BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE, INDIA

ACOUSTICAL PROPERTIES OF SOUND ABSORBING MATERIALS AND ROOM DESIGN

A notable feature in the design of public buildings is the greater attention now given to their acoustics. Acoustical design is to be carried out such that the highest standard of audibility and clarity are established within the buildings where satisfactory listening conditions are required. This Digest is concerned with the design of rooms in which the primary objective is clear communication from the source to a group of listeners.

Under normal circumstances, the sound travelling directly from a speaker (source) to a listener becomes unintelligible beyond a distance of 9 metres. Reinforcement of sound can generally be done by using different surfaces of the room as redistributing elements. For useful reinforcement, the sound which is reflected from different surfaces of a room should reach the listener within 30 milliseconds of the direct sound. In other words, the difference in the path between the direct and reflected sounds should not be more than 12 metres.

Sound have many different properties (like loudness and frequency) and these properties differ, to a significant degree, according to the type of sound generated at the source. The difference of levels, for example, from the loudest to the softest tones, is more in music than it is in speech, although the minimum level remains the same in both cases. Similarly, musical sound extends to a wider range of frequencies (30 Hz to 10,000 Hz) than does the sound of speech (500 Hz to 4000 Hz).

For the design of enclosures where good acoustics is absolutely necessary it is important to give sufficient attention to different factors which affect the quality of sound. Attempts have, therefore, been made in this Digest to throw some light upon the inter- action between different aspects of sound and the internal physical environment of the room.

Reverberation Time

A sound impulse takes some time to dissipate through gradual declination. It is important to know, the time taken by this decay for high intelligibility to the listener. This decay is measured in terms of the amount of time required for any sound impulse to decay to one millionth of its initial value. This is termed as the reverberation time (R.T.). It can be calculated from the following formula:

$$T = \frac{0.16V}{A}$$

where V = the volume of the hall in cu. metres,

T = the reverberation time in seconds, and

A = absorption units in sq. metres $= \Sigma S\alpha$

where α is the absorption coefficient of are a S. Thus reverberation time increases with increase in volume of the room and/or with decrease in the amount of absorption.

Values of reverberation time given in Table I may be used for design purpose.

Table I

Recommended Values of Reverberation Time

Activity	Optimum Reverberation Time (500–1000 Hz) in seconds.
1. Lecture, convocation & similar activities using sound amplification	0.6—1.0
2. Cinema	0.6—1.2
3. Drama plays	0.8—1.2
4. Chamber music	1.0—1.4
5. Orchestra	1.2—1.4

The volume per seat (person) is close to 4.2 cu. metres. A value of 5.7 cu. metres should not be usually exceeded.

Generally the designer makes a preliminary calculation of reverberation time when room volume and seating capacity have been established. This provides a rough estimate of the total absorption capacity that must be provided in the room for better audibility.

Sound Absorption

The sound absorption coefficient of a material is defined as the fraction of the incident sound energy absorbed by it. It depends on the nature of the material, on the frequency of the sound and on the angle at which the sound waves strike the surface of the material. For comparing the absorption capacity of different materials, a scale based on the concept of *Noise Reduction Coefficient* (NRC), is used. It is the average of the coefficients at four frequencies 250, 500, 1000, 2000 Hz.

Since the absorption coefficient of any material varies considerably with the angle of incidence of the sound waves, two types of measurements are normally carried out, one for normal incidence and the other for random incidence. The normal incidence sound absorption coefficient is useful for comparing the absorptivity of different materials and can be measured with a small sample of the material. The other measurement is done in a special chamber known as Reverberation Chamber in which sound waves strike the test sample from many directions simultaneously and therefore large areas of the sample are required. Generally the chamberc oefficients are higher than normal incidence absorption coefficients. The values of the absorption coefficients for different indigenous acoustical materials tested in C.B.R.I. are given in Table II and Table III.

The audience in a room provides absorption amounting to about 0.46 units (sq. metres) per person and this is nearly constant over the important frequency range. Curtains also provide good absorption. On the other hand concrete and masonary act as reflectors and have absorption coefficient less than 0.05.

