STUDIES ON QUALIFICATION OF THE ROOM FOR DETERMINATION OF SOUND POWER OF WOODWORKING MACHINERY

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CONTENTS

1. INTRODUCTION

1.1. Purpose and Significance

Recently, the problem on environmental pollution has become center of wide interest. In particular, there has been given much attention to the industrial noise problem as well as to the air pollution or the water pollution problem. In proportion as the industry has advanced, industrial machines also have been improved into efficient ones with a view to making products much more faster. In the woodworking industry, those intentions brought to heighten the rotation speeds of cutter blocks or saw blades of machines because wood materials were cut easier than other raw materials such as metals or plastics. And now, the rotation speed of the spindle setting knives or saws is from 3 000 rpm to 6 000 rpm, and the one of router machines, in particular, attains 20 000 rpm.[1] Therefore, the noise levels measured about those woodworking machines are excessibly high. (Research workers reported that they extended from 80 dB to 110 dB.[2][3]) And this quantity tends to go up exponentially as the revolution of the spindle increases.[4][5]

As was mentioned above, woodworking machinery is noisy, so that a prompt noise control is needed to them. However, sound pressure levels or noise levels which are the fundamental data are almost all measured at different positions in dissimilar circumstances, and thus it is difficult for us to compare them directly. The reason is that the sound pressure levels in itself is not a satisfactory quantities as it is dependent on the distance between the source and the observer as well as on the environment in which the measurements are made.

On the other hand, the sound power levels emitted by machines are essentially independent of the environment in which the data are obtained. The sound power levels are, therefore, to be preferred as they can also be used to compare to each other. The sound power levels, however, cannot be measured directly with any instrument, but be calculated from sound pressure levels with formulae (see Sec. 3.4). Thus we may say that the accuracy of the values of sound power levels generally depends on the measurement accuracy of the sound pressure levels. It will be thought that to heighten the measurement accuracy of the sound pressure level is to make desirable circumstances for the measurement of it, that is, to obtain the accurate free-field or diffuse- field, otherwise, to exclude the environmental factor by using the comparison method.[6)]

Though the ideal free field will be formed in broad and flat areas in outdoors such as grounds or fields where are not surrounded by any obstacle, such places cannot be given easily in practice. Even if these places can be got, we must, in the next place, have attention to disturbances against the measurement such as atmospheric phenomena (wind, rain, temperature, moisture, etc.) or background noises (the whisper of leaves, the song of birds, the noise of men or vehicles, etc.). Therefore, we usually practice the measurement of sound pressure levels in rooms. However, in fact, rooms may have different characteristics on acoustics, because they have different shapes, different dimensions or different finishes on their boundaries to each other. Especially, woodworking shops, which are often used for the place of noise measurements as the machine to be measured is situated in it, have strong features to them. Moreover, inside of it, many machines or raw materials are arranged besides the machine to be tested, and they often become obstacles against the sound waves radiated from the source. Therefore, we must, first of all, grasp the acoustic characteristics of the room to be used for the measurement.

It will be the best choice to use the ideal anechoic or reverberant chamber. But, it is thought to be a troublesome job for the makers or users of the machine to remove the heavy and large one from factory-, or woodworking shop-rooms and to situate it in those test chambers for the noise measurement over and over again. Even if they could do so, it might be actually difficult for them to have those complete test chambers as it would cost a lot of money for constructions. we need not to have those chambers, but it is also true that we will not get the gratifying results in an ordinary room even if the data supplied for calculation of the sound power is increased a few numbers.

In this study, the author aimed to give the better space for the noise measurement around the machine to be tested. To practice this, the built-up of some new test rooms which were able to be given in a common room with the ready manner was planed out and examined.

Particularly, in this study, great emphasis were put on the side of test environments.

1.2. Past Studies

It may be from the mid 1950s that research works on noise problems of woodworking machinery had appeared to give some solutions in good earnest. In this field, it were worthy of notice that the works on planing machine noise by G.Pahlitzsch and E.Liegmann[4], and B.Thunell[5], and the work on circular saw machine noise by G.Pahlitzsch and W.Meins[7]. These papers gave much contribution to later investigations on this field. Various research workers had given valuable studies on woodworking machinery noise problems not only in foreign countries, but also in Japan really in the 1960s. (Results of them were summarized by H.Sugihara[8], according to the progress of investigations in this field.) But, there were almost no studies on problems of measurement fields of machinery noise or on methods for measurement of it. For, research workers need not have attention to the test environments or the method for measurements as far as the data that they got in their manner are not to be compared to each other. Those results are improper in the case that they want to compare with other worker's data. Measurement results must be given according to some standards for noise measurement, or must be used for the calculation of sound power of the source. In order to give comparable data, following two criterions are worthy of notice: "Test Code for Evaluating the Noise Emission of Woodworking Machinery," by WMMA[9], and JIS B 0114-1976[10]; "Measuring Method of Noise Emitted by Wood Working Machinery," by H.Sugihara[11] and et al.

Studies on the test environments for the sound measurement, or on the measurement methods of sound pressure have almost all been given by acoustitians. In acoustics, especially in room acoustics, two quantities are needed to describe the acoustic conditions in rooms, that is, reverberation time and sound-absorption coefficient. The concept of these two quantites was given by W.C.Sabine.[12] Since then, there has been given theoretical considerations about the relationship between above two quantities by various workers.[13][14][15]

It is well known that the total sound field of the room is described by so-called "Beranek's formula".[16] This formula is led on the following assumption; the total sound field within enclosure is produced by the energy density of the direct field, and by that of the reverberant field. And then, there is a certain relation between the energy density and the sound pressure. The applicability to the practical use of this formula which gives the sound pressure distribution of the room was examined by Y.Ogawa.[17]

The sound field in the anechoic and in the reverberant room falls on the case that the reverberant sound field term or the direct sound field term of the "Beranek's formula" was neglected. Results of studies on various problems risen at the construction of these special rooms have been arranged in "Noise and Noise Control, Volume.1, Chapter 4" by M.J.Crocker and A.J.Price[18] into details. D.A.Bies[19] examined the uses, the limitations and the possible tests for facilities of an anechoic or a reverberant room.

International Standards Organization (ISO) has published six standards 3741-3746[20][21][22][23][24][25] outlining different methods of sound power determination. The first three standards deal with measurements in a diffuse field while the last three are for free field environment. These standards are classified into three sections; precision, engeneering and survey methods. ISO standards have an agreement with the measurement accuracy for each method, and that is novel in standards.[26] In International Conference on Noise Control Engineering 1978, a few works[27][28] on the measurement of sound power of the source according to these ISO standards were reported.

Many experiments and results on noise measurement problems were referenced for the determination of these standards. In them, researchers on acoustics seemed to have much interest in the field of measurements in reverberant rooms, and in situ measurements.[29]

D.A.Bies[19] said about the directivity of the source which could be measured only in the free field conditions (or in the anechoic rooms) as follows: "For the purpose of noise control, information about directivity may be reasonably well known from other sources or it may be unimportant. Thus, there are many instances in which the measurement of sound power alone is quite sufficient, and information about the source's directional properties is of little or no concern." P.K.Baade,[30] also, commented to the free field measurement as follows: "Measurements in the free field provide not only acoustic power spectra but also directivity information. The facility and test effort, however, are relatively costly and hard to justify since directivity information in usually not needed." These two comments seems to justify the unnecessity of usual use of free field conditions.

On the measurement problem of sound power in reverberant fields, acousticians were especially concerned to the diffusion[31] in the room caused by the excitation of pure tone or very narrow band noise. Because the number of normal modes of vibration in the room decreases as the frequency of the sound emitted becomes low, there could not be given good diffusion in those frequencies, especially in case of pure tone or narrow band noise. And so, the output of the source could not be pronounced exactly in lower frequencies.[32][33] For the improvement of diffuseness in the reverberant rooms, researches on rotational diffusers were studied by D.Lubman,[34] C.E.Ebbing,[35] T.J.Schltz[36] and et al.

Another subject that they had been interested in was to make noise measurements of machines in situ.[37][38][39] (By "in situ" is meant that the machine is "in the natural or original position.") This subject would be important to the field of the noise measurement on woodworking machinery, because these machines are relatively large and heavy and those are not so easy to be moved from their original places.

Subjects on the determination of sound power of the noise source are almost all concerned to the measurement in the anechoic or the reverberant room. In them, a few works are seen on the determination in the ordinary rooms such as the factory, the office. For example, R.J.Wells and F.M.Wiener[40] reported the results on the determination of sound power by comparison methods using the reference sound source in ordinary spaces. But, one needs the reference sound source or the equivalent source the sound power of which is known, when one use this comparison method. Therefore, this method would be equal to the free-field measurement method or the reverberant-field measurement method finally, if one has not been given any sound source to be referenced.

And more, J.B.Moreland[41] showed the same method as was used in this study for the measurement of sound distributions, though the theme was another. The result presented by him was referenced as one of the few examples that were measured in the ordinary room space.

1.3. Outline of the Study

As was stated in above section, various studies have been given on problems of the sound power determination. But very few studies have existed on the measurement in ordinary rooms or ready test rooms. It seems that the study on the noise measurement in those environments is important. For, almost all measurements are practiced in such acoustically undesirable environments and therefore results measured in those test environments have not all utility when they are used for calculation of sound power.

This study was begun for the necessity of the recommended test room that was constructed for the improvement of the test environment with ready manner and with low costs.

In this section, the outline of this study is summarized briefly.

In chapter 2, problems on the measurement of the sound pressure in the common room for the determination of the sound power were revealed, and the necessity of new environment for noise measurement test to be able to give more desirable results is pointed out. For the purpose of getting useful environment for tests, some special test space or rooms were built up with easy manner in the original room, that is, in the woodworking shop-room, and acoustic characteristics of those environments were investigated.

In section 2.1, the woodworking shop-room was tested for an example of the common rooms for noise measurements. From the measurement results of sound distribution using some woodworking machines as the sound source, it was pointed out that the undesirable wave forms of sound pressure levels on distributions were seen in the room. This phenomenon was investigated more carefully using architectural acoustical methods, and the necessity of the construction of desirable test rooms was suggested.

In section 2.2, the results of the measurement in the space surrounded with two kinds of cloth curtains chosen along above demands were described. This test space had not so large sound absorption, and was not so completely isolated with outer space, i.e., the woodworking shop room space, it could not become the useful environment for the noise measurement.

Section 2.3 dealed with the acoustic characteristics of the semi-anechoic test room whose walls and the ceiling were made of woodfiber mats which were the materials of semi-hard board. This porous materials have larger absorption than cloth curtains used in previous section, so that, the space surrounded with this absorptive materials became more anechoic than that surrounded with cloth curtains. But as the room had the smaller volume, some problems were risen in it to the low frequency sound. And more, the floor of the test room (it was not covered with woodfiber mats as the machine had to be set on it) prevented the reasonable distribution of the sound pressure levels in high and narrow frequencies, too.

Section 2.4 described on the acoustic characteristics of the reverberant test room which had lauan plywoods (7-ply, a thickness of 21 mm) for boundary walls and a ceiling. And more, in section 2.5, results with the installation of diffuse equipments, i.e., thin aluminum plates to cover the wall and hard board panels to be suspended in the room space were discussed, because this reverberant test room had the necessity to have much diffusion on the lower frequency sound or narrow band noise.

In chapter 3, discussions were done with the results of the sound pressure level measurement of the woodworking machinery used in previous special test rooms. And then, the sound power levels of these machines were calculated at each other environment, and compared. And last, results were discussed in details and the utility of these special test rooms readily made according to the aim of this study were qualificated.

Conclusions were summarized in chapter 4.

The measurement equipments and the measurement techniques used in this study were dealed in Appendix.

2. QUALIFICATION OF TEST ROOMS CONSTRUCTED FOR NOISE MEASUREMENT

2.1. Sound Field in Common Room--a Woodworking Shop-room

2.1.1. Introductory remarks

The sound power determination of the noise source is normally performed in the room where it--the machine--is situated. (The machinery source may be altered to the position where the effect of reflections from walls or other obstacles is not caused, if it can be removed from its original space.) Rooms used for the test, therefore, are almost all factory spaces, woodworking shop spaces and so on. However, it is doubtful whether the sound pressure in these rooms distribute theoretically, that is, the sound pressures measured are same as that calculated from so-called Beranek's formula[16] or not. So, it is not right to apply JIS Z 8731-1966[42] to the noise measurement. The reason is that the item 2.3*, or 7.4* of this standard means that the point to be observed must be in the free field.

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*Item 2.3.: Rooms must have larger dimensions compared with that of the sound source or the distance between the source and the observer.

Item 7.4.: (3) Large machines or equipments (whose largest dimensions are above 50 cm)...the distance of measurements must be at least 100 cm from the surface of them.

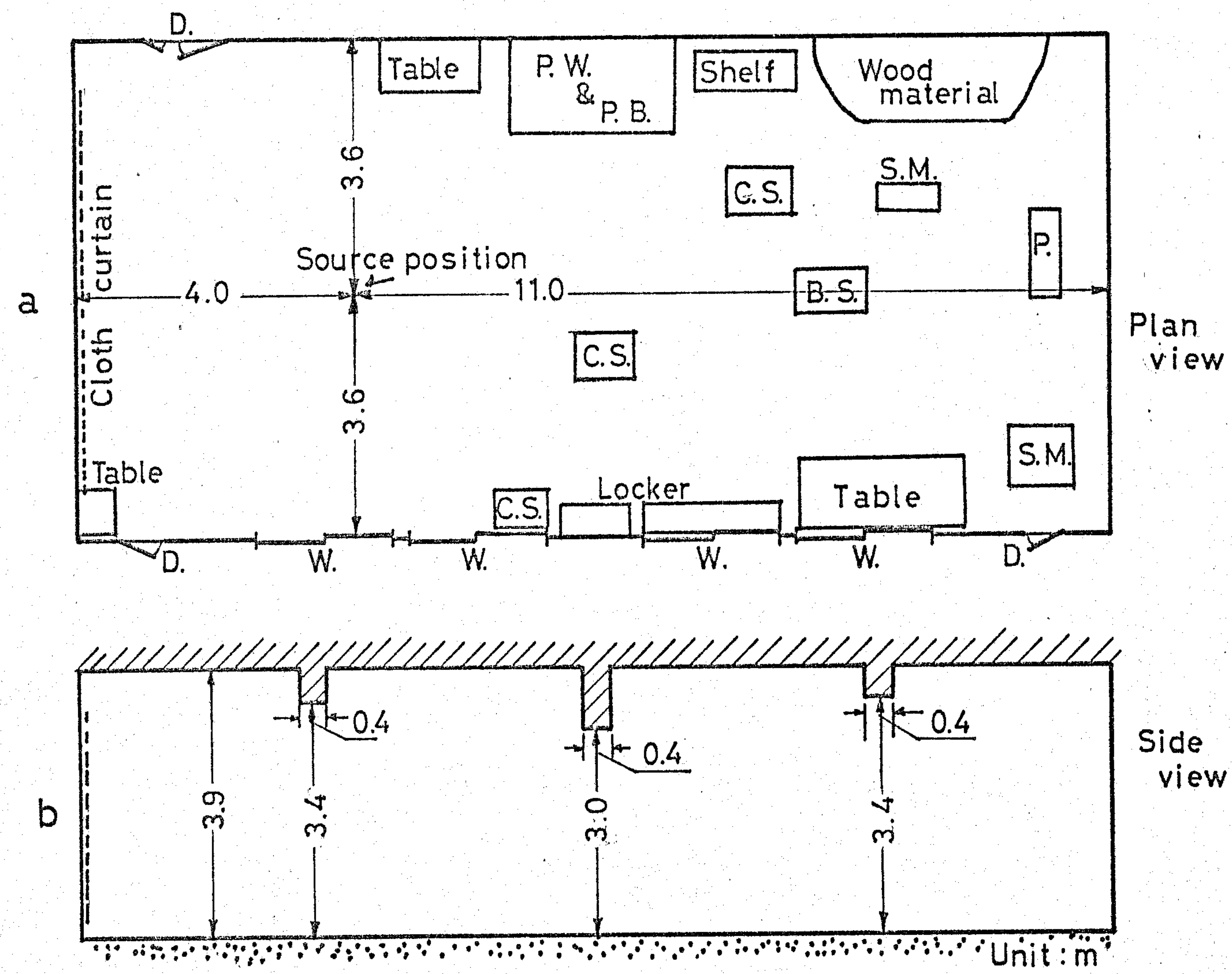
If the room space is not in the free field condition, it is not suitable to measure the sound pressure level from the source in it. And therefore, if such room is the only place given for the measurement, it is necessary for us to make it more preferable place for the measurement by any means.

In this section, the acoustical characteristics of the woodworking shop-room, which is one of the common test environment, are discussed in detail through following tests,

- the sound distribution measurement using some woodworking machines as the source,
- the sound distribution measurement of 1/3-octave band noise filtered from broad band random noise generated by the random noise generator and radiated from an isotropic sound source,
- the reverberation-time measurement of the room.

2.1.2. Measurement of sound pressure level from woodworking machinery

The plan and side views of the woodworking shop used for the sound pressure measurement were shown in Fig. 2-1-1 a,b. Dimensions of the room are 7.2 m (width) by 15.0 m (length) by 3.9 m (height). The volume of this room is approximately 420 m^3, and its surface area is 390 m^2. Boundary walls are made of concrete; the floor is finished with mortar, and the ceiling has the face of woodwool-cement panel. There are four grass windows (1.26m x 1.72m x 4) and two wooden doors (1.85m x 0.96m x 2) on the north side wall, which is the under side



B. S. : Table band saw
C. S. : Circular saw bench
D. : Wooden door
P. : Planer
P. B. : Particle board
P. W. : Plywood
S.M. : Sanding machine
W. : Window

Fig. 2-1-1 The plan and side views of the woodworking shop.

wall of Fig. 2-1-1 a. (This side wall is designated as "B" in this report.) There hangs the cloth curtain (2.95 m by 6.8 m, a thickness of 10mm), which is made of felt and tent cloth, on the front of east side wall, and which is the left side wall of Fig. 2-1-1 a. (This side wall is denoted by "A".) There is one wooden door on the left of south side wall, which is the above side wall of Fig. 2-1-1 a. (This side wall is denoted by "D".) The west side wall, which is the right side wall of Fig. 2-1-1 a, and is designated as "C", has not any window or door. These conditions of side walls are illustrated in Fig. 2-1-2.

Directions that the sound pressure levels are measured are indicated by A,B,C,D or A-B,B-C,C-D,D-A, and these are given according to above four side wall's symbols. For example, direction A is the one that comming right to "A" wall from the sound source with parallel to the floor. Direction A-B is the one that comming right to the edge formed by "A" and "B" walls from the sound source with parallel to the floor (see Fig. 2-1-3).

Woodworking machines used as the sound source are a hand feed planer, a single surface planer and a circular saw bench. These are specified in Appendix.

When a hand feed planer is used as the sound source, measurement directions are slightly different from others, and those directions are designated as a,b,c,and d, as the cutter-head of the planer is set on the frame with the slant of 10 degrees. Therefore, directions a,b,c, and d are different from A,B,C,and D by 10 degrees. These directions are illustrated in Fig. 2-1-4.

