the basic principles of auditorium design and the use of column-type loudspeakers when required. For the benefit of architects and engineers, only some of the important features are highlighted.

Site of the Auditorium

The site of an auditorium should be selected as far as possible in a quiet area, away from external noises. Should such a quiet siting prove difficult, the nature of the noise must be looked into and proper sound insulation should be incorporated in the building. The latter depends on the external noise level. As the level of noise reaching indoor should not usually exceed a level of about 50 db, the insulation required for an external noise level of 90 db is 40 db (1/10,000 of the outside level). The air-borne sound attenuation provided by some common constructions is given in Table 1.

The prevention of structure-borne noise such as the noise from pile-driving, heavy vibrating machines, street carts and running trains, involves expensive construction, such as floating floors and walls and suspended ceilings. If the noise comes from a nearby vibrating machine, it is usually better to float the source of noise on resilient foundations and house it in an acoustically treated room.

Size of the Auditorium

In an auditorium, the seating should be so arranged that the audience is as near the stage as possible. The optimum ratio of length to width is not a fixed number, but varies with the size and shape of the seating area. It also depends on whether a sound amplification system is used. For most rooms, ratio of length to width, between 2:1 and 1.2:1 have been found satisfactory (1).

TABLE I

Air Borne Sound Attenuation (db) Of Common Walls

Type of partition	500C/s	Average (100-3200 C/s)
1. 11.4 cm (4½ in.) Single brick wall with 1.27 cm (½ in) plaster on both sides.	47	47
2. 11.4 cm (4½ in) double brick wall. 11.4 cm brick+5 cm air+ 11.4 cm brick with 1.27 cm (½ in.) plaster on exposed sides.	53	52
3. 11.4 cm (4½ in.) brick wall with 1.27 cm (½ in.) Plaster on one side.	38	44
4. 6 mm Plywood+14 mm air+ 6 mm Plywood	21	25
5. 6 mm Plywood+14 mm air+ 6 mm Plywood (cavity loosely filled with glass wool).	23	28

Shape of the Auditorium

An important factor influencing the acoustics of a hall is the shape of the interior. This should enable the audience in all parts of the hall to get a clear reception of the speech or the music. Among the wide variety of floor plans, there are three basic shapes; rectangular. fan, and horse-shoe. Other shapes such as oval or circular give rise to acoustical defects which require compensating measures including the use of expensive sound absorbing materials. While rectangular halls have certain acoustical advantages, the fan and horse-shoe shapes are preferred since they draw the audience nearer to the stage.

A hall for the performance of music should be relatively long, narrow and rectangular, since parallel walls provide desirable sound reflections. First order reflections from the walls and ceilings of such halls should reach the remote seating areas within 45 milliseconds of the arrival of direct sound. Splayed hard surfaces (Fig. 1) at the sides of a stage and proscenium opening are useful in reflecting sound to rear parts of the hall. The absence of reflective surface close to the stage is a serious defect. It results in the arrival of a weak, ill-defined direct sound at a specified location in the hall often accompanied by delayed first order reflections.

Seats in the hall should be raked so that the heads of one row do not intercept direct sound to people in the row behind A clearance of about 100 mm (4in) should be provided between the sight lines from two consecutive rows.

The sound level is often too weak for distinct hearing. This phenomenon is speedily noticeable in long halls where the audience at the rear seats receive practically no sound. Recourse has therefore to be taken to indirect sound reflected from hard surfaces set-up in the vicinity of the stage (Fig. 1 & 2). Any sound reaching near seats after 45 milliseconds of the arrival of direct sound will be heard as an echo. In order to ensure against interfering echoes, effective ceiling and wall reflectors should be within 8 m of the sound source.