Shape of the Room

A slightly concave rear surface is useful for deliberately providing some reinforcement of the sound reaching distant seating areas. But cylindrical or spherical enclosures focus the sound in particular areas and should, therefore, be avoided.

A pair of large parallel surfaces causes a single sound impulse to be reflected back and forth, the successive transits being heard as a series of pulsations called "Flutter echo" It is quickly damped out if either surface is sufficiently absorptive or irregular. There is usually no problem between a horizontal ceiling and the floor as the latter is generally broken up by furniture and audience.

Splayed hard surfaces (Fig. 1) at the sides of a stage and the proscenium opening are useful in reflecting sound to rear parts of the auditorium. A reflective surface close to the stage is, therefore, a good practice.

Seats in the room should be raked so that the heads of the persons in one row do not intercept direct sound to persons in the row behind. A clearance of, 10 cm should be provided between the sight lines (ear being in the same line as the eyes) from two consecutive rows.

To further increase speech communication in a room, it is essential to increase the strength of direct sound as compared to the reflected sound. This is achieved by introducing (Fig. 2) (i) a flat reflecting 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.

Reinforcement of Sound through Loudspeakers

As has been mentioned earlier, sound energy generally needs to be reinforced to reach the rear listeners. Rooms smaller than 1400 cu. m., if properly designed, should not need electronic reinforcement, for most speakers and most musical performances, but beyond this size, electronic reinforcement is usually desired for speech. Column type of loudspeakers offer some advantages over other systems. In this system, a number of loudspeakers are mounted 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 central speaker and decreases towards the end speakers.

The length and tilt of column loudspeakers 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 and h is the height of the column centre from the average 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 two consecutive speakers. As an example, let the centre of the column be chosen as 7.0 m above the ground and 6.0 m above the ear level (the ear level being taken as 1.0 m above the ground). The ratio of this height to the length l is then 0.20. From Fig. 3 one can get the length of speaker column as 1.3 m and the forward tilt as 17°.

Table II

* Normal Incidence Data for Absorption Coefficient

Sl. No.	Name of the Material	Manufacturer	Thickness (cm.)	Density Kg/m³	Absorption Coefficients 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC	Backing
1.	Sitatex - perforated 1600 (Standard)	M/s. Plywood Products Sitapur (U.P.)	1.9	—	.12	.17	.21	.66	.67	.68	.43	Rigid backing
2.	Sitatex-perforated Random (standard)	-do-	1.9	—	.12	.18	.26	.45	.48	.62	.34	,,
3.	Sitatex-perforated 964 (standard)	-do-	1.9	—	.08	.17	.28	.51	.54	.56	.37	,,
4.	Sitatex-perforated 1681 (standard)	-do-	1.9	—	.09	.15	.33	.54	.74	.76	.44	,,
5.	Sitatex (plain)	-do-	1.3	—	.13	.18	.21	.18	—	—	.18	,,
6.	Sitacore	-do-	2.5	—	.05	.11	.28	.40	.60	.43	.35	,,
7.	Sitatex-perforated 964 (White)	-do-	1.9	—	.07	.13	.23	.42	.66	.51	.36	,,
8.	Sitatex perforated 1681 (White)	-do-	1.9	—	.09	.15	.30	.57	.71	.66	.43	,,
9.	Sitatex-perforated 16C0 (White)	-do-	1.9	—	.08	.15	.28	.62	.70	.63	.44	,,
10.	Sitatex-perforated Random (White)	-do-	1.9	—	.09	.14	.28	.50	.52	.58	.36	,,
11.	Anil board	M/s. Anil Hardboard Bombay	1.3	—	.08	.13	.15	.22	.33	—	.21	,,
12.	Fibrosil	M/s. Indian Rockwool Co. (Pvt.) Ltd., Delhi-6.	5.0	96	.07	.16	.33	.66	.84	.92	.50	,,
13.	Fibrosil resin bonded slabs	-do-	2.5	—	.06	.10	.20	.46	.81	.95	.39	,,
14.	Lloyd board	M/s. Punj & Sons (Pvt.) Ltd. New Delhi-1.	2.5	240	.06	.25	.40	.79	.82	.80	.57	,,
15.	Fibreglass	-do-	2.5	80	.07	.11	.15	.33	.71	.92	.37	,,
16.	Spintex	-do	2.5	80	.09	.14	.22	.53	.88	.93	.45	,,
17.	Fibreglass crown wool	-do	2.5	32	.11	.14	.27	.35	.71	.90	.37	,,
18.	Spintex	-do	2.5	64	.18	.18	.52	.46	.86	.96	.55	,,
19.	Sample of Vermiculite Cem: Vem 1:6 Water : Cem 2:1	M/s. Newkem Products Corp., Bombay-14.	2.5	—	.12	.19	.21	.23	.26	.27	.22	,,