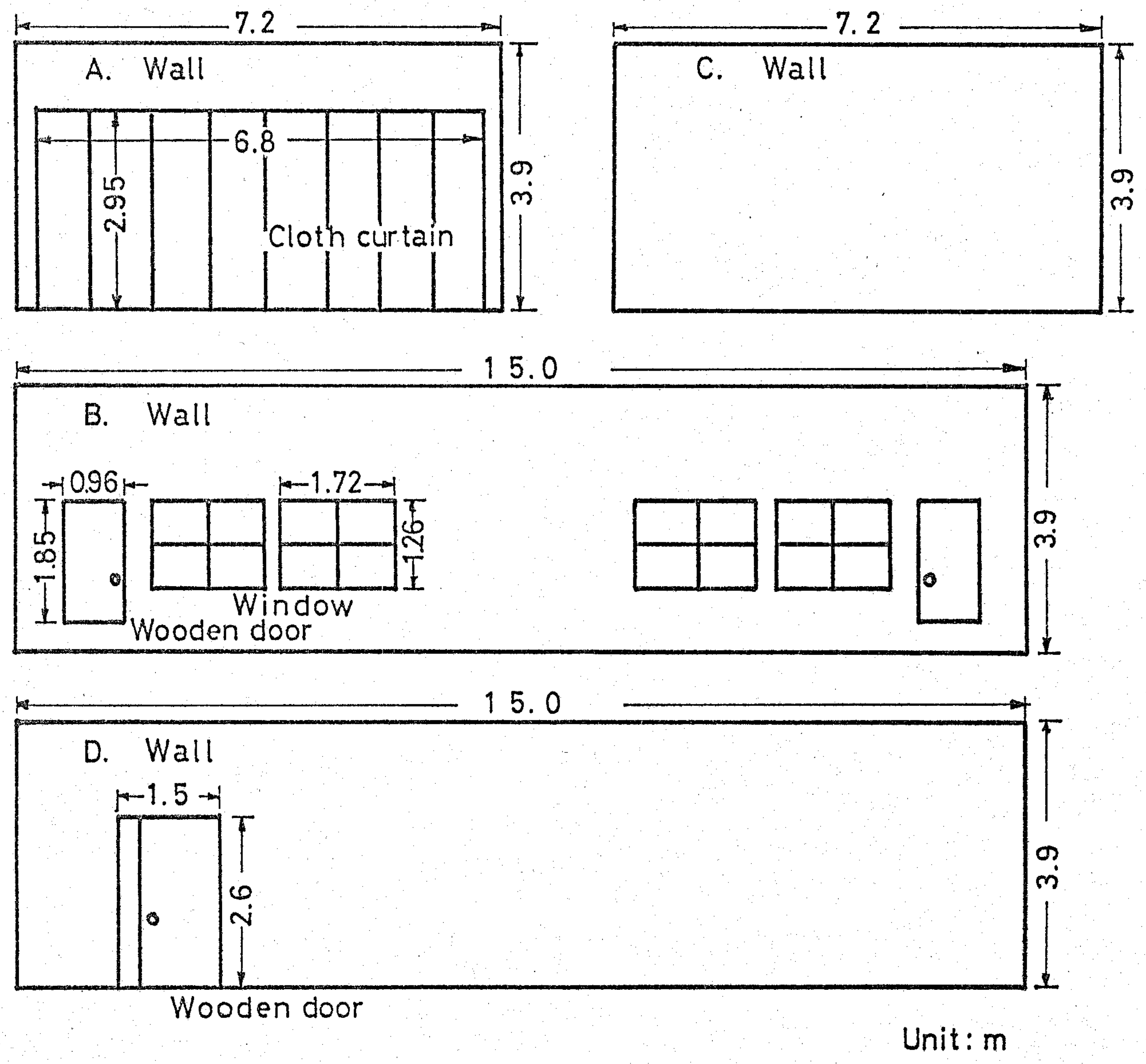


Fig. 2-1-2 The conditions of the side walls (side view).

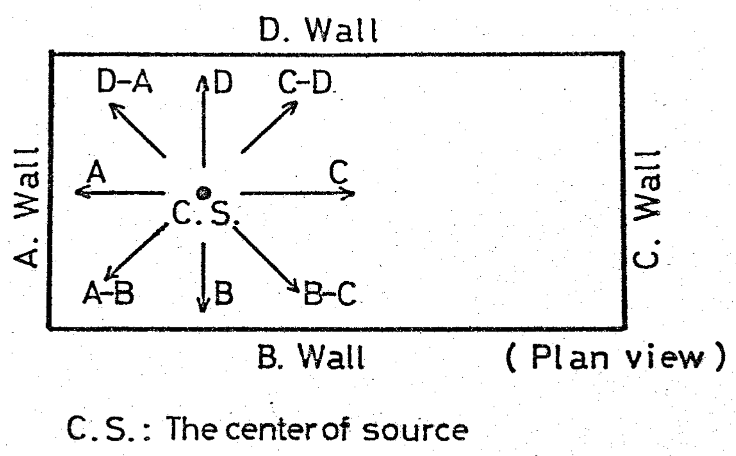


Fig. 2-1-3 The measuring directions and the symbols. The microphone was traced through lines with parallel to the floor in these directions.

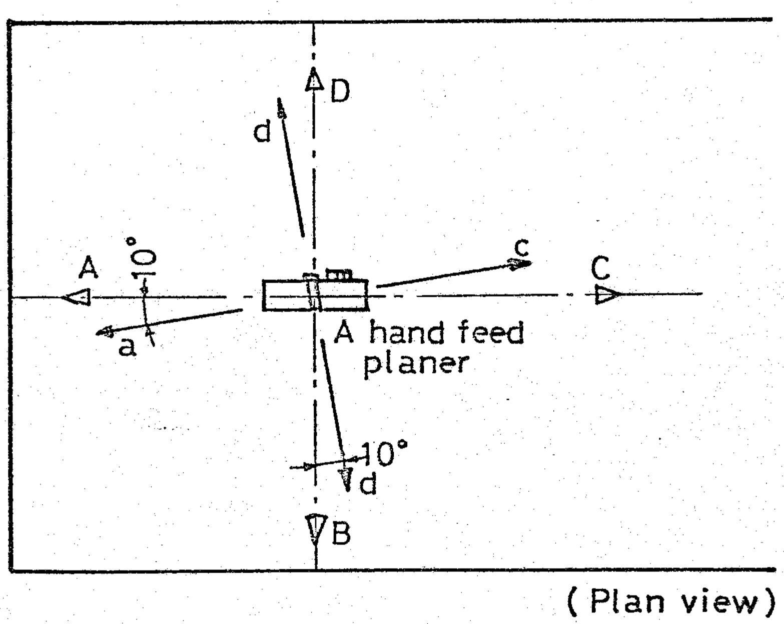


Fig. 2-1-4 The measuring directions in case of the hand feed planer source. The cutter-head of it was attached to the frame with a slant of 10 deg.

Hand feed planer noise

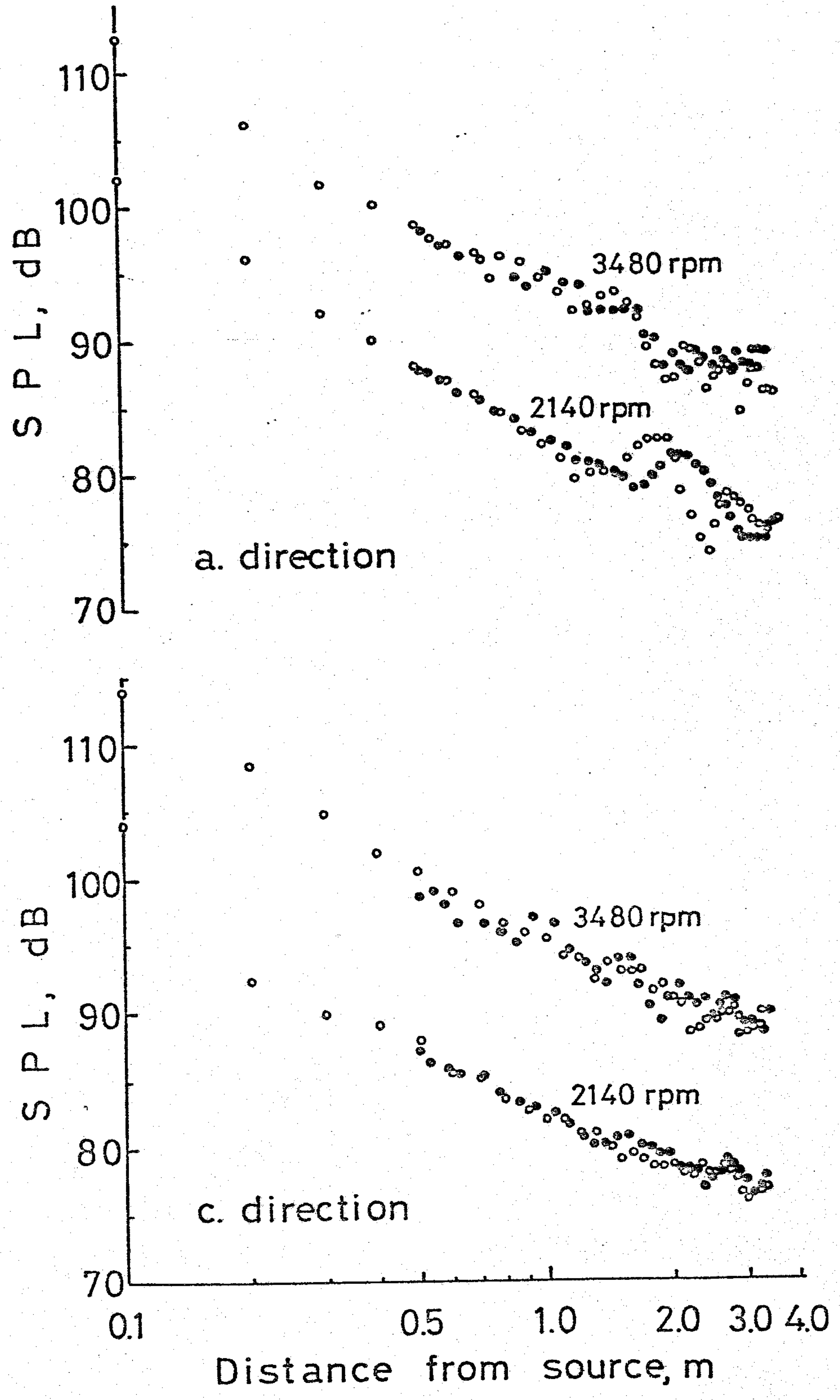
The sound pressure level (SPL) versus the distance from source are seen in Fig. 2-1-5. The cutterhead of the machine is rotated with 2140 rpm and 3490 rpm. This cutter-head (Diameter: 200 mm) has eight slots for setting knives. In the experiment, two slots symmetric with respect to the axis are opened and others are covered with plastic cases (cutter knives are not attached in the test, see Fig. 3 in Appendix). The height of the microphone is 1.0 m and 1.5 m from the floor, and SPLs measured at the height 1.5 m are plotted with the distance direct from the source. The horizontal axis of Fig. 2-1-5 is a logarithmic scale.

Single surface planer noise

The single surface planer used for the experiment is a low-noise-type machine, which is covered with casting or thin steel plates except the infeed, the outfeed, and the duct openings (see Appendix). The cutter-head (Dia.: 105 mm, Length: 400 mm, The number of cutter knives: 3) is operated by the rotation speed of 5050 rpm. The machine was set on the floor under the condition that the infeed opening was faced to "A" wall. Results were shown in Fig. 2-1-6. The horizontal axis of this figure represents the distance from the source surface on a logarithmic scale. The height of the microphone is 0.9 m from the floor.

Circular saw noise

A circular saw which is set up on the spindle of the


110
100
90
80
70
S P L, dB
3480 rpm
2140 rpm
a. direction
110
100
90
80
70
S P L, dB
3480 rpm
2140 rpm
c. direction
0.1
0.5
1.0
2.0
3.0
4.0
Distance from source, m

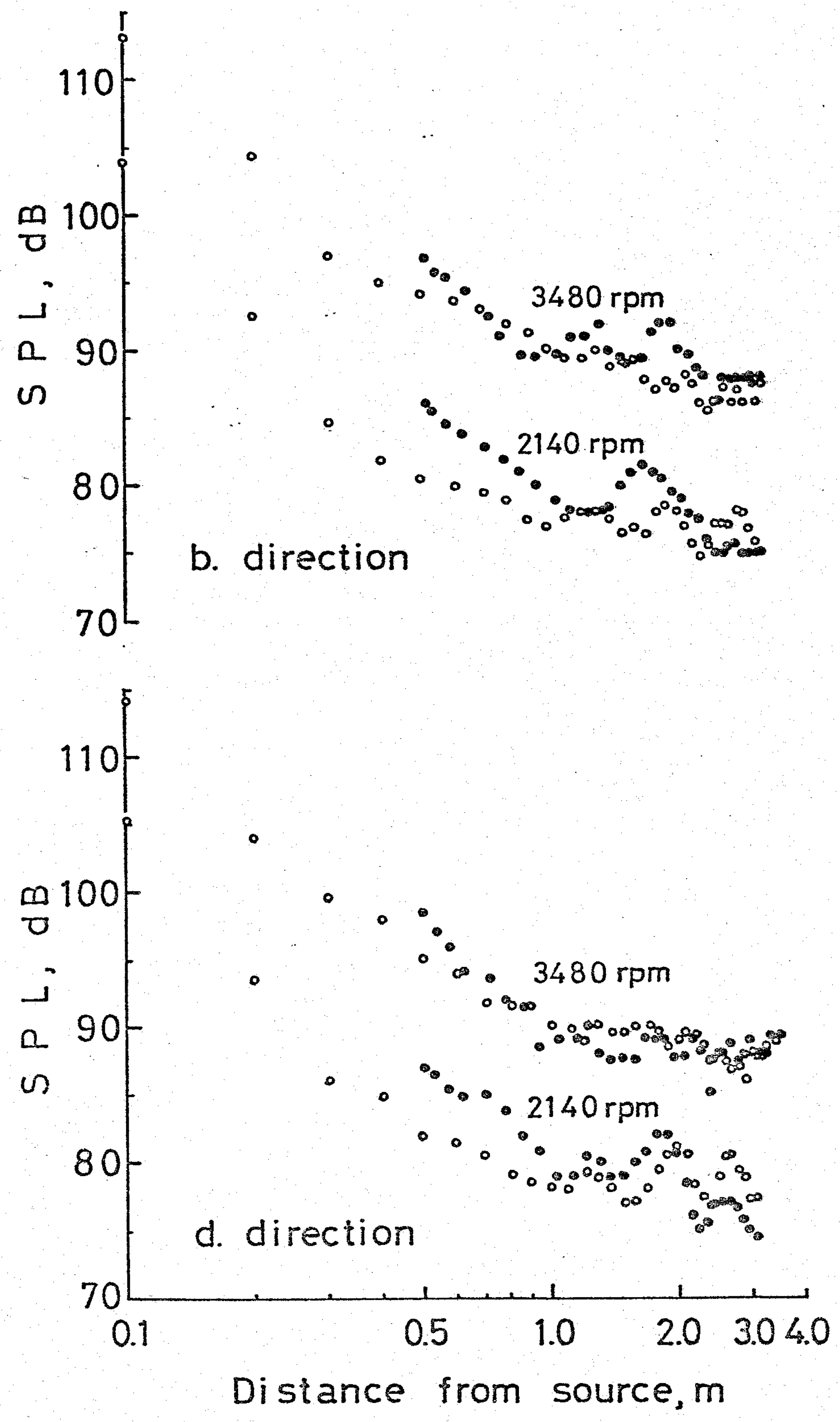


Fig. 2-1-5 SPL versus distance from source. The room was excited by hand feed planer noise.

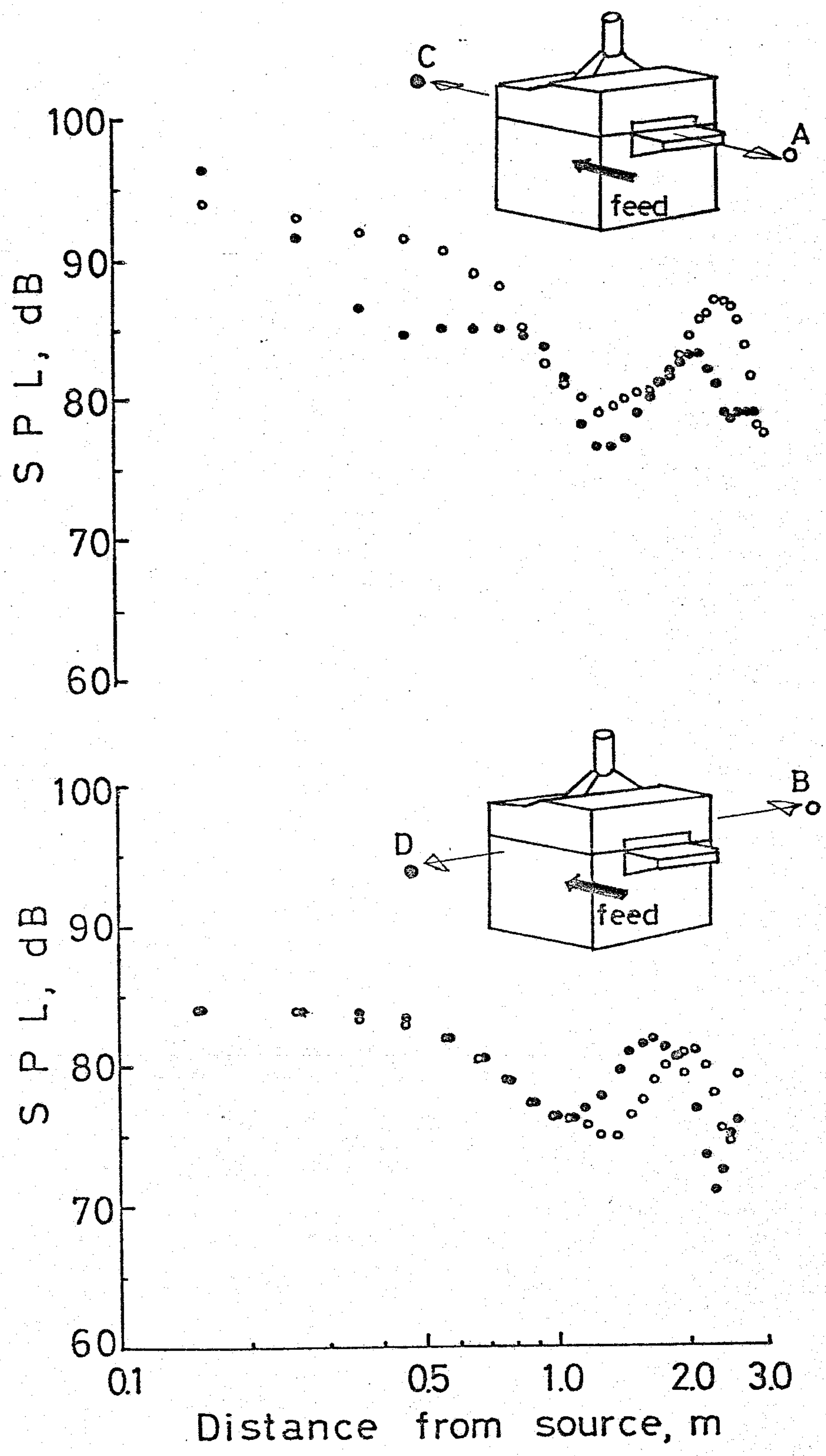


Fig. 2-1-6   SPL versus distance from source. The room was excited by single surface planer noise.

machine is a miter saw whose diameter is 255 mm and the number of saw teeth is 100. Measured results are seen in Figure 2-1-7. The height of the mic. was 0.9 m from the floor.