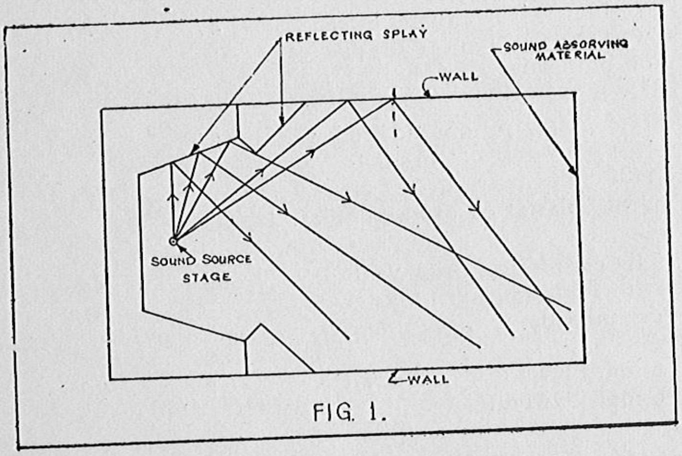

FIG. 1.

Plan of rectangular hall showing useful reflections from the walls plug, and stage insets.

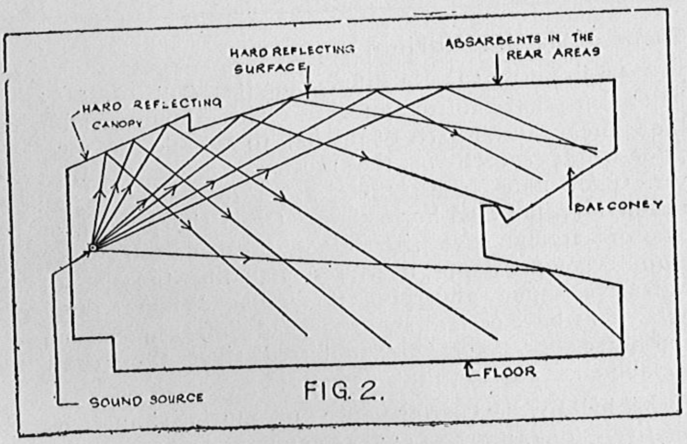

FIG. 2.

Longitudinal section through a hall showing a correct ceiling layout for useful sound reflections to the rear seats. Path difference between the direct and the reflected sound at no listening point exceeds 12 m (about 40 feet).

To further increase the speech communication in a hall, it is essential to increase the strength of the direct sound as compared to the reverberent sound. This is achieved by introducing (2) (i) a flat reflective ceiling in front of the proscenium, and (ii) side reflectors near the stage. The ceiling reflectors are inclined from the horizontal so as to direct the sound towards the audience in the hall. Column loudspeakers are useful in such situations.

Optimum Reverberation Time

Problem concerning speech communication in large halls arise out of their long reverberation time. There is an optimum value of the reverberation time for each hall. Optimum reverberation time of halls used for music should be more than those used for speech only. Suitable values for R.T. to be used when designing halls in India are given in Table 2.

TABLE 2

Recommended Values For Reverberation Time

Activity	Optimum Reverberation time (500-1000 C/s)
1. Cinema	0.6—1.2 seconds
2. Lecture, Convocation & similar activities using sound amplification	0.6—1.0 seconds
3. Chamber music	1.0—1.4 seconds
4. Drama plays	0.8—1.2 seconds
5. Orchestra	1.2—1.4 seconds

Reverbration time increases with increase in volume and with decrease in the amount of sound absorption. Various considerations show that the volume per seat of the audience should be close to 4.2 cu meters. A volume of 5.7 cu meters should not usually be exceeded. Thus for a seating capacity of 600 persons a hall-volume of about 2500 cu. meters is sufficient.