*Tested in the Acoustics Laboratory, Central Building Research Institute, Roorkee, India. More test results of other materials are available on request.

Table III

* Reverberation Chamber Data for Absorption Coefficient

Sl. No.	Name of the Material	Manufacturer	Thickness (cm.)	Density kg/m^3	Absorption Coefficients 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC	Backing
1.	Sitatex-perforated 1600 (standard)	M/s Plywood Products Sitapur (U.P.)	1.9	—	.05	.10	.52	.75	.80	.85	.54	Rigid Backing
2.	Sitatex-perforated random (Standard)	-do-	1.9	—	.05	.07	.56	.68	.80	.99	.53	,,
3.	Sitatex (Standard)	-do-	1.9	338	.05	.10	.61	.78	.91	.96	.60	,,
4.	Sitatex-perforated 964 (Standard)	-do-	1.9	—	.04	.07	.53	.75	.98	.99	.59	,,
5.	Sitatex-perforated 1681 (Standard)	-do-	1.9	—	.06	.09	.51	.82	.84	.99	.57	,,
6.	Sitatex-perforated 964 (White)	-do-	1.9	—	.04	.09	.51	.75	.91	.85	.57	,,
7.	Sitatex-White	-do-	1.9	384	.10	.18	.62	.78	.74	.69	.58	,,
8.	Sitacore	-do-	2.5	—	.05	.16	.41	.46	.70	.72	.43	,,
9.	Sitatex-perforated 1600 (White)	-do-	1.9	—	.06	.10	.45	.73	.74	.85	.50	,,
10.	Sitatex perforated 1681 (White)	-do-	1.9	—	.06	.07	.52	.91	.91	.92	.60	,,
11.	Sitatex-perforated random (White)	-do-	1.9	—	.06	.15	.63	.67	.76	.91	.55	,,
12.	Scrimmat Fibreglass	M/s. The Bombay Co. Pvt. Ltd. Wallace Street, Bombay.	5.0	80	.20	.62	.99	.93	.61	.42	.79	,,
13.	Unifrormly perforated Jolly Board	M/s. Anil Hardboard Bombay.	1.27	300	.06	.12	.55	.66	.67	.76	.50	,,
14.	Randomly perforated Jolly Board	-do-	1.27	300	.15	.18	.52	.58	.76	.58	.51	,,
15.	Fibrosil	M/s. Indian Rockwool Co. Ltd. Delhi-6.	.50	—	.40	.55	.90	.99	.99	.92	.88	,,