It is found that the theoretical decrease of sound pressure level following inverse square law is not caused in the field about one meter distant from the source in the woodworking shop-room. In particular, when a hand feed planer or a single surface planer is used as the sound source, SPLs take the wavy-formed distribution to the distance from source. This wavy distribution is thought to be caused by low frequency sound components,[*1] because they are obviously seen in the case of planing machine noise that is composed dominately of lower frequency spectrums. (Spectra of above machinery noises are shown in Figs. 2-1-8, 2-1-9 and 2-1-10.)

2.1.3. Acoustic characteristics of the woodworking shop-room

The value of sound-absorption in the room must be known if the theoretical investigation is made on the sound distributions in the room in obedience to "Beranek's equation". It is given from the reverberation time measured in the room using the Sabine equation.[*2]

The reverberation times (T) and the total sound-absorptions ($A = S\bar{\alpha}_{sab}$, S is total surface area of the room, $\bar{\alpha}_{sab}$ is average Sabine absorption coefficient) of this woodworking shop-room are shown in Table 2-1-1.

The distance at which the direct and reverberant sound levels becomes equal is given from following two equations,

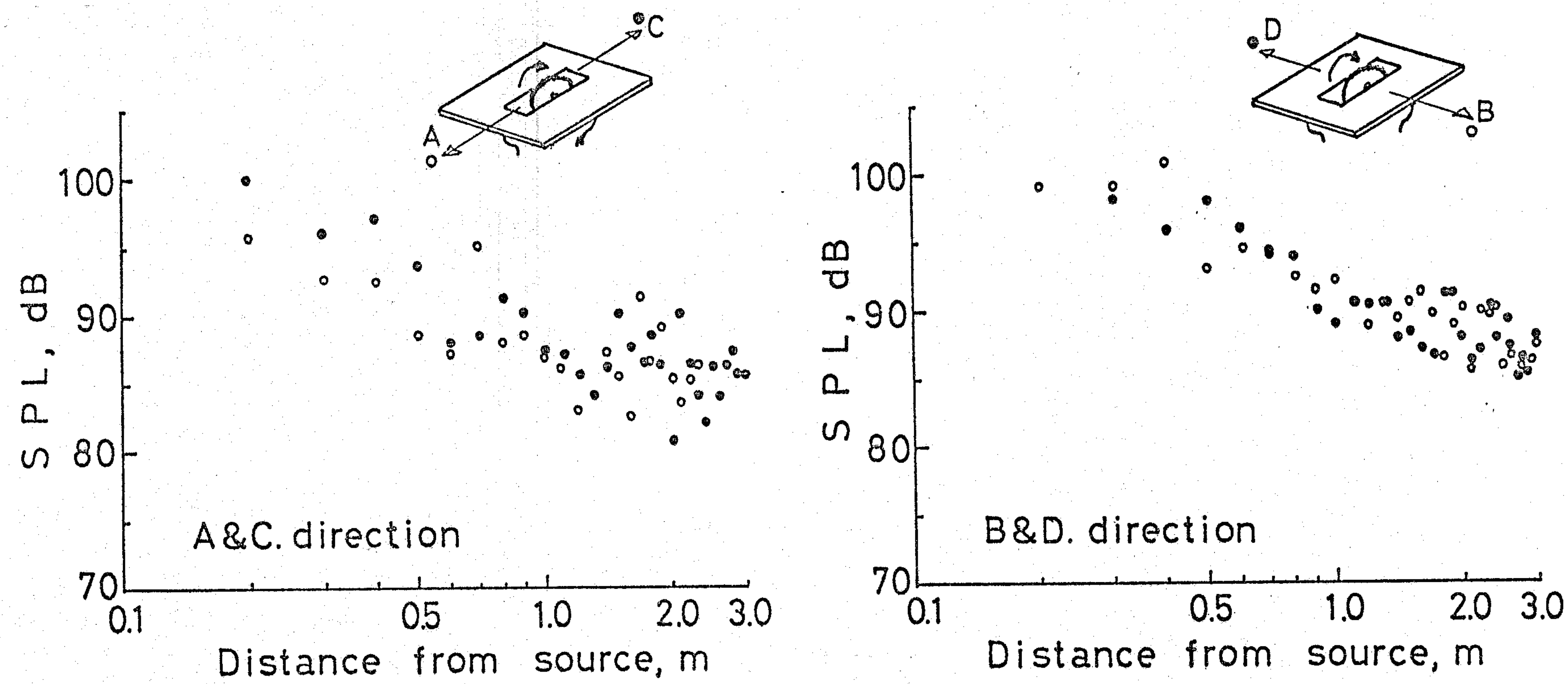


Fig. 2-1-7 SPL versus distance from source. The room was excited by circular saw noise.

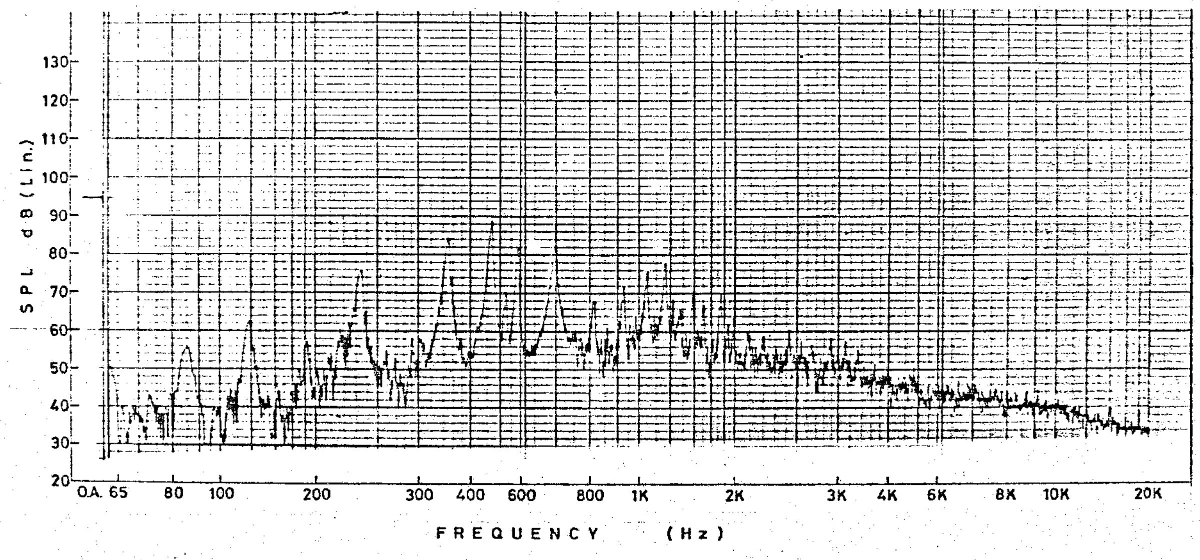


Fig. 2-1-8 Constant percentage (1%) frequency spectrum of hand feed planer noise (in a case of the rotation 3480 rpm).

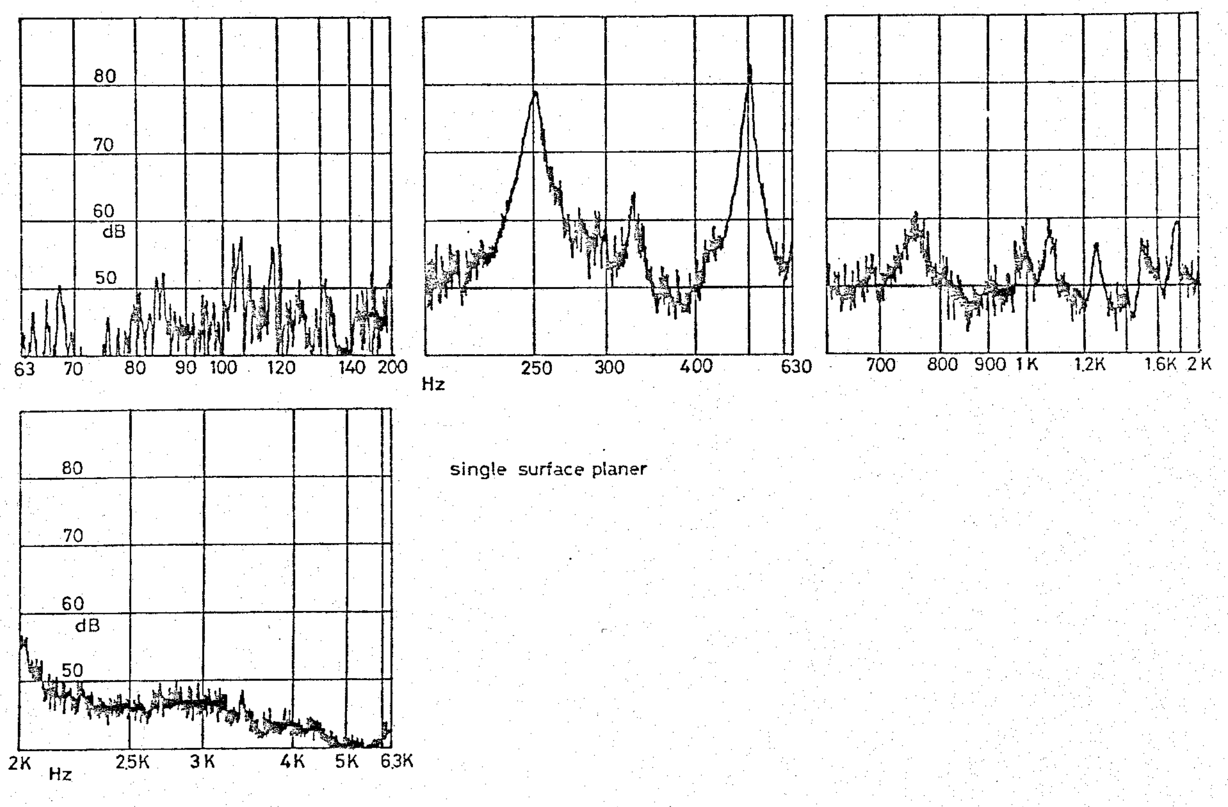


Fig. 2-1-9 Constant percentage (3%) frequency spectrum of single surface planer noise.

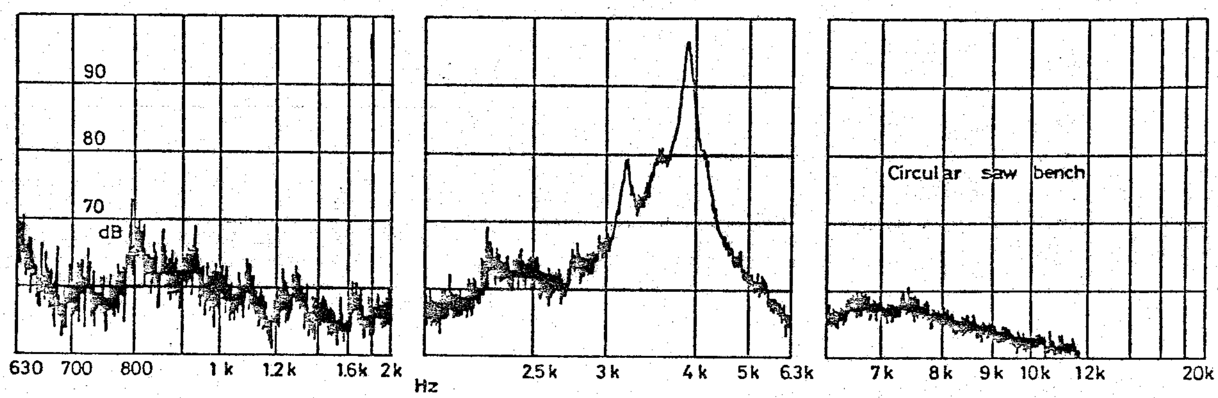


Fig. 2-1-10 Constant percentage (3%) frequency spectrum of circular saw noise.

Table 2-1-1 Reverberation time (T) and total room absorption (A) of the woodworking shop-room.

C.F.*1	T*2 (sec)	A*3
O.A.	1.0	67.2
125 Hz	1.4	48.0
250 Hz	0.9	74.7
500 Hz	0.8	84.0
1 k Hz	0.8	84.0
2 k Hz	0.6	112.0
4 k Hz	0.5	134.8
8 k Hz	0.4	168.0

*1. One-third octave band center frequency.

*2. The average reverberation time of several numbers of data shown as follows; 125 Hz, 250 Hz...20, O.A., 500 Hz...15, 1k Hz, 2k Hz...10, 4k Hz, 8k Hz...5.

*3. This value was calculated with the aid of Sabine equation. See Sec. 2.1.3 note.

Footnotes

*1 For a rectangular room a simple relationship exists between the room dimensions, l_x, l_y and l_z, and the frequencies corresponding to the normal modes of vibration of the room. This relationship is

$$f = \frac{c}{2} \left[\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_z}\right)^2 \right]^{\frac{1}{2}}$$

where

n_x, n_y and n_z = integers, 0, 1, 2,...

l_x, l_y and l_z = dimensions of the room along axis, m

c = speed of sound, m/sec.

And the number of normal modes, N, below a particular frequency, f, is given by

$$N = \frac{4\pi V f^3}{3c^3} + \frac{\pi S f^2}{4c^2} + \frac{Lf}{8c}$$

where

V = volume of the room, m^3

$S = 2\,(l_x l_y + l_y l_z + l_z l_x)$, the total surface area of the room, m^2

$L = 4\,(l_x + l_y + l_z)$, the sum of the lengths of all the edges, m

N = number of normal modes.

On differenciating above equation with respect to f one obtains an expression which yiels an approximate value for the number of modes, ΔN, in the band of frequencies, Δf, which is centered on f,

$$\Delta N = 4\pi V\left(\frac{f}{c}\right)^3 + \frac{\pi f}{2}\left(\frac{f}{c}\right)^2 + \frac{L}{8}\left(\frac{f}{c}\right)\ \frac{\Delta f}{f}$$

From above two equations, one could recognize that the lower the frequency and the narrower the bandwidth, the fewer the number of normal modes. Therefore, the woodworking shop-room would have filled by only few normal modes when it is excited by lower frequency noises such as planing machine noises. And thus, the sound pressures would distribute wavy with the wave-forms of few modes of vibrations excited in the room.

*2 The Sabine equation is represented as follows, that is,

$$T = \frac{0.16\ V}{S\ \bar{\alpha}_{sab}}$$

where

V = room volume, m^3

S = total surface area of the room, m^2

$\bar{\alpha}_{sab}$ = average Sabine absorption coefficient for the whole room

$S\bar{\alpha}_{sab}$ = total absorption in sabins (m^2),

T = reverberation time, sec.

that is,

$$p_D^2 = \frac{W \rho c Q}{4 \pi r^2}$$

and

$$p_R^2 = \frac{4 W \rho c}{A \ (= S\bar{\alpha}_{sab})}$$

where p_D^2 is mean square direct sound pressure

p_R^2 is mean square reverberant sound pressure

W is sound power

ρ is density of the acoustic medium (usually air)

c is speed of sound in the acoustic medium

Q is directivity factor of the source

r is distance from source.

As

$$p_D^2 = p_R^2$$

so,

$$r = (Q \cdot S \bar{\alpha} / 16 \pi)^{\frac{1}{2}}$$

is given. The distance r is sometimes called the critical distance or the Radius of Reverberation.[43)]

In the woodworking shop room, it is calculated that r is made to 1.2 m at frequency 250 Hz supposing Q = 1. This value supports that results measured within regions at

distance about one meter from source are affected by sound waves reflected from boundaries.

Characteristics of this woodworking shop-room concerning the distribution of sound pressures are investigated in detail with random noise. Random noise (white noise,* pink noise:* ordinary used in architectural acoustics) is generated from the random noise generator, and amplified and radiated from an isotropic sound source. Over-all (O.A.) and filtered 1/3-oct. band sound pressure levels were measured (see App.3). The distribution of sound pressure levels was measured in four directions (direction A, B, C and D), and the result about direction A was shown in Figs. 2-1-11 and 2-1-12 as they have the same tendency on distributions.

Sound pressure levels per 1/3-oct. bandwidth were given as follows, that is, random noise (pink noise) was radiated from the source and O.A. sound pressure was filtered by constant percentage filter (1/3-octave band pass filter) and seven 1/3-octave band levels were obtained. The center frequency of those bands are 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz.

In Fig. 2-1-11, the sound pressure levels of 1/3-oct. bands whose center frequency are 125 Hz, 250 Hz and 500 Hz are plotted as the function of distance from source as examples of low frequency band levels. The sound pressure level at 0.3 m from source center is defined as 0 dB. The value shown in figures represents the relative sound pressure level (RSPL) to the one at distance 0.3 m from source. The height of the source

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* White noise is defined as the one whose frequency spectrum is continuous and uniform, and whose spectrum density (or spectrum level) is substancially independent on frequency over a specified range.[44)]

* Pink noise is defined as the one that has constant energy per octave bandwidth, i.e., each octave band contains the same amount of sound energy such that the sound energy is inversely proportional to the frequency.

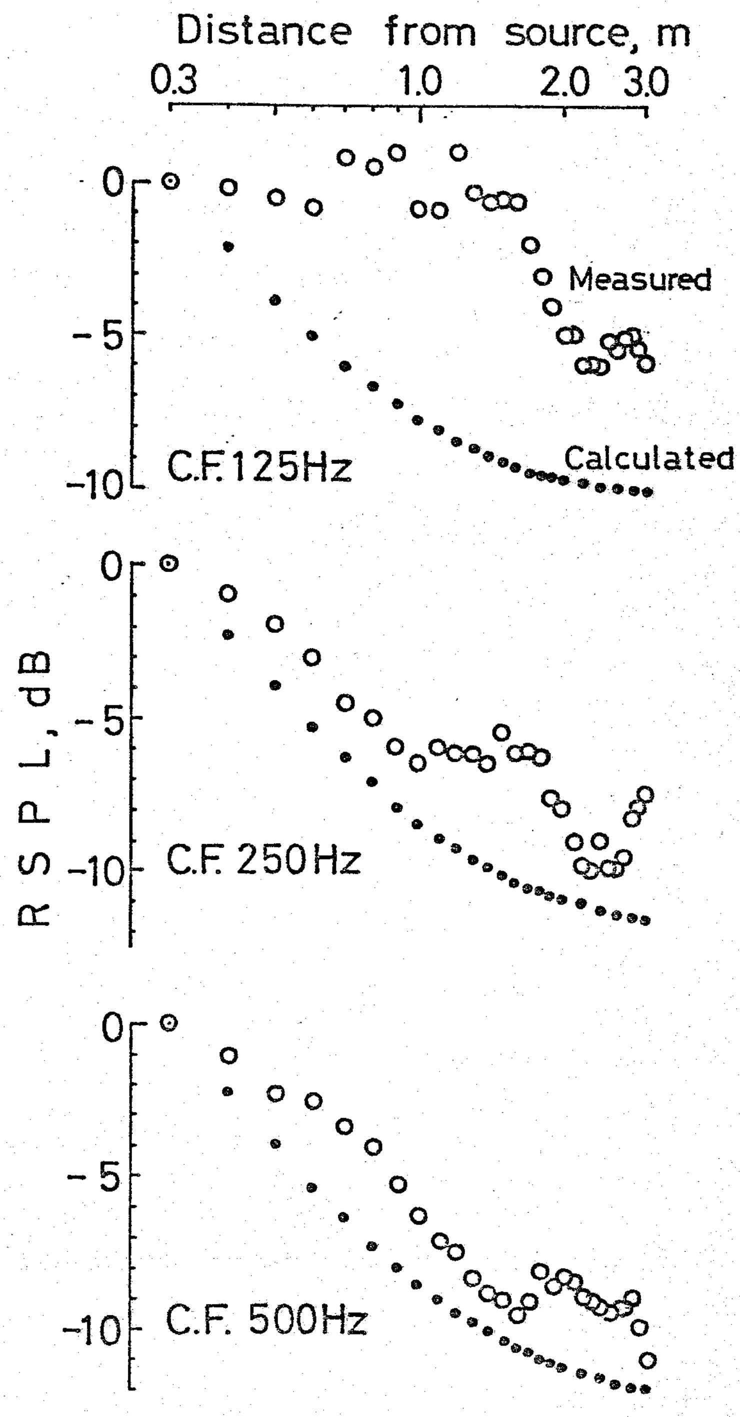


Fig. 2-1-11 One-third oct. band SPL versus distance from source. Broad band random noise was radiated from an isotropic sound source, and 125 Hz-, 250 Hz- and 500 Hz-band levels were measured.