Sound Absorption

In auditoria, halls and theatres the bulk of sound absorption is provided by the audience. In order to calculate sound absorption, two thirds of the audience is assumed to be present. An average adult provides nearly 0.46 units (sq. meters) of sound absorption (Table 3), which is equivalent to 0.92 sq. meters of absorbing area having an absorption coefficient of 0.5. The total absorption by the audience at the

TABLE 3

Sound Absorption Coefficients

Sl. No.	Material	Manufacturer	Thickness	Density	Absorption Coef. C/s 125	250	500	1000	2000	4000	NRC	Mounting
1.	Audience seated in fully upholdstered seats (per person)	—	—	—	0.18	—	0.46	—	0.51	—	—	—
2.	Seats (unoccupied) fully upholstered (per seat)	—	—	—	0.16	—	0.40	—	0.44	—	—	—
3.	Curtain hung in folds or spaced away from wall	—	—	—	0.10	—	0.40	—	0.50	—	—	—
4.	Asbestos spray on solid backing	CBRI, Roorkee	25 mm	—	0.12	0.33	0.38	0.73	0.98	0.90	0.60	With rigid back
5.	Porous brick burnt with 20% saw-dust.	CBRI, Roorkee	20 mm	913Kg/m³	0.24	0.27	0 33	0.41	0.39	0.30	0.35	,,
6.	Fibre-glass Crown RB-wool	Fibre-glass Pilkington Ltd. Bombay	25 mm	16 Kg/m³	0.18	0.23	0.54	0.75	0.85	0.88	0.59	,,
7.	—do—	—do—	25 mm	24 Kg/m³	0.24	0.30	0.59	0.78	0.92	0.98	0.65	,,
8.	—do—	—do—	25 mm	32 Kg/m³	0.17	0.23	0.63	0.77	0.92	0.92	0.64	,,
9.	—do—	—do—	50 mm	16 Kg/m³	0.25	0.52	0.79	0.84	0.91	0.98	0.76	,,
10.	—do—	—do—	50 mm	24 Kg/m³	0.35	0.59	0.96	0.98	0.98	0.98	0.88	,,
11.	—do—	—do—	50 mm	32 Kg/m³	0.31	0.61	0.97	0.98	0.98	0.98	0.89	,,
12.	—do—	—do—	25 mm	16 Kg/m³	0.16	0.28	0.62	0.83	0.84	0.78	0.64	,,
13.	—do—	—do—	25 mm	24 Kg/m³	0.26	0.36	0.67	0.87	0.91	0.90	0.70	,,
14.	—do—	—do—	25 mm	32 Kg/m³	0.23	0.36	0.86	0.91	0.91	0.98	0.76	,,
15.	—do—	—do—	50 mm	16 Kg/m³	0.31	0.55	0.86	0.87	0.91	0.98	0.79	,,
16.	—do—	—do—	50 mm	24 Kg/m³	0.31	0.65	0.98	0.98	0.87	0.98	0.87	,,
17.	—do—	—do—	50 mm	32 Kg/m³	0.31	0.67	0.98	0.98	0.94	0.98	0.89	,,

middle frequencies (500 to 1000 c/s) is 0.46 x number of persons. Where the calculated reverberation times are in excess of the optimum, extra absorption must be provided by treating suitable areas with sound absorbing materials (3). The total absorption is found by multiplying the area of each surface by its absorption coefficient (fraction of the incident sound energy it absorbs) and then adding them together.

The location of the absorbing treatment should be chosen carefully. Areas that serve as beneficial reflectors and areas close to the stage should not be covered. Rear walls must be acoustically treated particularly when they are concave in shape, as these are likely to cause long delayed reflections to the front seats. It is always wise to instal soft acoustical materials at heights above 2.4 meters to prevent their damage by rough handling. Corners and edges between ceiling and walls should be acoustically treated.

Sound Amplification System

In an open space the sound emitted from a source travel directly to the listener. In an enclosure there are multiple reflections from various surfaces. In order to increase the loudness of the sound in an enclosure, Public Address system is often needed.

A column type of loudspeaker may be used with advantage. In this system, a number of loudspeakers are placed in a closed wooden cabinet one above the other. The inner sides of the cabinet are lined with about 2.5 cm thick acoustical material. The speakers are connected in a way that the sound intensity is maximum in the middle and decreases towards the ends. Such a column loudspeaker would be more directional in the vertical plane, and non-directional in the horizontal plane. This has two main advantages over the ordinary loudspeaker and the unaided voice. First it may be used to direct most of the speech towards the audience, thus decreasing the intensity of the reverberent sound which is undesirable for good intelegibility. The second is that the fall-off in intensity of the direct sound with distance can be reduced by positioning the column so that more distant listeners receive more of the sound beam. Correct placing of the loudspeaker in relation to the original source helps to create an impression that the sound is coming from the speaker. The speaker column should preferably be above the source, and so tilted that it transmits the beam of sound to the listeners. The weakness of sound immediately below the column is very useful in reducing acoustic feed-back.