16.	Lloydwool Board (in bags of Jute)	M/s. Punj & Sons (Pvt.) Ltd., New Delhi-1.	2.5	98	.14	.26	.99	.99	.85	.93	.77	,,
17.	Spintex (Resin bonded)	-do-	5.0	40.5	.18	.69	.84	.90	.82	.73	.81	,,
18.	-do-	-do-	5.0	65	.36	.80	.96	.96	.94	.73	.91	,,
19.	-do-	-do-	5.0	65	.36	.75	.88	.90	.86	.73	.85	,,
20.	-do-	-do-	2.5	49	.13	.32	.82	.95	.96	.94	.76	,,
21.	-do-	-do-	2.5	49	.16	.41	.84	.96	.95	.92	.79	1" air gap
22.	-do-	-do-	5.0	49	.23	.58	.85	.96	.98	.94	.84	Rigid Backing
23.	-do-	-do-	5.0	49	.28	.66	.98	.97	.95	.94	.89	1" air gap
24.	Fibreglass Crown RB-Wool-100 (RB-1)	M/s.Fibreglass Pilkington Ltd., Bombay-1.	2.5	16	.18	.23	.54	.75	.85	.88	.59	Rigid Backing
25.	-do- -150 (RB-2)	-do-	2.5	24	.24	.30	.59	.78	.92	.98	.65	,,
26.	-do- -200 (RB-3)	-do-	2.5	32	.17	.23	.63	.71	.92	.92	.64	,,
27.	-do- -100 (RB-1)	-do-	2.5	16	.16	.28	.62	.83	.84	.78	.64	1" air gap
28.	-do- -150 (RB-2)	-do-	2.5	24	.26	.36	.67	.87	.91	.90	.70	,,
29.	-do- -200 (RB-3)	-do-	2.5	32	.23	.36	.86	.91	.91	.98	.76	,,
30.	-do- -100 (RB-1)	-do-	5.0	16	.25	.52	.79	.84	.91	.98	.76	Rigid Backing
31.	-do- -150 (RB-2)	-do-	5.0	24	.35	.59	.96	.98	.98	.98	.88	,,
32.	-do- -200 (RB-3)	-do-	5.0	32	.31	.61	.97	.98	.98	.98	.98	,,
33.	-do- -100 (RB-1)	-do-	5.0	16	.31	.55	.86	.87	.91	.98	.79	1" air gap
34.	-do- -150 (RB-2)	-do-	5.0	24	.31	.65	.98	.98	.87	.98	.87	,,
35.	-do- -200 (RB-3)	-do-	5.0	32	.31	.67	.98	.98	.94	.98	.89	,,
36.	Sound Deadening Quilt	-do-	2.5	—	.09	.29	.50	.71	.88	.89	.59	Rigid Backing
37.	Fibreglass Rigid Board	-do-	2.5	—	.16	.25	.65	.78	.89	.90	.64	,,