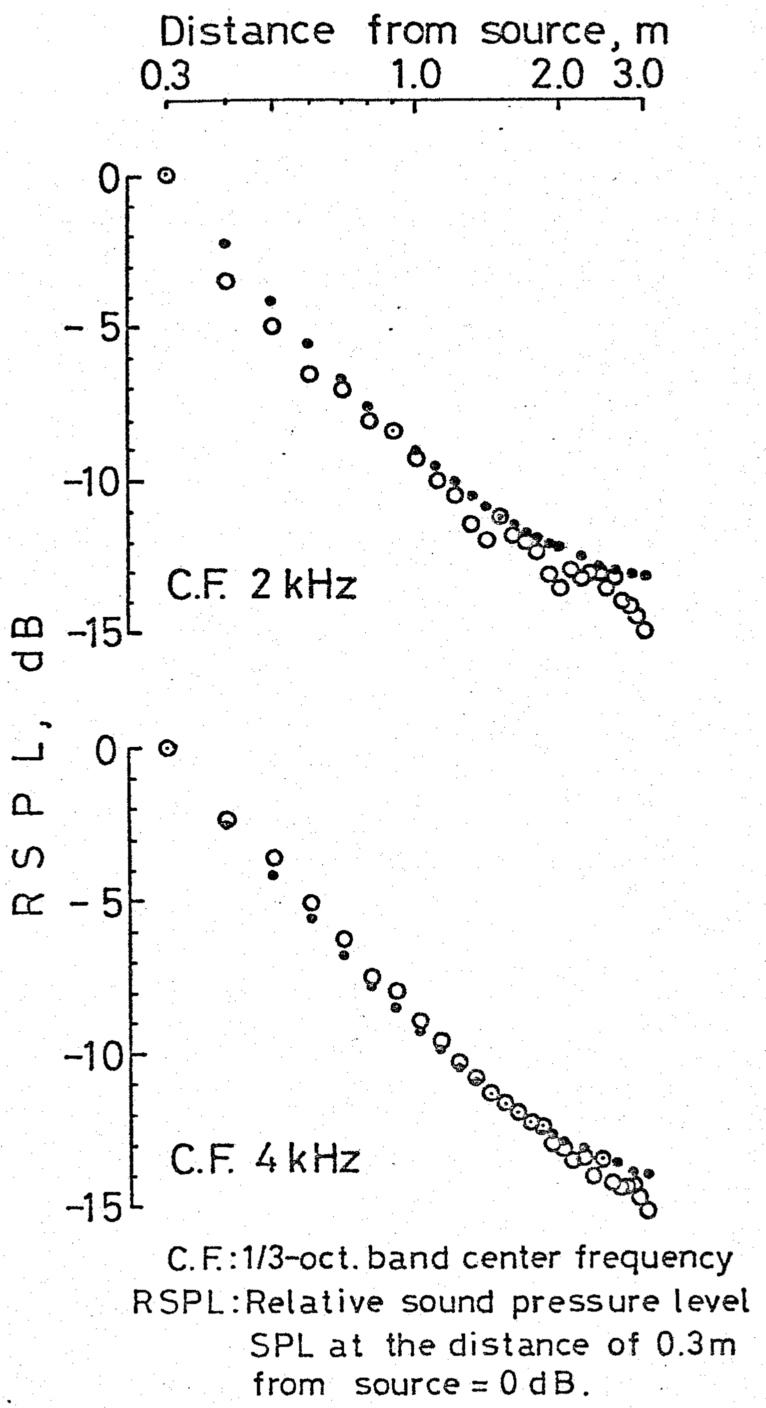


Fig. 2-1-12 One-third oct. band SPL versus distance from source. 2 kHz- and 4 kHz-band levels were measured.

and the microphone is 1.0 m from the floor. Black spots shows theoretical values calculated from Beranek's equation. Results at 2 kHz- and 4 kHz-bands were shown in Fig. 2-1-12 with the same manner.

In the lower frequency bands than 500 Hz, sound pressures observed are different from ones that calculated, and the form of distribution is wavy. On the other hand, in the higher frequency bands, measured values agree with theoretical ones well, and the wavy distribution is not produced.

It is necessary to examine whether the values of sound pressures are same or not at the positions which have the same distance from source, and which are in different directions from source. The reason is that the room has different finishes about walls, and many obstacles are situated irregularly in it.

An isotropic sound source was used as the source, and the microphone was faced to the same one side of the source to avoid the influence of radiation characteristics of it.

Standard deviation of four values in four directions (A, B, C and D directions) measured at the distance 1.0 m and 1.5 m from source (the height of the source and the microphone is 1.0 m) are shown in Table 2-1-2 for each 1/3-octave band (containing O.A. values). Without the value at O.A., standard deviations varied within a range of 1.0 dB to 1.7 dB at the distance of 1.0 m from source, and 0.7 dB to 1.6 dB at the distance of 1.5 m from source. The effect of frequency is not seen in results.

Results were summarized as follows. And more, the approach to overcome the problems given forth were also mentioned in later.

Table 2-1-2 The standard deviation (SD) of 1/3-oct. band sound pressure level measured at four mic. positions (a distance from source; 1.0 m, 1.5 m) in directions A, B, C and D.
Broad band random noise was radiated from source (an isotropic sound source). The height of the source and the microphone was both 1.0 m from the floor.

		Center frequency of 1/3-oct. band, Hz						
	O.A.	125	250	500	1 k	2 k	4 k	8 k
$SD_{1.0m}$	0.4	1.6	1.3	1.0	1.1	1.7	1.7	1.5
$SD_{1.4m}$	0.2	1.7	0.7	1.1	1.6	1.5	0.8	1.6

unit: dB

1. Though the woodworking shop-room whose volume is not so small as the room used for the place of noise measurement, the regions within about one meter from source are already affected by sound waves reflected from boundaries, particularly, in low frequency bands.

2. The sound pressure of lower frequency band noises (than 500 Hz-band) is obviously distributed wavy with the distance from source. This phenomenon is seen in results of planing machine noises. The data obtained in those sound fields may contain noticeable error, and the sound power calculated from these pressure levels may not be the reliable quantity to evaluate the property of the source.

3. In this room, the sound pressure levels measured in different directions from source were dispersed over a certain range. It is thought to be caused as the acoustic condition of walls are different to each other. To hold down the error caused by the surroundings, a lot of data are need to be taken at many points. But, this operation will make the measurements tedious.

It is considered to be the means of solving to item 1 and 2 that to increase the room absorption and to enlarge the region of direct sound field. However, it is not practical to add the absorbing materials in woodworking shop-rooms as those rooms are,in essence,not the place used for the measurement. It might be the one of solutions that to build the room whose boundaries are made of absorbing materials and which has enough volume to surround the machine to be tested and to practice the measurement, in the original room-space. Item 3 will be, also, solved if the same materials are used for boundaries.

The following purpose is considered in this investigation, that is, the test space should be built in any kind of rooms readily and cheaply. On this point, the aim of this study is different from other ones that to construct complete acoustic test rooms such as anechoic rooms or reverberation rooms. And, therefore, it may be considered that data given in it lead some large errors compared to the one obtained in the ideal acoustic test room.

2.2. Noise Measurement Space Surrounded with Cloth Curtains

2.2.1. Introductory remarks

From SPL distribution measurement in the woodworking shop-room which is one of common test rooms, it is appeared that the room space is not desirable for us to use sound pressure level measurements for the determination of the sound power of noise sources. Especially, the phenomenon that sound pressures decay in waves through the distance from source, and which is obviously seen in case of low frequency noises, will make it difficult for us to get right values on sound power levels, as even a few differences of the position of measurements cause large differences on measured values in those circumstances.

When those rooms are used as the places for the sound pressure level measurements, it is necessary to convert them into more desirable place with any acoustic arrangement.

In this section, it is examined to build the new test space surrounded with cloth curtains which are obtained easily and not so expensive, and the acoustic characteristic of the space is examined to see whether one could use it as the place of sound pressure measurements or not.

2.2.2. Make-up of the test space with cloth curtains

The test space to be built must be small about the volume to be constructed in the woodworking shop-room, and this space should essentially be got in any room space. But, on the other hand, the space must be large as one can get the point for moise measurements excepting near field around the source. Thus, it was thought that the test space to be built should be a cube the side of which was three meters long (the volume: 27 m^3, the total surface area: 54 m^2) as this form was easy to to be constructed and at least the distance of one meter away from source could be given in it easily.

In construction, steel angles (a unit dimension: 40 mm x 40 mm x 3 000 mm, a thickness 2 mm, see Fig. 2-3-2) were used as the frame of the cubic test room.

To partition this new test space from the outside room, cloth curtains were used as materials of boundary walls, because they were easy to get, easy to use, easy to take down and comparatively cheap.

Generally, absorption of curtains are not so large in lower frequency range as in higher frequency range.[45] Thus in the examination, two kinds of curtains were used as materials of boundaries, and the depth of air between these curtains were changed into three degrees (17 cm, 34 cm and 68 cm) to absorb low frequency sound energies effectively. And more, plaits of curtains were also changed into some degrees to see the effect of surface areas increased for sound-absorption.

Two kinds of curtains offered as absorbing materials have following characteristics, that is,

1. Thick curtain ... made of felt mat covered with tent cloth.
Thickness: 10 mm, Surface density: 1.8 kg/m^2

2. Thin curtain ... made of mixed nylon and vinylon.
Thickness: 1 mm, Surface density: 0.2 kg/m^2

In the report, two kinds of curtains were designated as above for convenience.

Above two kinds of curtains were spreaded among the angle frames with certain conditions. These conditions were arranged in Table 2-2-1. In it, the foot numbers (1,2 and 4) represent the stage of plaits of thin curtains, and the foot symbols (a, b and c) represent conditions of air depth between inner thin and outer thick curtains at side wall parts. Plaits of thin curtains were taken to one, two and four times per unit area. The depth of air between two kinds of curtains were taken to 68 cm, 34 cm and 17 cm that fell on quarter wavelength of 125 Hz, 250 Hz and 500 Hz. The reason is that the acoustic particle velocity must be zero at the wall (in theoretically, a hard wall) while at a quarter wavelength from the wall it will be a maximum and thus the material placed there will absorb energy well.[46)]

The shape of the test space surrounded with these curtains were illustrated in Fig. 2-2-1. In this figure, the source set on the floor is an isotropic sound source used for the test of sound distributions. As one can see from this figure, the ceiling part of the test space is composed of only thick curtains. The floor was left as it is, i.e., any acoustic

Table 2-2-1 Conditions of cloth curtains surrounding the test space.

Symbol		
A		Thick curtain
B		Thin curtain
	B_1	without plaits
	B_2	two times of plaits per unit area
	B_4	four times of plaits per unit area
C		Thin and thick curtains (Double wall condition)
	C_a	the depth of air space: 17 cm C_{1a} C_{2a} C_{4a}*
	C_b	the depth of air space: 34 cm C_{1b} C_{2b} C_{4b}*
	C_c	the depth of air space: 68 cm C_{1c} C_{2c} C_{4c}*

* Foot numbers (=1,2, and 4) represents the condition of plaits of thin curtains, and equal to definitions of above condition "B".

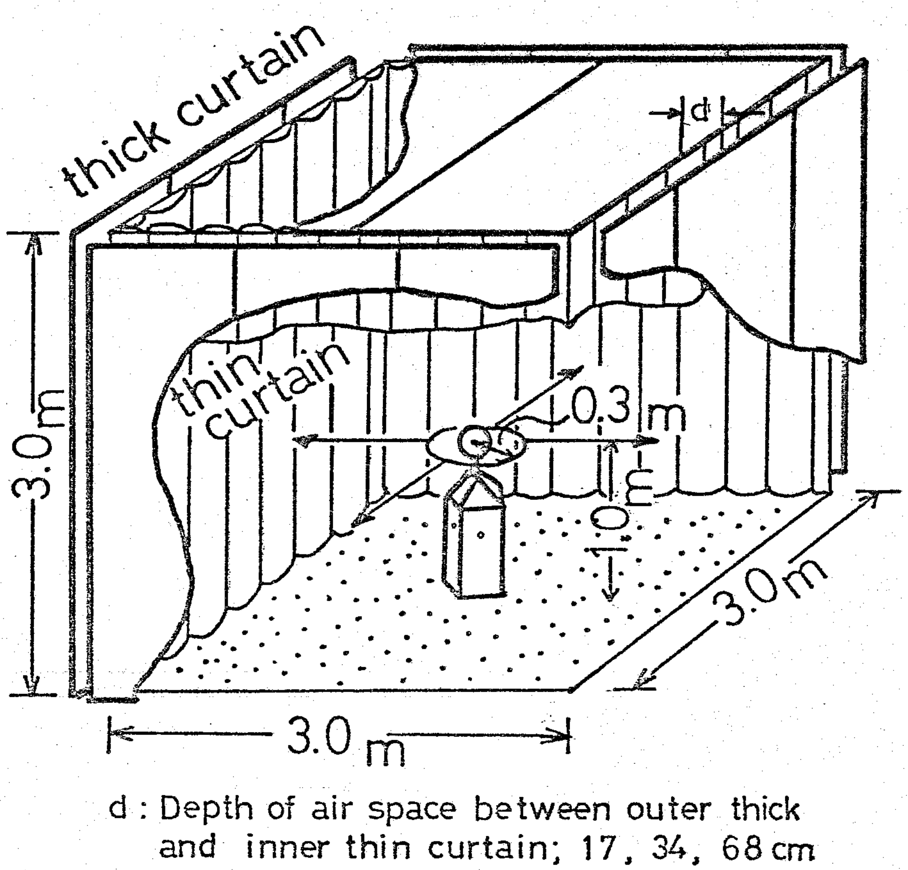


Fig. 2-2-1 A sketch of the test space (the secondary space) surrounded with cloth curtains.

treatment was not given on the floor made of concrete mortar. And, several conditions on curtains were applied only to side wall parts.

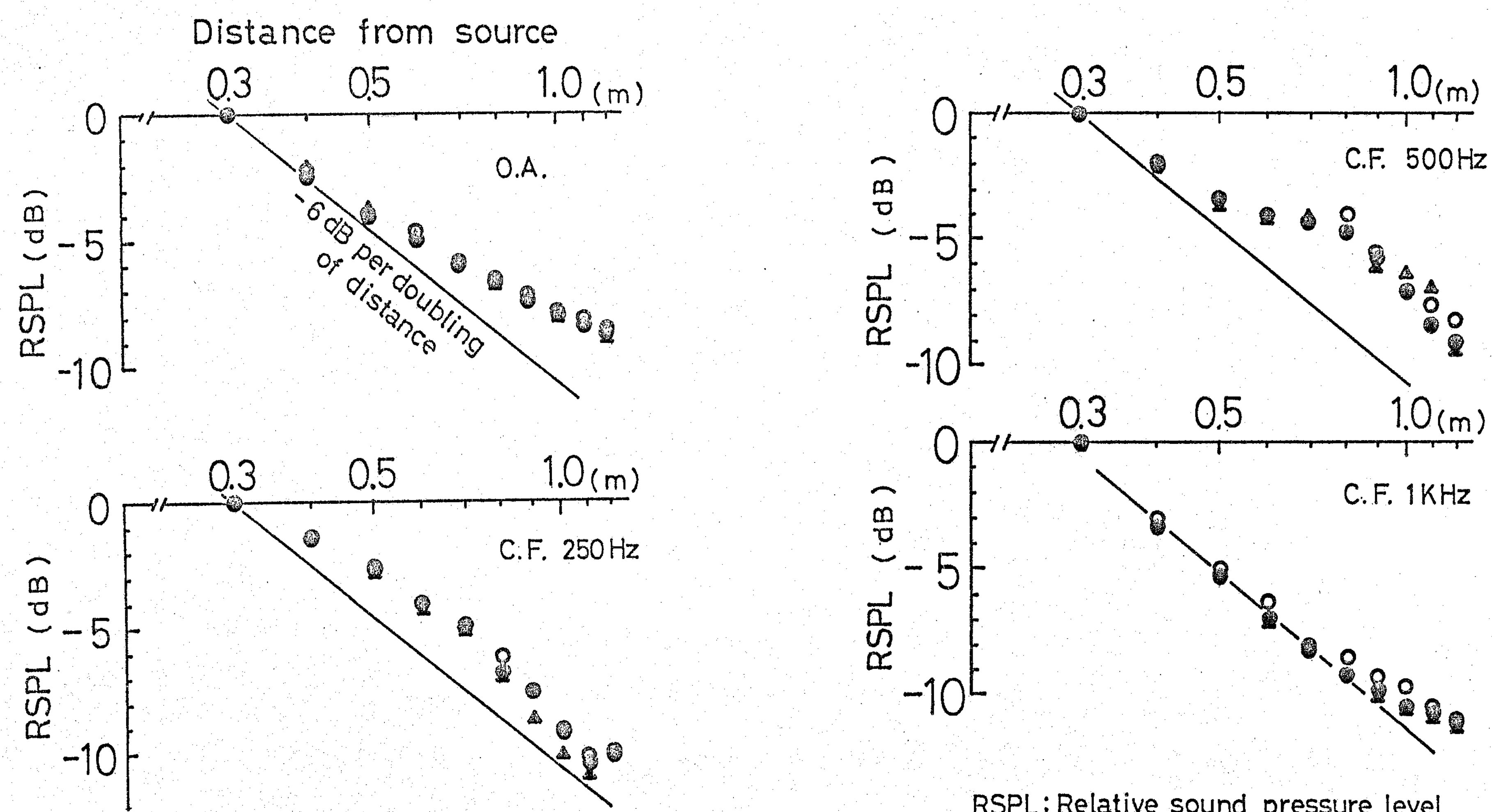
In this thesis, such a new test space is designated as "secondary space", and the woodworking shop-room before the test space is built as the "original space".

2.2.3. Qualification of the test space

The qualification of this test space was practiced by the experiment of sound distributions in it using broad band random noise. An isotropic sound source was used as the source and it was set on the center of the floor of the secondary space. The microphone was traced in four directions, and they were shown in Fig. 2-2-1. These directions are right to each side wall and parallel to the floor and they are same as direction A,B,C and D. The height of the source and the microphone was both 1.0 m from the floor.

Results of B_1, B_2 and B_4 were shown in Fig. 2-2-2 for O.A., and 250 Hz-, 500 Hz- and 1 kHz-1/3 octave band. The values at each condition in each distance from source are the average of four data measured in four directions, and the solid line of the figure represents the theoretical decay of the sound pressure in the free field, i.e., the decay according to the inverse square law (-6dB/doubling of distance). The horizontal axis of the figure represents the distance from source with logalithmic scale. The vertical axis represents the relative sound pressure level from the level at 0.3 m from source.