The length and tilt of column loudspeaker are interdependent. In Fig. 3, ℓ is the horizontal distance from the position on the floor above which the column is to be located to the point farthest away from the column (4) h is the height of the column centre from the ear-level. After h/l is known, one can determine from Fig. 3 the tilt of the column loudspeaker for a given nd where n is the number of loudspeakers in the column and d is the distance between each speaker.

For the example, suppose that the centre of the column can be placed 6.5 m above the ground, which is about 5.5 m above ear-level. The ratio of this height h to the length 1 is then 0.175. From fig. 3 one can get the length of speaker column as 1.5 m and the forward tilt as 15°.

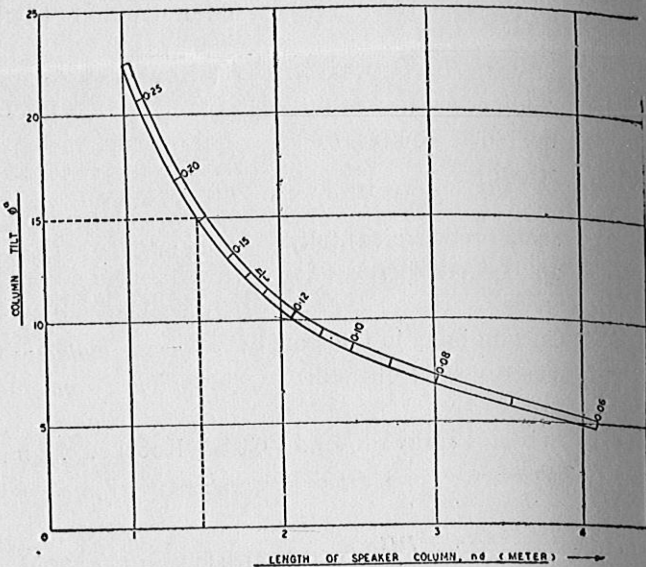

Fig. 3

Relation between the length or column loudspeaker and column tilt when h and l are known.

A microphone, preferably with a cardioid characteristics, a quality amplifier and a speaker column correctly designed and located, make a suitable combination for large or small indoor or outdoor requirements.

Illustration Examples

Consider a hall 3,000 cu. meters in volume accommodating 600 persons with a reverberation time of 1.2 seconds. The total absorption required is

$$A=\frac{0.16\times 3000}{1.2}=400 \text{ units (sq. meters).}$$

Of this total absorption, $0.46\times 400=184$ units (sq. meters) are provided by 400 occupants (two thirds of the total audience) and the balance of 216 units are required to be provided by the vacant seats, sound absorbing materials, plastered surfaces, wooden panelling on wainscot and floor cover on the aisles. Of these, 100 units may be obtained from 200 sq. meters of sprayed asbestos or perforated board on the rear wall having absorption coefficient 0.5 at 500-1000 c/s. The rest 116 units, should be provided by the vacant seats and the materials just mentioned.

References

1. Knudsen and Harris: Acoustical Designing in Architecture, pp. 182.
2. See Figs. 2 and 3 in CBRI Building Digest No. 39
3. Sound absorption coefficient of acoustical materials; Table 1-CBRI Building Digest No. 39.
4. Nickson A.F.B.: Acoustics and Amplifying Systems, "Architectural Science Review", Vol. 3 No. 1, pp. 8-14, March 1960.

There is a demand for short notes summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need, this Institute is bringing out a series of Building Digests from time to time and the present one is the 64th in the series. Readers are requested to send to the Institute their experience of adopting the suggestions given in this Digest.

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