* Tested in the Acoustics Laboratory, Central Building Research Institute, Roorkee, India. More test results of other materials are available on request.

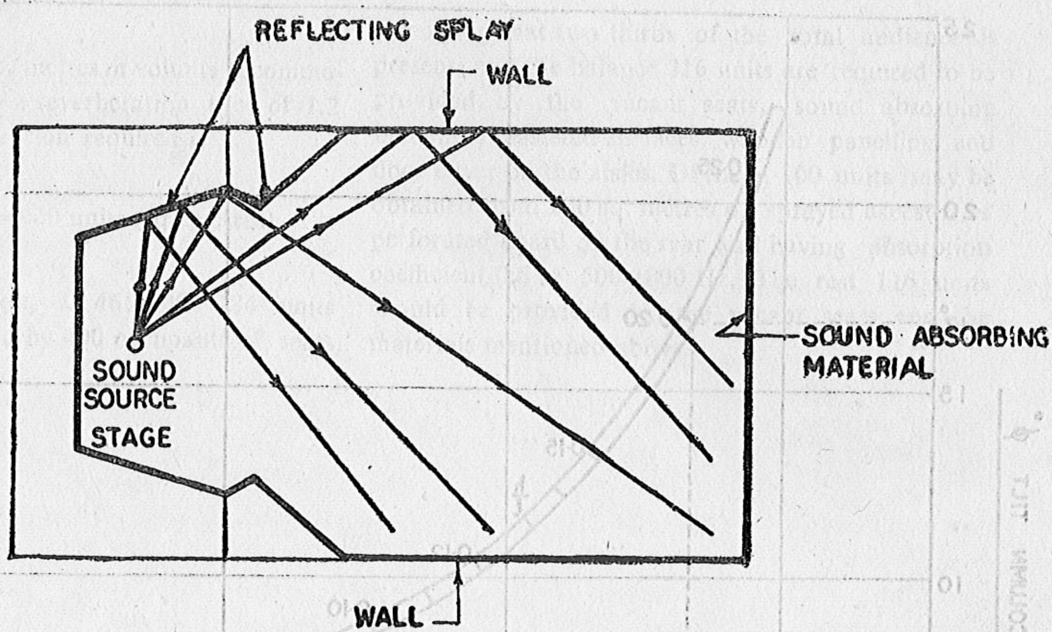

FIG. 1 PLAN OF RECTANGULAR HALL SHOWING USEFUL REFLECTIONS FROM THE WALLS PLUG AND STAGE INSETS.

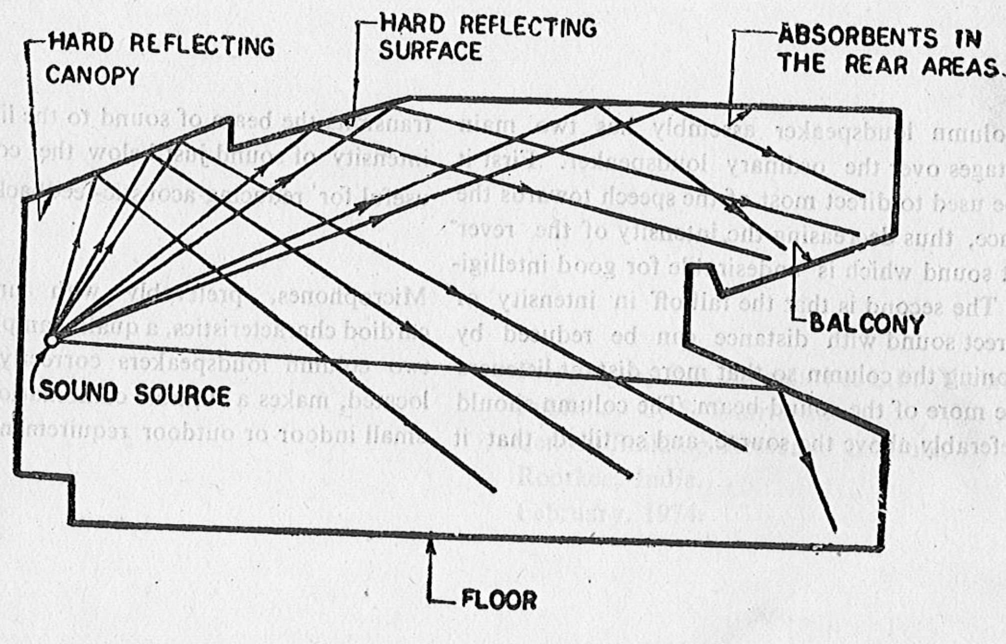

FIG. 2 LONGITUDINAL SECTION THROUGH A HALL SHOWING A CORRECT CEILING LAYOUT FOR USEFUL SOUND REFLECTIONS TO THE REAR SEATS. PATH DIFFERENCE BETWEEN THE DIRECT AND THE REFLECTED SOUND AT NONLISTENING POINT EXCEEDS 12M.