From these results, remarkable differences of SPL



RSPL : Relative sound pressure level $SPL_{0.3m} = 0$ dB

C.F. : Center frequency of 1/3-oct. band random noise

Fig. 2-2-2 One-third oct. band SPL (containig over-all levels) versus distance from source in the secondary space. Typical frequency band (250 Hz-, 500 Hz-, and 1 kHz-band) levels were selected.

B_1: ○ , B_2: ● , B_4: ▲

distributions are not revealed among three conditions on plaits of thin curtains. And more, the wavy form is still seen in the decay of sound pressures below 500 Hz-band.

Figure 2-2-3 shows the results at the conditions C_{4a}, C_{4b}, and C_{4c}. In areas about one meter distant from source, distribution patters are slightly different among another conditions of curtains in 250 Hz-band, while they are almost same to each other conditions except this band. And the effect of double wall structure cannot be seen in results. The reason is thought as the thick curtain used for outer parts of side wall is quite unlike to "hard wall", and more, the thin curtain has not so much absorption in low frequency ranges.

Figures from 2-2-4 to 2-2-7 show the distribution of sound pressure levels in the secondary space comparing with the one measured in the original space. In these figures, all values that were measured at four directions are plotted, and mean values are connected with dotted lines. In Fig. 2-2-4, 250 Hz-band SPL distributions were shown. In it, (a) is the result in the original space and (b) is the one in the secondary space at the condition C_{4b}. In the original space, measured values are dispersed widely. On the other hand, the dispersion in data is comparatively narrow in the secondary space, and a certain pattern is seen on distributions. This tendency on SPL distribution was also seen in another frequency bands that were examined. From them, it can be recognized that the sound field becomes similar about the direction from source by surrounding each side wall part with same materials, while the sound field in those space is not equal to the free field condition.

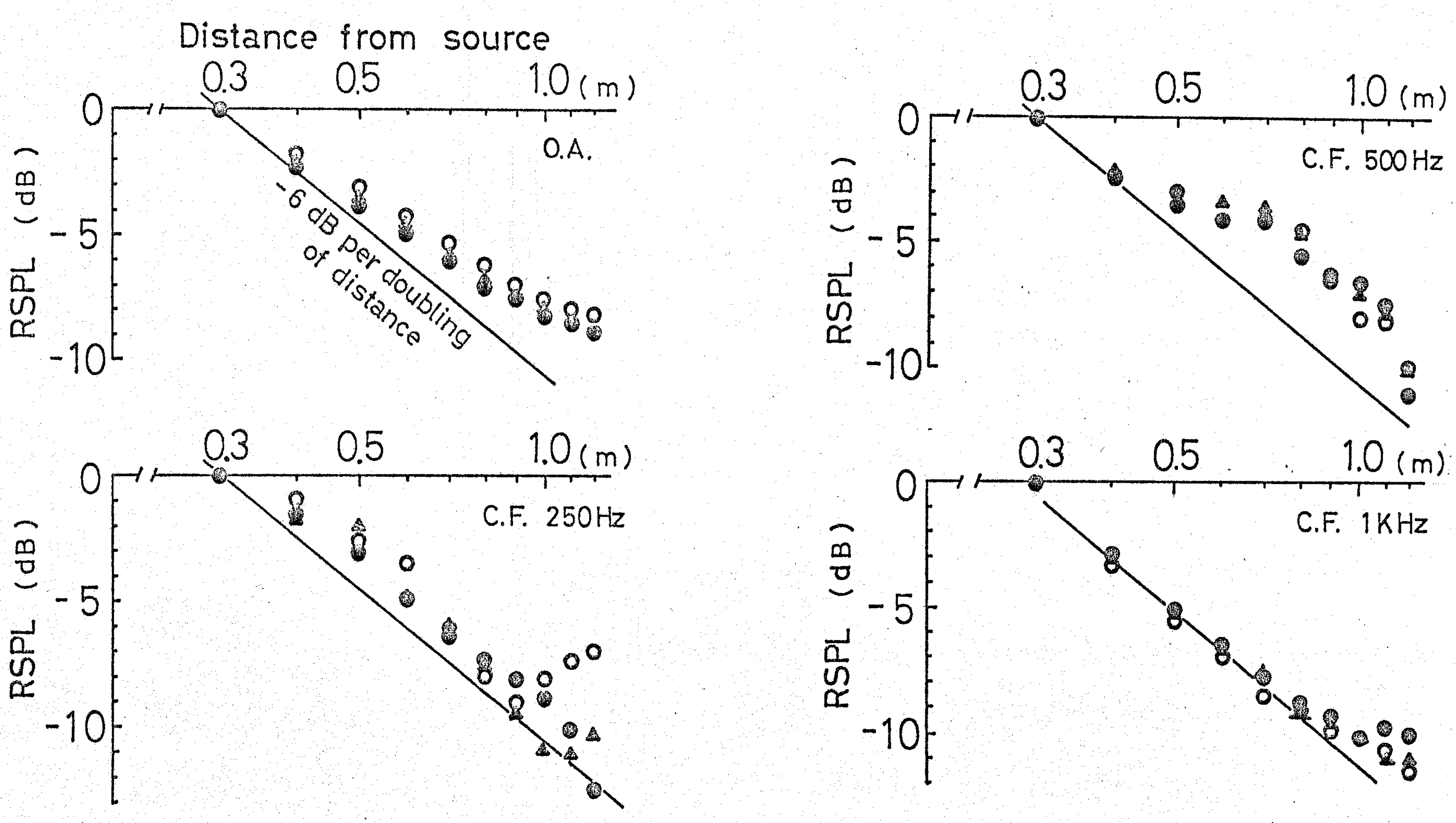


Fig. 2-2-3 The effect of double structure of boundary curtains. The depth of air space between inner thin and outer thick curtains were 17 cm (●), 34 cm (○), and 68 cm (▲).

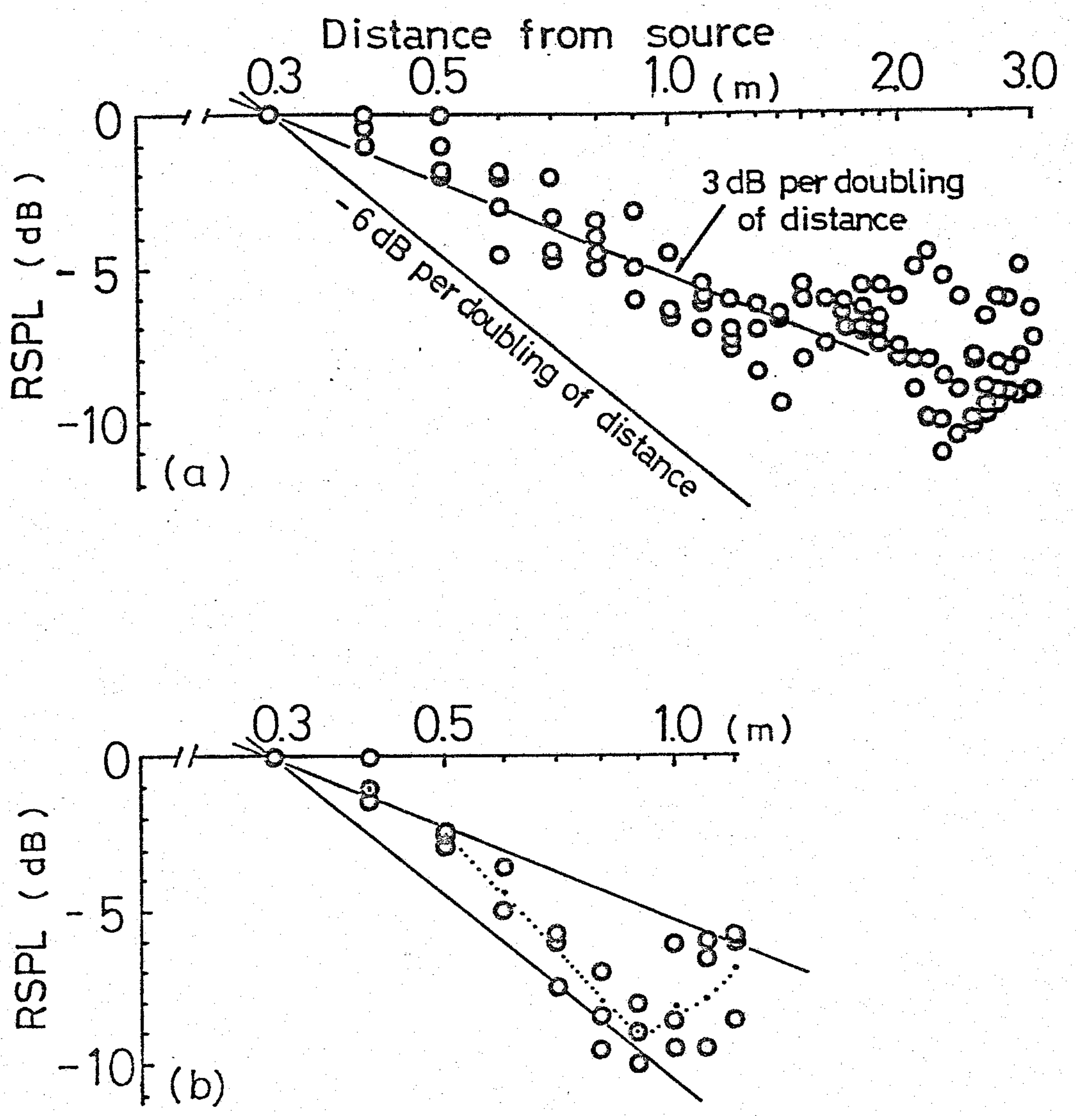


Fig. 2-2-4 SPL (250 Hz-band level) versus distance from source in the original (a) and the secondary (b) space. The condition of curtains of the secondary space was C_{4b}.

In 500 Hz-band, SPL distributions were slightly different in the secondary space from that of the original space. Figure 2-2-5 (b) represents the result of the condition A, and Fig. 2-2-5 (c) represents that of the condition B_1. From these figures, there can be seen the "hill of levels" at the distance of 0.8 m from source for both conditions in the secondary space. This peak in the distribution of levels is not seen in the original space (Fig. 2-2-5 (a)). It would be caused by reflecting sound waves from boundary curtains. It represents that curtains used for the test can not have remarkable absorption to low frequency sounds for any conditions of them. On the other hand, at 1 kHz-band, sound pressure levels decay along the inverse square law within one meter from source in the secondary space. This effect is caused as the total absorption is increased by curtains hung on boundaries. It is seen in Fig. 2-2-6. The dotted line in figure (a) represents the drop of SPL resulting from Beranek's formula. Figure (b) is the result given in the condition B_1, and figure (c) is the one given in the condition C_{4b}. In high frequency bands above 1 kHz, there exists almost no difference among distributions of SPL between two spaces except that surrounded with only thick curtains. The result of 4 kHz-band were shown in Fig. 2-2-7 about the boundary curtain's conditions of A and B_4. These are average values of four data measured at the same distance from source in four directions. It could be recognized that the sound field in the space surrounded with only thick curtains is different from others, and sound pressure levels distribute with the slope of - 3 dB per doubling of distance in it. They would be happened because the absorption of the space

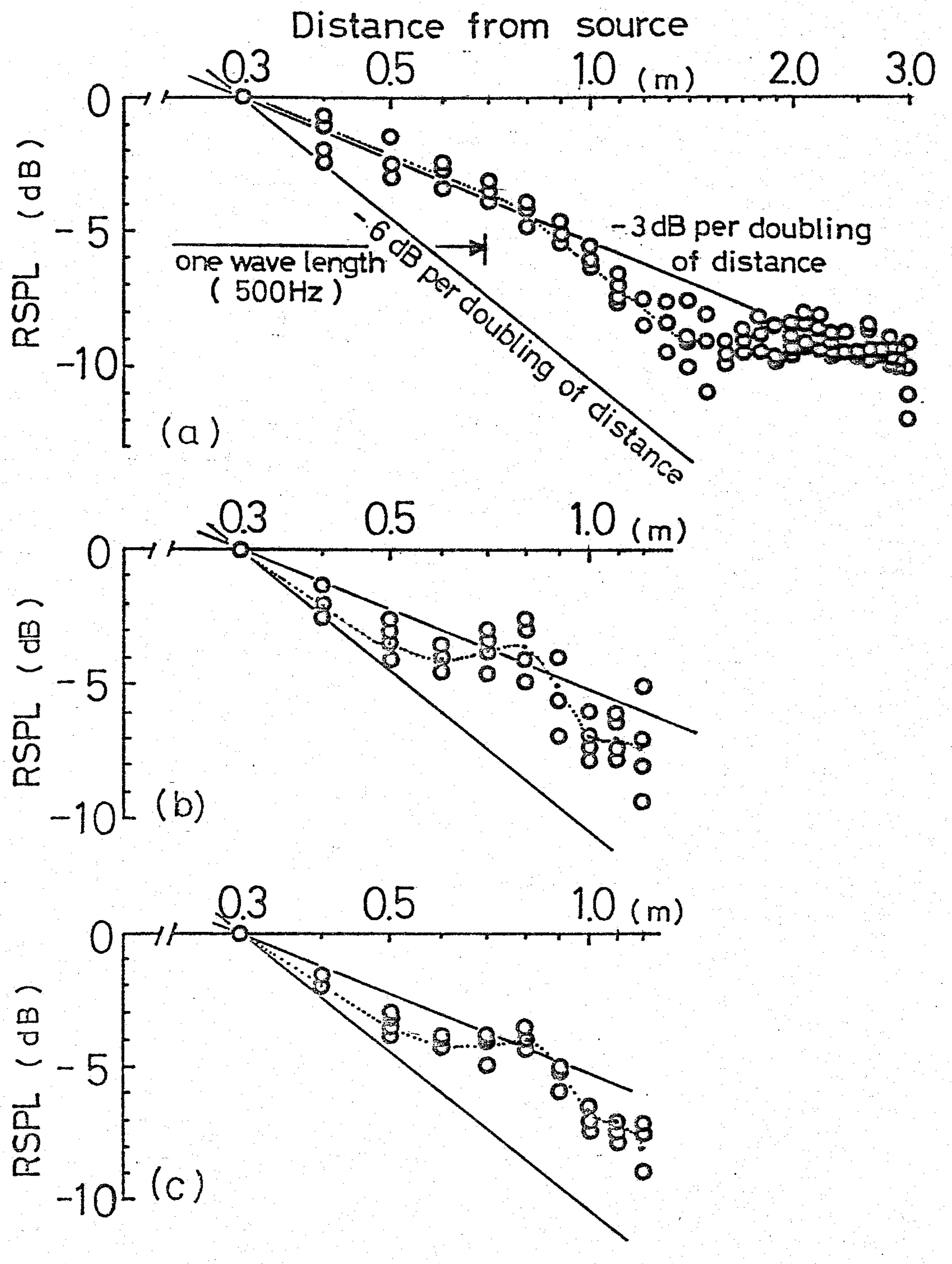


Fig. 2-2-5 SPL (500 Hz-band level) versus distance from source in the original (a) and the secondary (b and c) space. (b)...A_2 (c)...B_1.

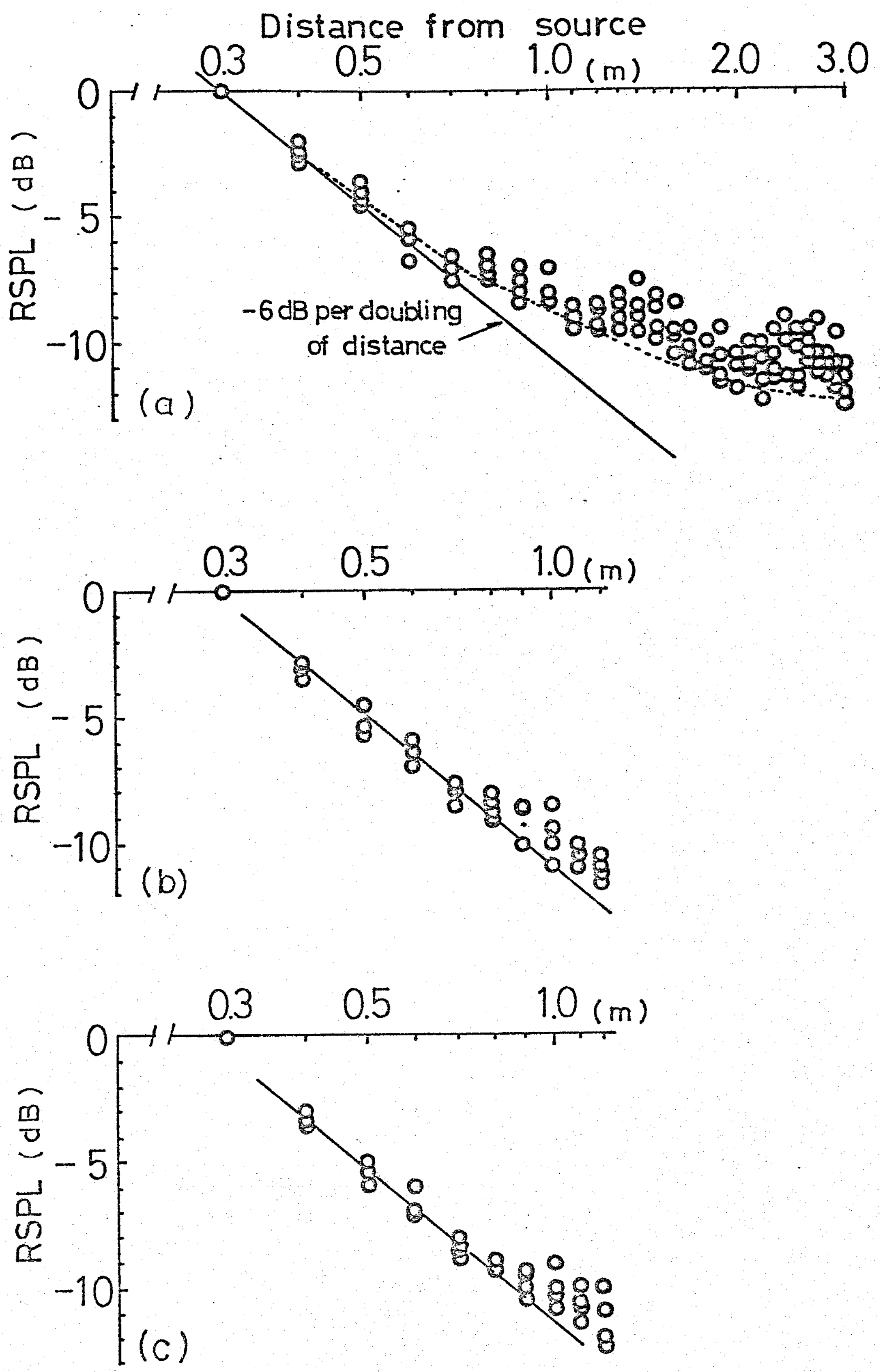


Fig. 2-2-6 SPL (1 kHz-band level) versus distance from source in the original (a) and the secondary (b and c) space. (b)...B_1, (c)...C_{4b}.

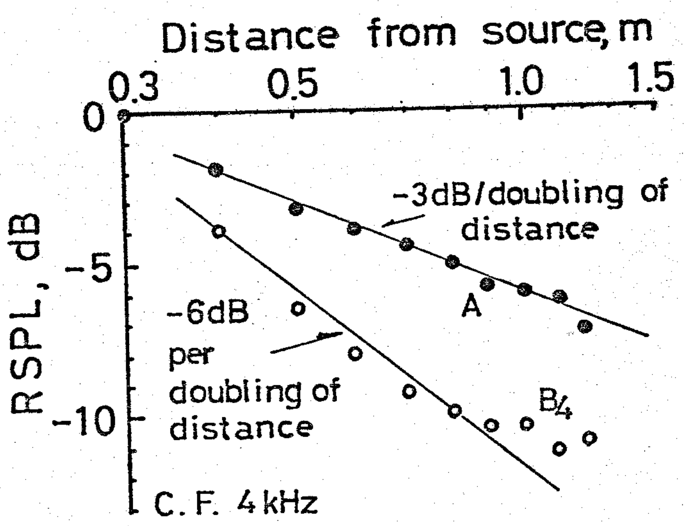


Fig. 2-2-7 The average 1/3-oct. band SPL (4 kHz-band level) versus distance from source. The conditions of curtains of the secondary space were A (●) and B_4 (o).

surrounded by them becomes not so large in higher frequency ranges.

It may be conclude from above results that the secondary space surrounded with cloth curtains has not become the desirable place for sound measurements compared with the original space, because two kinds of curtains used for wall parts were not so absorptive as were expected. Therefore, attempts to make side walls double wall structure with two kinds of curtains or to add plaits to thin curtains would have almost not the effect. Especially, we cannot expect any desirable effect in case that only thick curtains are used for materials of boundary walls.

2.3. The Semi-anechoic Test Room Whose Walls and Ceiling were Built of Woodfiber Mat

2.3.1. Introductory remarks

One of the experiments to make the comparatively small tast room that had the desirable conditions on sound measurements was done with cloth curtains for materials of boundaries. Though there were many advantages for using cloth curtains, the space surrounded with them could not become satisfactory one as they were not so absorptive as were expected. The test room to be built is small the volume and which shows the effect of falling down the total sound absorption in it. To overcome this, and to make the test room more useful place for sound measurements, boundary walls would be more absorptive.

In this section, the woodfiber mat that was raw materials for making semi-hard boards was used as materials for boundary walls. It has been already made clear to some extent that the sound field around the source is not different by the direction from source to be measured, if one uses the same materials for boundary walls of the test room.

2.3.2. Built-up of the test room with woodfiber mat walls

Woodfiber mats used for materials of walls are raw materials for semi-hard boards. They are composed of western hemlock, Port Orford ceader, etc., and have the thickness of 80 mm (the surface density: 7.2 kg/m^2, the density: 90 kg/m^3, porous materials).

One often uses glassfiber mats as absorbing materials for anechoic rooms. It has the density of 10 kg/m^3 or 12 kg/m^3.[45) 47)48)] And often, it is reformed to wedge shapes. Several works have been reported on the effect of wedges in low frequencies. The wedge-shaped wall is, however, undesirable in this experiment as the room space for the measurement is limitted by projections of wedges. And more, much effort is needed when one makes flat mats to wedges. Therefore, the mat was used as it was, that is, with its original form (with flat-style) ~~to walls~~ in the test. One can see a report[49)] that glass fiber mats flat-styled has almost same effect as wedges on sound-absorption.

The test room created has the volume of 27 m^3 and the surface area of 54 m^2 (a cube). As was already written in previous section (in Sec. 2.2), the volume of the room has to be small to be able to be constructed in any room space. And more, measured results given at this section has to be compared directly with another results of this study.

The frames of the test room were made of steel angles, and the unit dimensions of them was illustrated in Fig. 2-3-1. The fibermats were placed among those angle frames by supported with fine wire nets, as those mats had not the toughness to support them by themselves. The mat and the fine wire net used for the test were shown in Fig. 2-3-2, and the sketch of the semi-anechoic test room constructed with above materials was given in Fig. 2-3-3. The floor of the room is not covered with mats as machines has to be set on it, and in this sense, the room is "semi-anechoic".

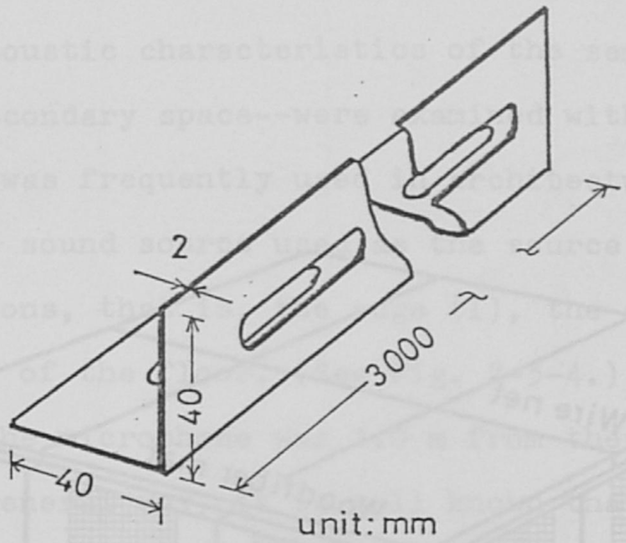


Fig. 2-3-1 A sketch of L-type steel angle used for materials of frames.

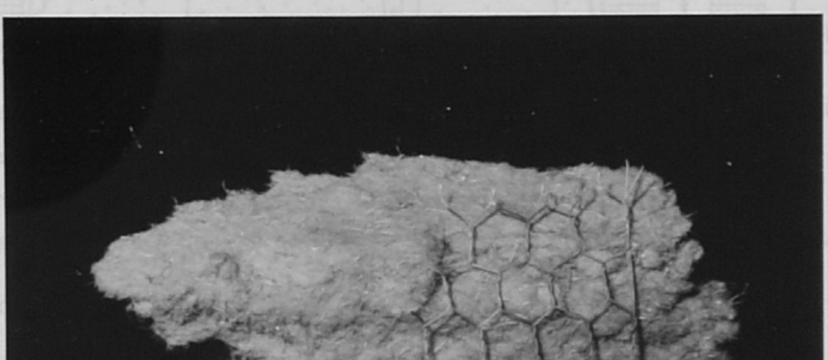


Fig. 2-3-2 A sample of woodfiber mats used as the absorbing materials. Fine wire nets with which the mat was supported were also seen.

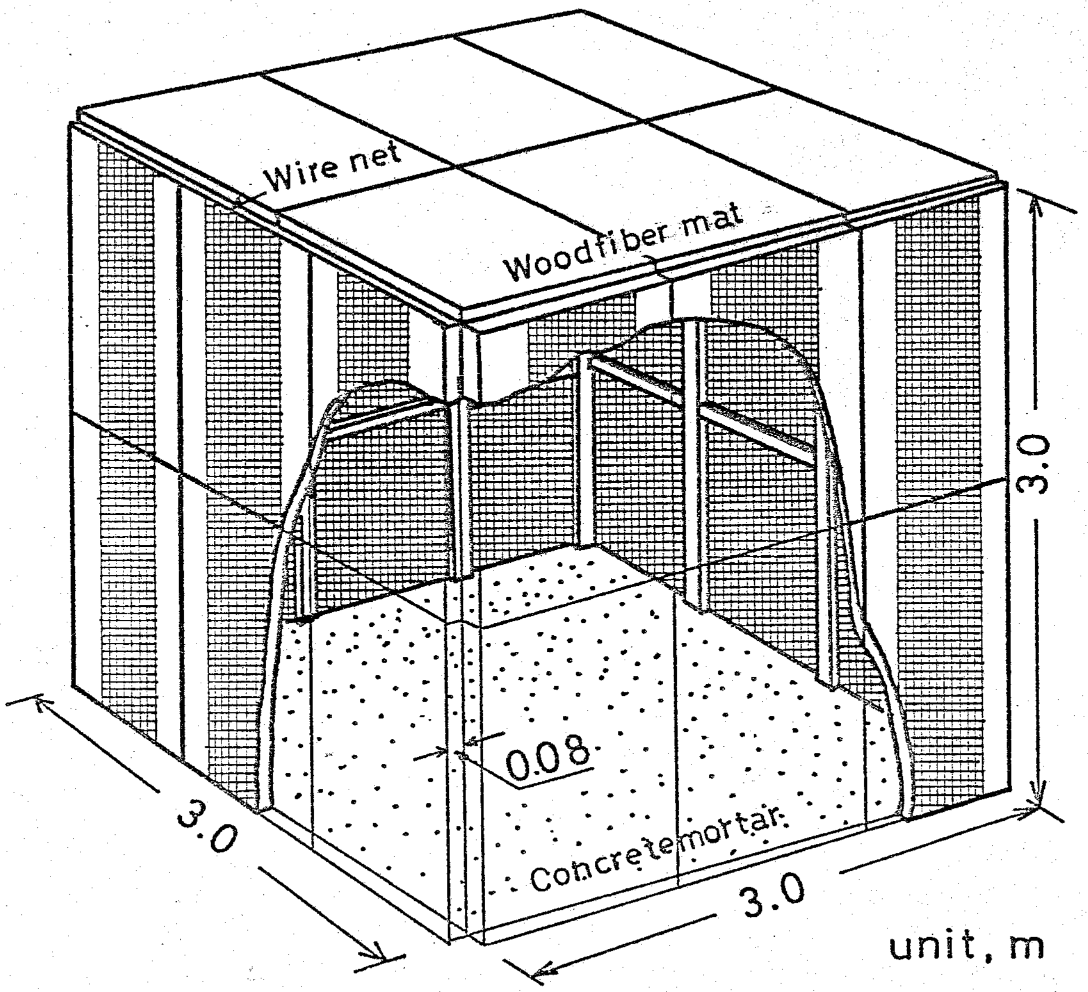


Fig. 2-3-3   A sketch of the semi-anechoic test room.

2.3.3 Qualification of the test room

The acoustic characteristics of the semi-anechoic test room--the secondary space--were examined with broad band random noise which was frequently used in architectural acoustics. An isotropic sound source used as the source was set on one of three locations, that is, the edge (I), the corner (II) and the center (III) of the floor. (See Fig. 2-3-4.) The height of the source and the microphone was 1.0 m from the floor.

In a general way, it is well known that the reverberation time gives much information to the acoustic characteristics of the room space to be tested. In the test, also, this quantity was measured first of all. The sound source was set on the corner of the floor as plenty of normal modes were able to be excited.[50] (All the normal frequencies of the room possess a pressure maximum in a corner of the room.[51])

Data were taken in many positions chosen arbitrarily in the room space (see App. 3.1), and the mean values were shown in Fig. 2-3-5 for each 1/3-oct. band, together with values given in the original space. The average Sabine absorption coefficient ($\bar{\alpha}_{sab}$) calculated from these reverberation times was given in Table 2-3-1. In the secondary space, the reverberation time is shorter than the one in the original room (T is 0.2 sec at O.A., and which value is 1/5 of the one in the original space), and is almost same through frequencies concerned. But, the absorption coefficient is not so large as was expected. The narrowness of the test room would give limitations to the increment of absorptions. (A ratio of the volume between the secondary space and the original space is 1/16 , and that of

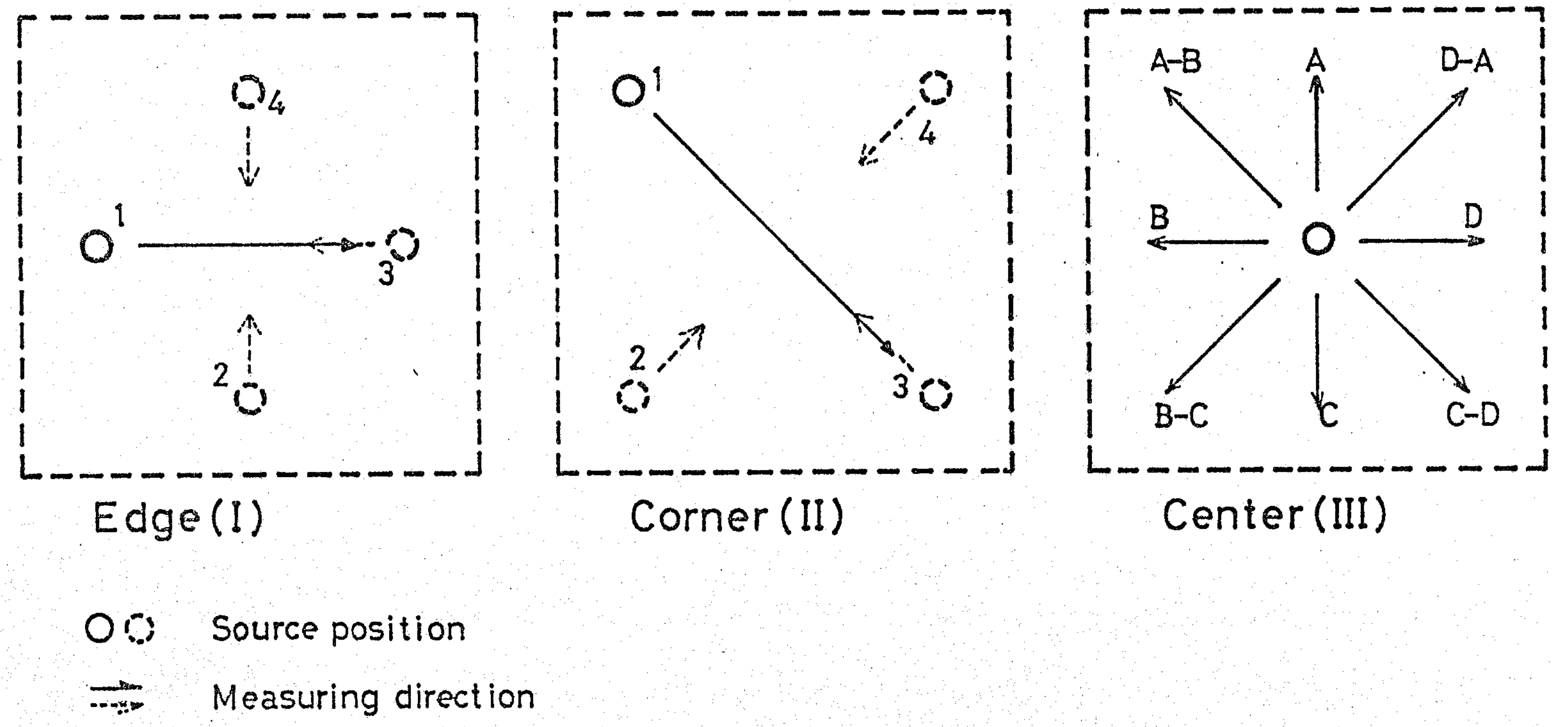


Fig. 2-3-4 The source positions and the measuring directions (plan view).

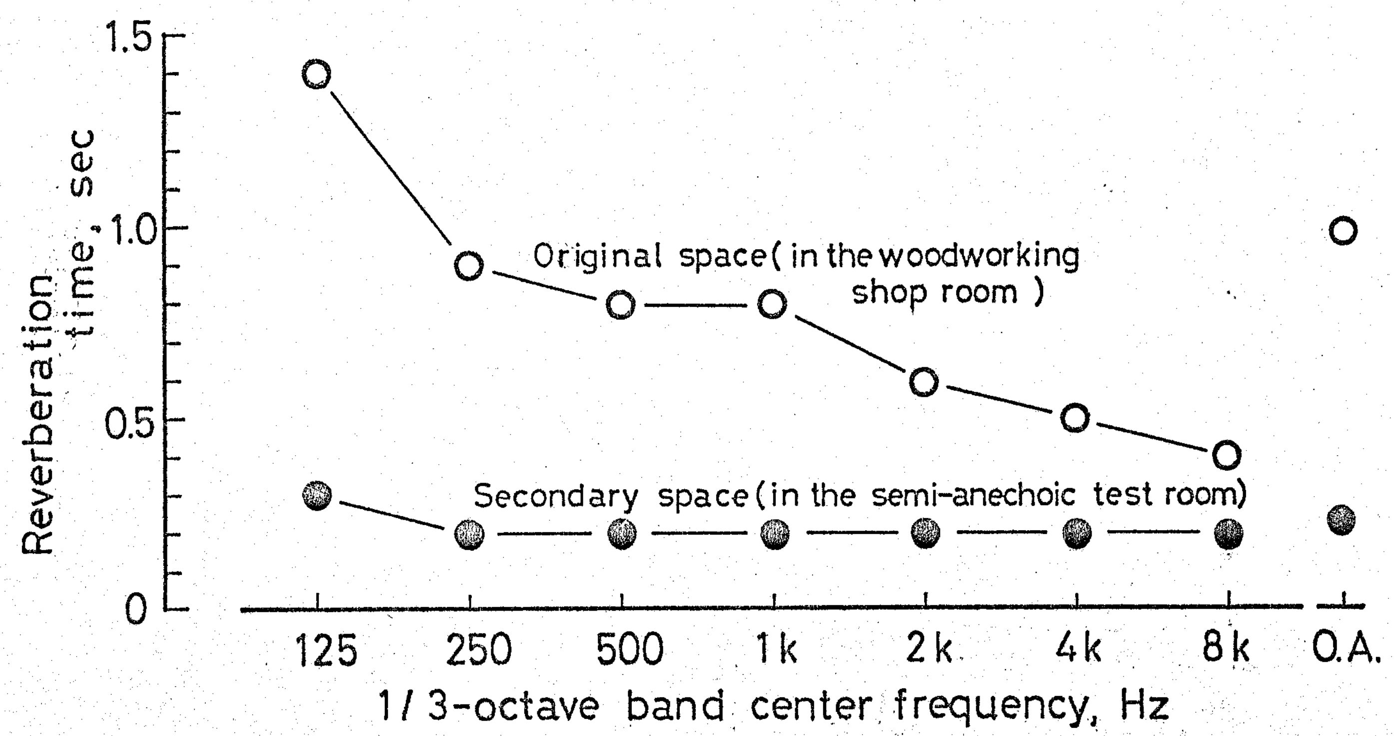


Fig. 2-3-5 The reverberation time at each 1/3-oct. band frequency range in the semi-anechoic test room and in the original room.

Table 2-3-1 The average Sabine absorption coefficient ($\bar{\alpha}_{sab}$) in the secondary space (in the semi-anechoic test room) and in the original space (in the woodworking shop room).

		Center frequency of 1/3-oct. band, Hz						
	O.A.	125	250	500	1 k	2 k	4 k	8 k
	Average Sabine absorption coefficient ($\bar{\alpha}_{sab}$)							
S.S.*	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4
O.S.*	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.4

* S.S.: Secondary space

O.S.: Original space

the surface area between them is 1/7.)

To see the sound distribution characteristic of the secondary space, the sound pressure was measured radially through 8 lines from the source situated at the center (III). (See Fig. 2-3-4, center(III). Directions denoted by A, ..., D-A in the figure are same as those in the original space.) Data were averaged among each four value* given at the same distance from source.

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* One is the value given from directions A,B,C and D, and the other is the one given from directions A-B,B-C,C-D and D-A.

The sum of each value averaged at each distance were averaged again, and then the standard deviations were calculated. Results were shown in Tables 2-3-2, and 2-3-3, compared with two test spaces (the original space and the secondary space).

In 4 kHz- and 8 kHz-band, dispersion is comparatively large both two parties (a party of directions A,B,C and D, and the one of directions A-B,B-C,C-D and D-A) in both test spaces. These results would be raised as the "isotropic" sound source has some directivities on radiation of sounds in those higher frequencies.[52)] With the exception of those two frequency bands, dispersion is small both two parties, especially in the secondary space. It is worthy to point out from them that the secondary space built of woodfiber mat is turned into more comfortable "uniform" environment, that is, the sound pressure distributes similarly in any direction from source in the secondary space.