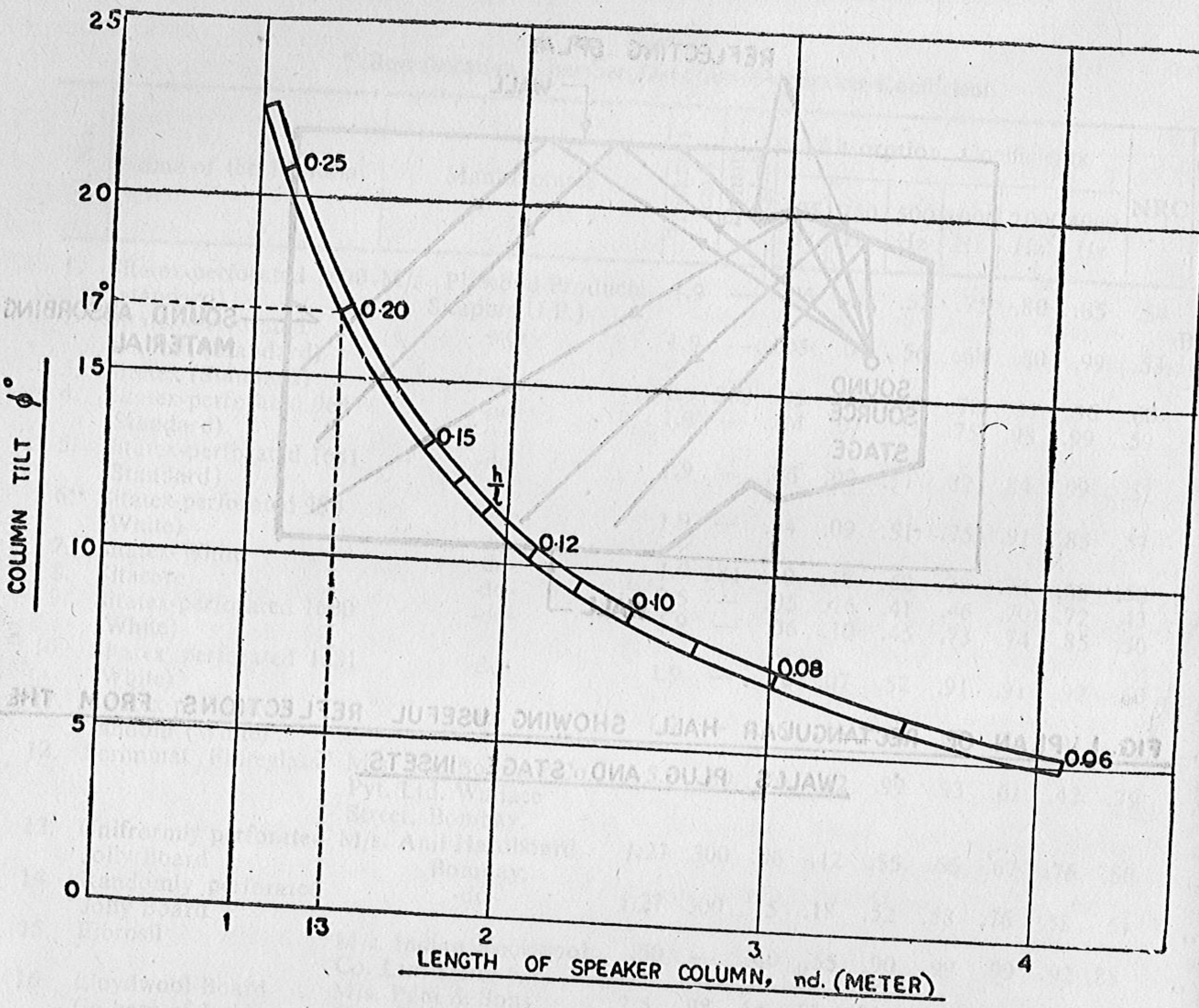

FIG. 3. Relation between the length of column loudspeaker and column tilt when h and l are known.

The column loudspeaker assembly has two main advantages over the ordinary loudspeaker. First it may be used to direct most of the speech towards the audience, thus decreasing the intensity of the reverberant sound which is undesirable for good intelligibility. 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. The column should be preferably above the source, and so tilted that it transmits the beam of sound to the listeners. The low intensity of sound just below the column is highly useful for reducing acoustic-feedback.

Microphones, preferably with unidirectional or cardiod characteristics, a quality amplifier and one or two column loudspeakers correctly designed and located, makes a suitable combination for large or small indoor or outdoor requirements.

Illustrative Example

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

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

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

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 107th in the series. Readers are requested to send to the Institute their experience of adopting the suggestions given in this Digest.

Prepared by P.S. Bhandari & L.B. Yadava
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