One-third octave band SPL distributions were shown in Figs. 2-3-6 and 2-3-7 about some representative frequency bands. The distribution results given in the case that the source was set on the center (III) were shown in Fig. 2-3-6. The value

Table 2-3-2 The mean value ($\overline{SD}$) of standard deviations of sound pressure levels measured in directions A, B, C and D.

		Center frequency of 1/3-oct. band, Hz						
	O.A.	125	250	500	1 k	2 k	4 k	8 k
	Mean standard deviation ($\overline{SD}$), dB							
O.S.*	0.5	1.3	1.0	0.7	1.1	0.8	2.0	2.9
	(0.2)	(0.4)	(0.5)	(0.2)	(0.3)	(0.2)	(0.8)	(0.8)
S.S.*	0.4	0.6	0.7	0.5	1.1	0.4	1.7	3.2
	(0.1)	(0.2)	(0.3)	(0.2)	(0.3)	(0.2)	(0.5)	(0.5)

* O.S.: Original space, S.S.: Secondary space.

Above values are means of each SD given at each distance from source in directions A, B, C, and D. ( ) is the standard deviation of mean standard deviations.

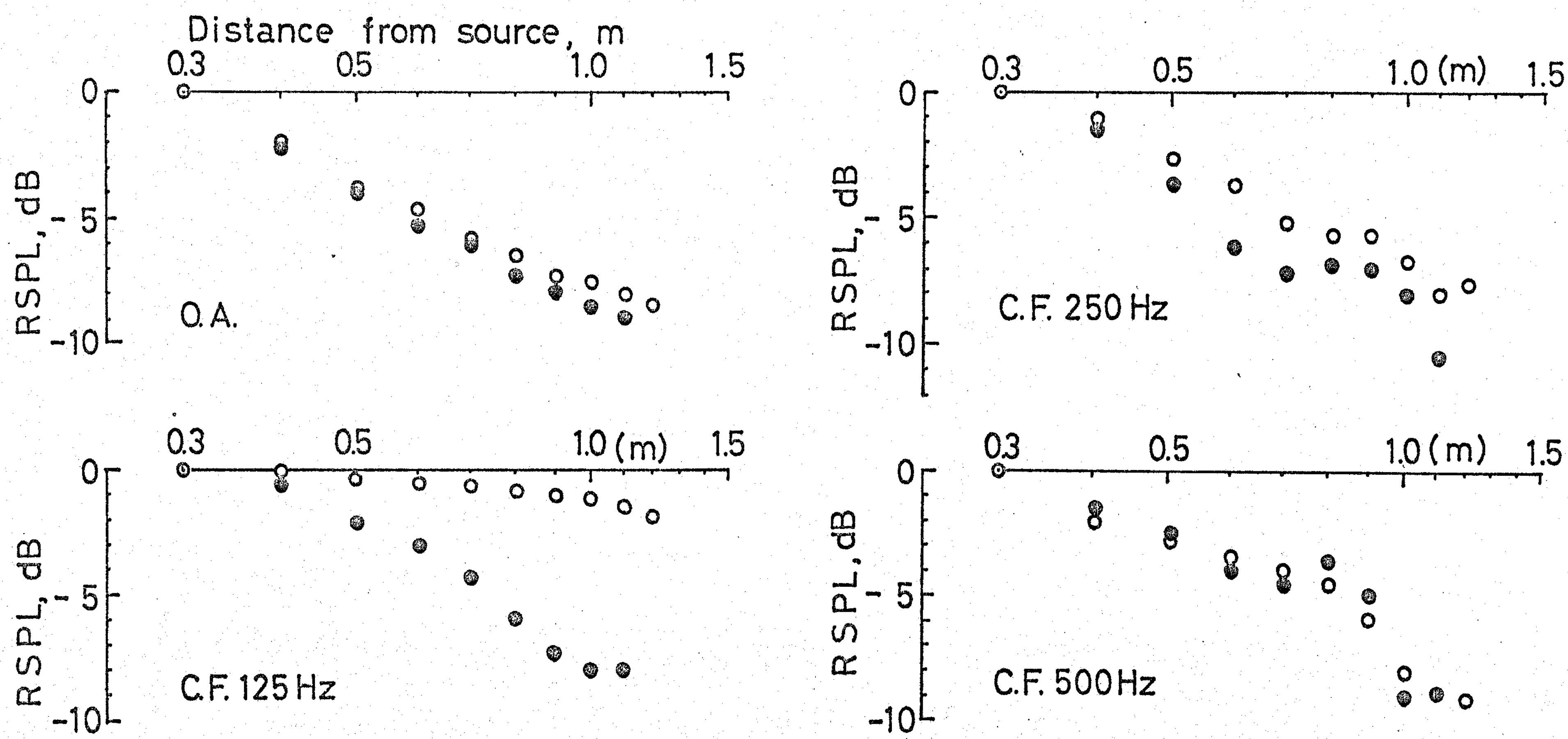
Table 2-3-3 The mean value ($\overline{SD}$) of standard deviations of sound pressure levels measured in directions A-B, B-C, C-D and D-A.

	O.A.	125	250	500	1 k	2 k	4 k	8 k
		Center frequency of 1/3-oct. band, Hz						
	Mean standard deviation ($\overline{SD}$), dB							
O.S.*	1.3	1.3	1.6	1.6	1.8	1.7	2.1	2.8
	(0.3)	(0.3)	(0.5)	(0.2)	(0.2)	(0.3)	(0.5)	(0.6)
S.S.*	0.3	0.5	0.9	0.5	0.8	0.7	1.0	3.1
	(0.2)	(0.3)	(0.4)	(0.2)	(0.4)	(0.1)	(0.6)	(0.6)

* O.S.: Original space, S.S.: Secondary space.
Above values are means of each SD given at each distance from source in directions A-B, B-C, C-D, and D-A. ( ) is the standard deviation of mean standard deviations.

at each distance from source is the mean value of 8 data given in 8 directions. The circle represents the value measured in the original space. The result given in the case that the source was set on the corner (II) was shown in Fig. 2-3-7. The value plotted in the figure is the average of values given at four source positions. (The sound source was set on one of four places in turn. See Fig. 2-3-4, corner (II).) In high frequency bands above 1 kHz, the sound pressure level is distributed almost theoretically, and the fluctuation is able to be ignored. But in low frequency bands below 500 Hz, the distribution is not so different from that in the original space. The reason why those results were given is thought as follows: The volume of the test room is small to be given "anechoic" characteristics in it, even if the boundary walls are absorptive. In other words, the matter that the room is narrow and the total surface area is small takes negative effects on constructing the comparatively small "anechoic" test room, though the room boundaries are composed of much absorptive materials.

The influence of the floor uncovered with woodfiber mats also might not be ignored, as the floor, which is the only reflective surface, would affect on the total absorption of the test room. In any case, it should have been known that some restriction is placed on constructing the desirable anechoic space for sound measurements with smaller volumes, especially in low frequency ranges.


Distance from source, m
0.3
0.5
1.0
1.5
1.0 (m)
0
-5
-10
RSPL, dB
O.A.
C.F. 250 Hz
C.F. 125 Hz
C.F. 500 Hz

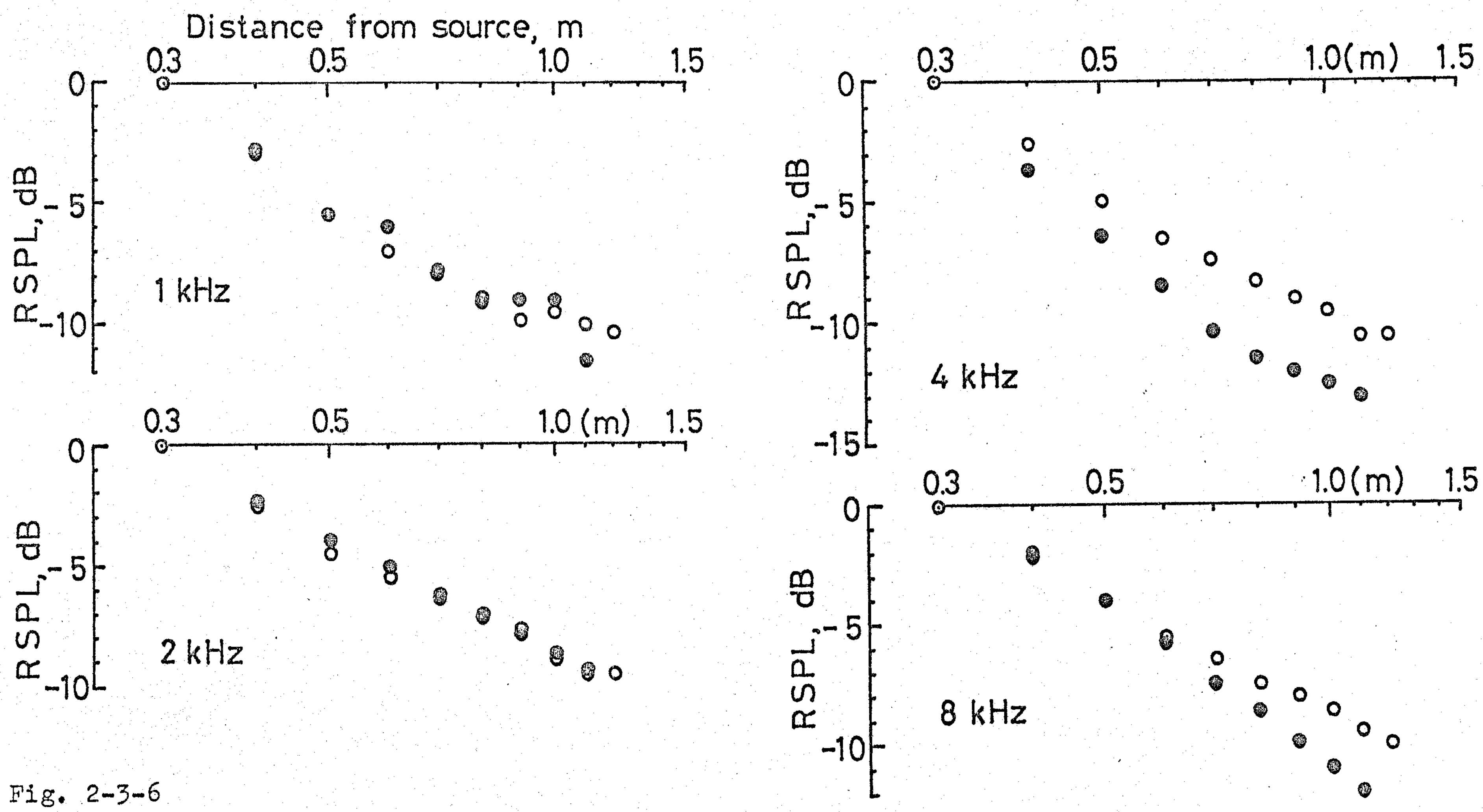
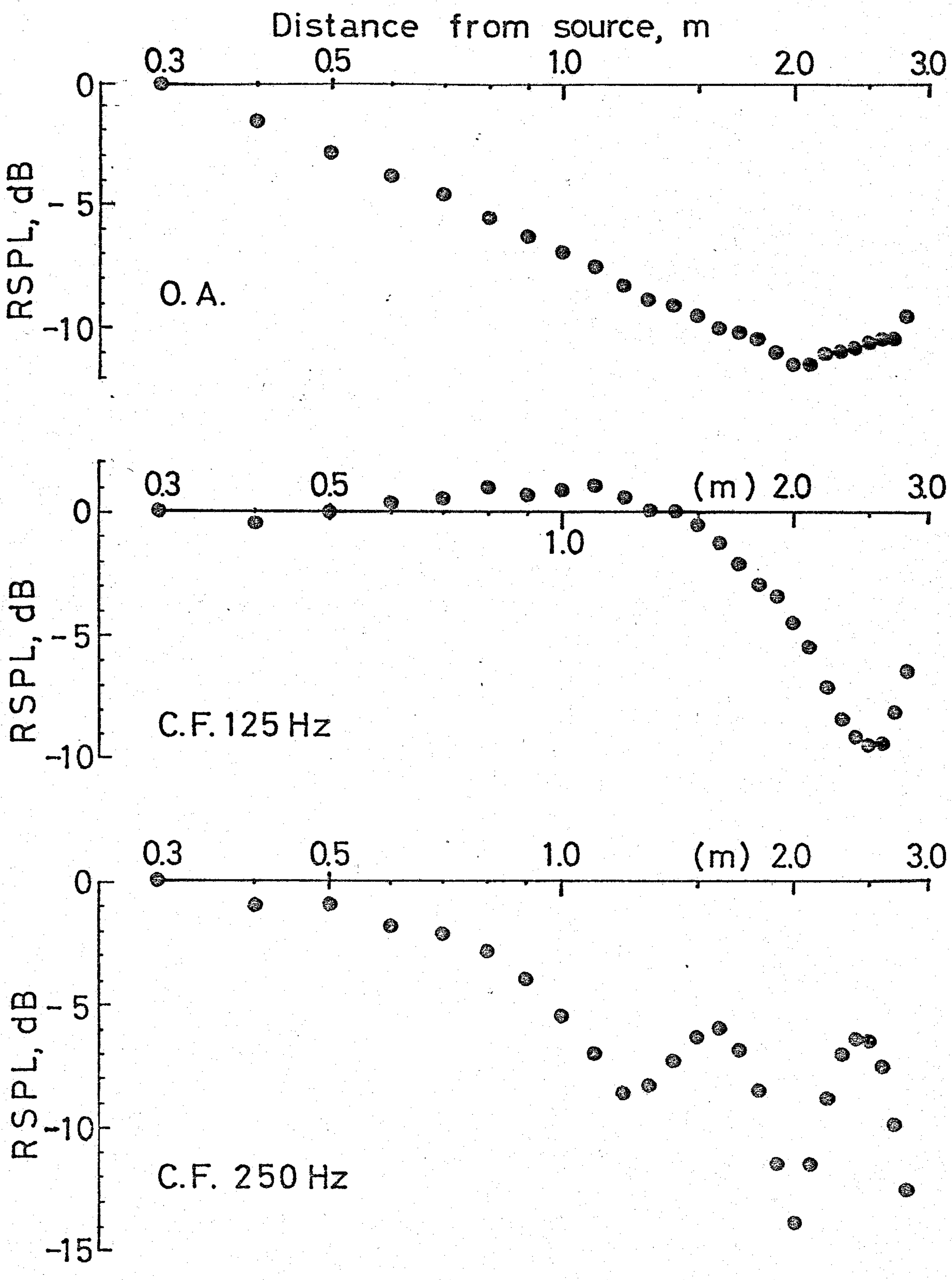
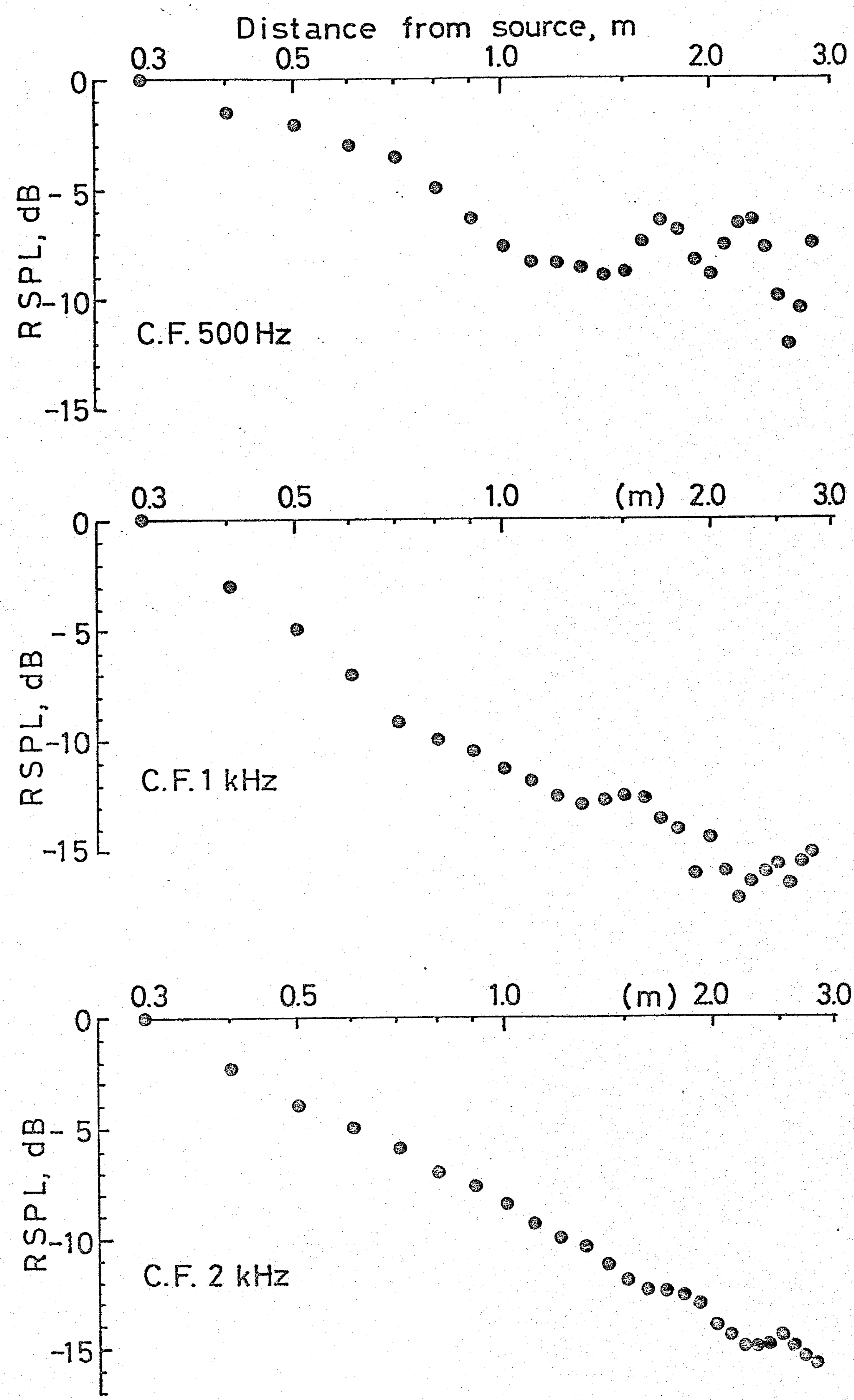


Fig. 2-3-6

SPL versus distance from source in the secondary space (●) and the original space (O). Broad band random noise was radiated from source and each 1/3-oct. band level was plotted. The sound source was placed at the center (III), and the height of the source and the mic. was 1.0 m from the floor.


Distance from source, m
0.3
0.5
1.0
2.0
3.0
0
- 5
-10
RSPL, dB
O. A.
0.3
0.5
(m) 2.0
3.0
1.0
0
-5
-10
RSPL, dB
C.F. 125 Hz
0.3
0.5
1.0
(m) 2.0
3.0
0
- 5
-10
-15
RSPL, dB
C.F. 250 Hz



Distance from source, m
0.3
0.5
1.0
2.0
3.0
0
- 5
-10
-15
RSPL, dB
C.F. 500 Hz
0.3
0.5
1.0
(m)
2.0
3.0
0
- 5
-10
-15
RSPL, dB
C.F. 1 kHz
0.3
0.5
1.0
(m)
2.0
3.0
0
- 5
-10
-15
RSPL, dB
C.F. 2 kHz

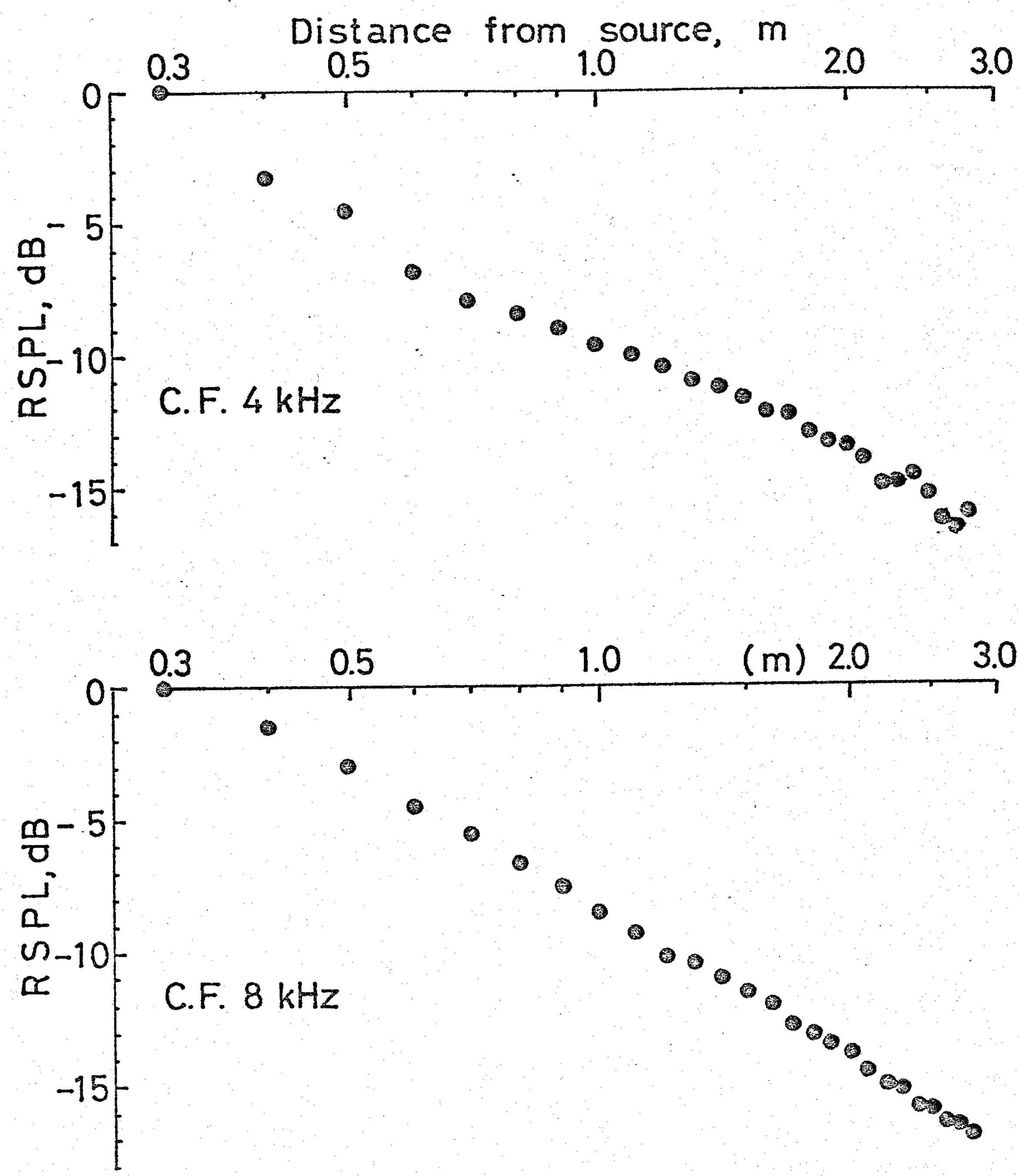


Fig. 2-3-7 SPL versus distance from source in the secondary space. Broad band random noise was radiated from source, and each 1/3-oct. band level was plotted. The location of the source was II, and the height of the source and the mic. was 1.0 m from the floor.

2.3.4. Influence of the hard floor of the test room

The test room was built as the "semi-anechoic" room the floor of which was not arranged acoustically because heavy machines had to be situated on it. Therefore, it must be examined how much effect will be caused on the total room absorption and sound distributions by the hard floor made of concrete mortar, and which is the only reflective plane in the test room.

In this section, the floor of the semi-anechoic test room was covered with the same mats as were used for walls, and then the influence of the reflected sound from it was examined by measuring and comparing the sound pressure level distributions in both two test room conditions.

The ceiling of the room whose floor was covered with mats was opened to outer space. However, the ceiling of the original room (the woodworking shop-room) surrounding the test room is 3.9 meters high, and the surface of which is covered with woodwool-cement boards (see Sec. 2.1.). One may say, therefore, that reflections from the ceiling do not influence to the measurement results given near the floor (the height of 1.0 m from the floor). So, results measured in the secondary space the floor of which was covered with mats were compared with the results given in the previous section without any corrections.

SPL distributions measured about some representative frequency bands were shown in Figs. 2-3-8 and 2-3-9. In this test, broad band random noise was radiated from an isotropic sound source set on the corner (II), and 1/3-octave band

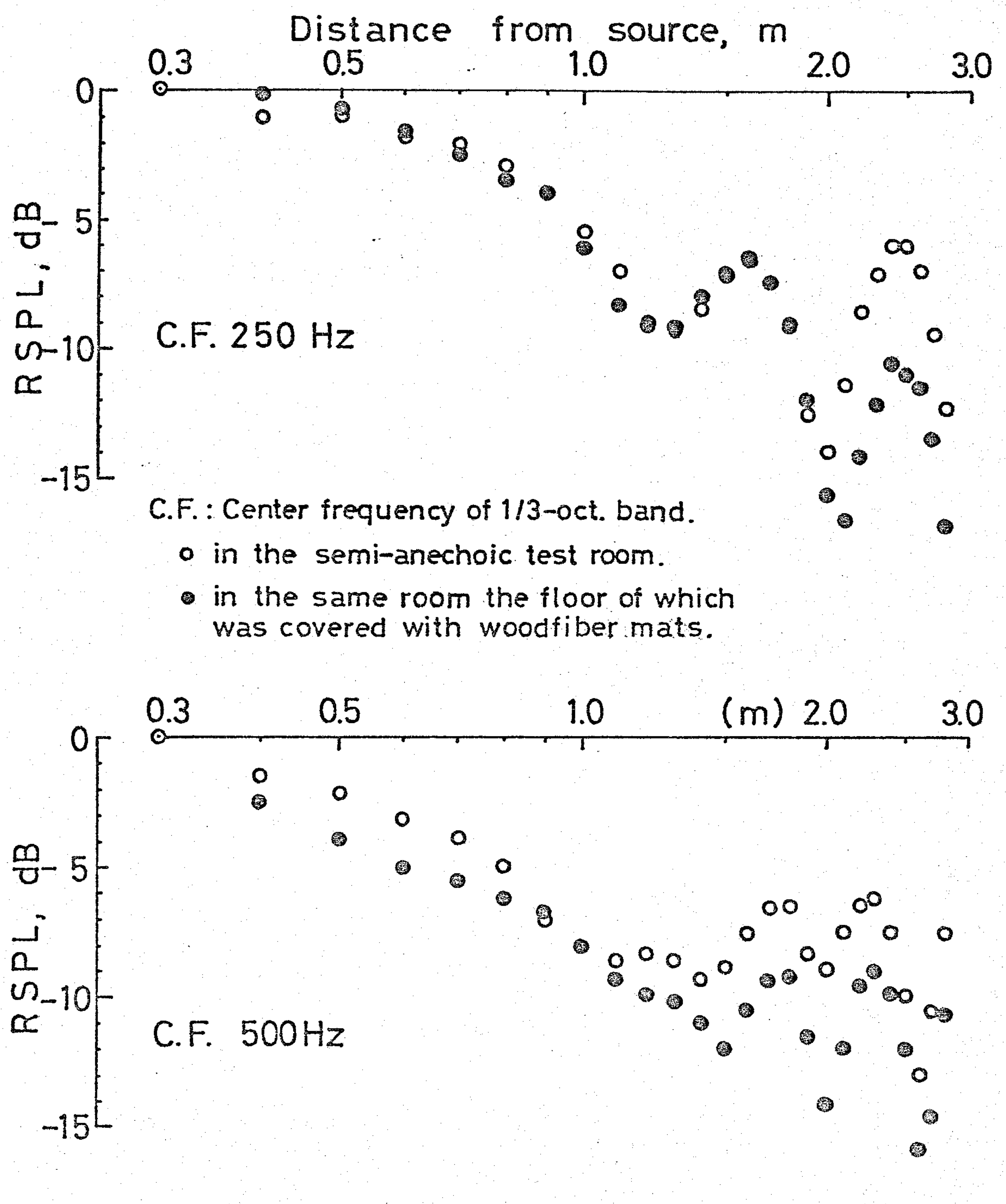


Fig. 2-3-8 Typical 1/3-oct. band (center freq. 250 Hz and 500Hz) SPL versus distance from source at the different floor condition of the semi-anechoic test room. The location of the source was II, and the height of the source and the mic. 1.0 m.

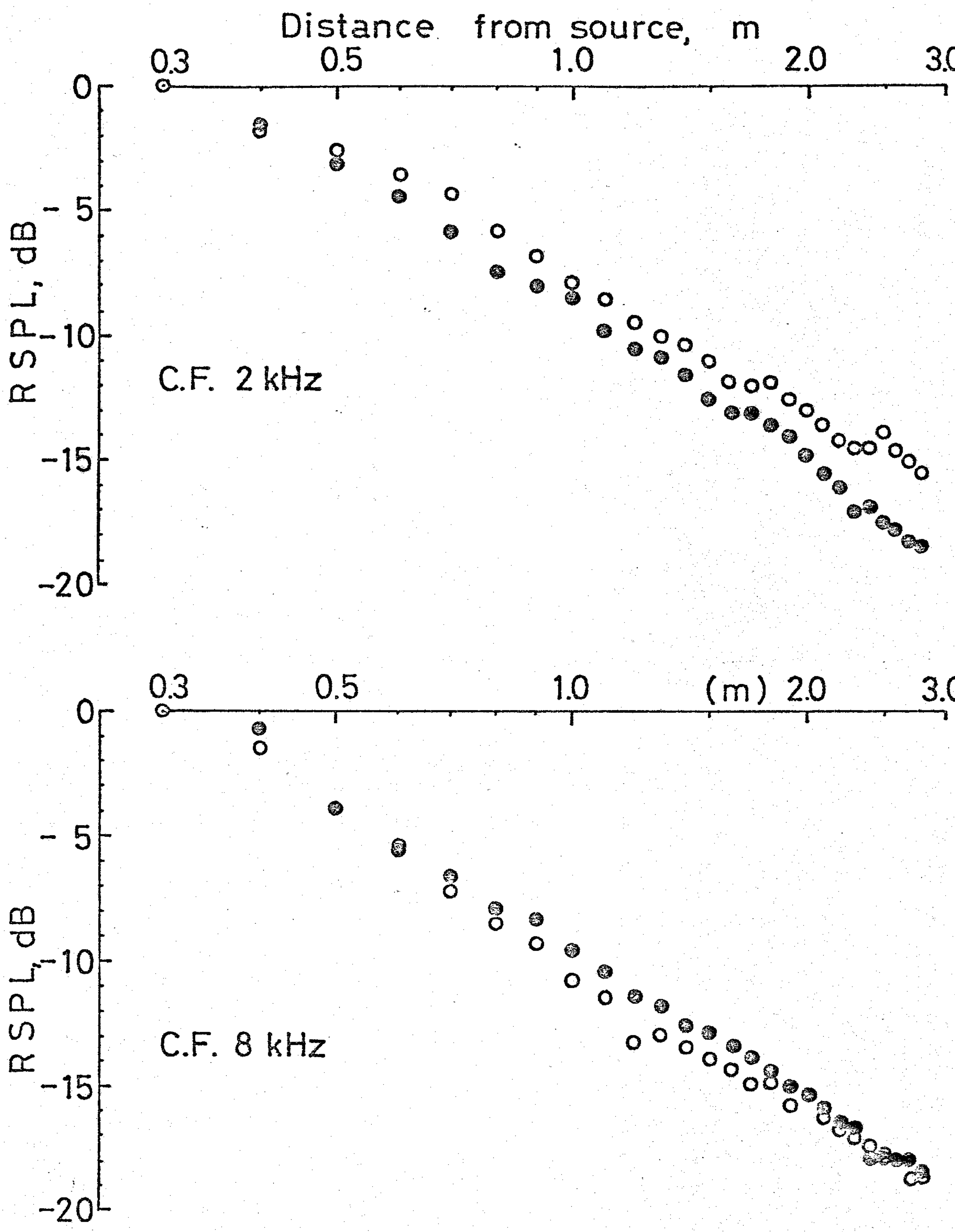


Fig. 2-3-9 Typical 1/3-oct. band (center freq. 2 kHz, and 8 kHz) SPL versus distance from source at the different floor condition of the semi-anechoic test room. The condition of the test was same as previous one.

sound pressure levels were measured at each distance from source. The height of the source and the microphone was both 1.0 m from the floor. The value represented by circle is the result at the semi-anechoic test room the floor of which is uncovered with mats. Alomst no differences are seen on the patterns of distributions between in two room conditions. And in low frequencies, the wavy-formed distribution is also seen. In lower frequency ranges, the sound waves would be reflected from every boundary walls containing the floor, reflect sound waves would interfere to each other or to direct sound waves from source, and more the woodfiber mat has not so large absorption in low frequencise as was expected. Thus, these results would be given. On the other hand, in higher frequencies, the reflected sound wave from the floor uncovered with mats would probably be interfered to direct sound waves from source.[53)54)] But, as the sound radiated from source is not the pure tone (or the single tone) but the band noise, interference patterns created in the sound field would be disappeared with among sound waves that have slightly different frequencies by filling the irregularity of sound pressures. Therefore, the same results would be seen on distributions of sound pressure level in the semi-anechoic room having hard floor as in the room whose floor was covered with woodfiber mat which is absorptive in higher frequencies.

To ascertain this assumption, the similar test was done with a circular saw bench as the sound source. This machine radiates narrow band and high frequency noise which is nearly equal to the single tone (see Fig. 2-1-10).

The result was shown in Fig. 2-3-10. The value plotted

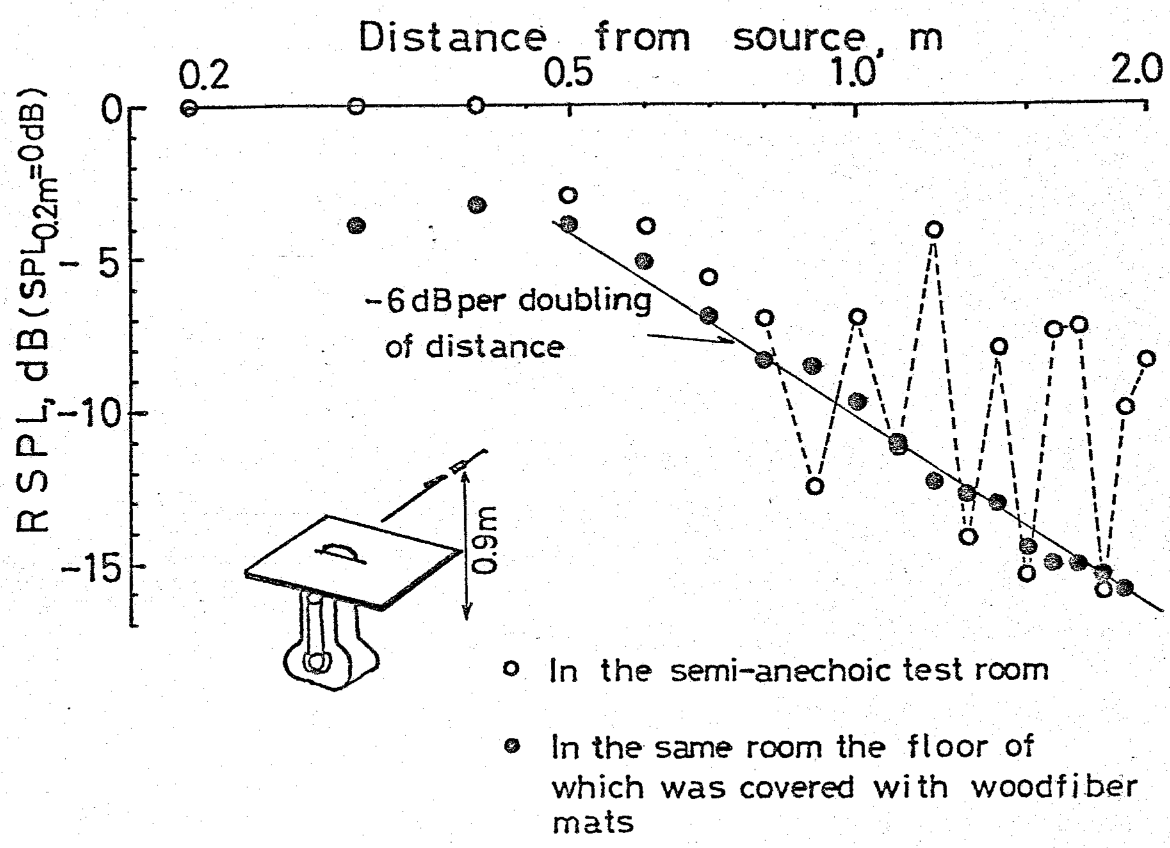


Fig. 2-3-10 SPL versus distance from source at the different floor condition of the semi-anechoic test room. The test room was excited by circular saw noise. The location of the source was the corner (II), and the height of the mic. was 0.9 m from the floor.

with circle is the result given at the semi-anechoic test room the floor of which is not covered with mats. In the room having the absorptive floor, the distribution of sound pressure level is almost theoretical and any fluctuation of levels does not arise. These are caused by woodfiber mats placed on the floor.

We must have the consideration that the effect of the hard floor of semi-anechoic room should not be ignored when high and narrow band frequency noise is radiated from source. And those noises are often radiated from ordinary woodworking machinery.

2.4. The Reverberant Test Room the Walls and the Ceiling were Built of Lauan Plywood

2.4.1. Introductory remarks

From foregoing investigations, it was known that there caused many difficulties on the experiment to create the desirable anechoic test room space readily and cheaply. For examples, the test room should be in "semi-anechoic" condition as the heavy machine must be installed in it, but the hard floor influences to the sound pressure level to be measured. The volume of the test room should be small if it is easily created in any room space, but the narrowness of the volume has negative effect to make the test room anechoic. Even if absorptive materials are used as boundary walls, they would have limits that they should be chosen as ones that are taken cheaply and are used readily.

Results from previous experiments shows that there is some limitations on building semi-anechoic test room with ready manner and with not so expensive materials. So, it was examined, next, to make the test room space "reverberant" in this section. To reflect sound energy will be easier than to absorb it. In a reverberant room to be built, sound energies need not be reflected completely, while they must be absorbed much to be given anechoic fields, because only diffused field is needed as the place for the determination of the sound power of the noise source. The narrowness of the room would have better influence when the reverberant test room is constructed. We need not consider, for instance, the influence of air absorption[55] at high frequencies as the volume of the room is small. If we consider the concept of "mean free path"[56], which is given as 4 V/S (V: room volume, S: surface area of the room), the value of it would become smaller in the test room to be constructed than in the original room. Therefore, sounds shall reflect more frequently at a unit time if the boundary walls are similarly reflective. And thus, diffuse sound fields would be able to be given easily in the narrower spaces.

2.4.2. Built-up of the test room with plywood walls

The reverberant test room was built with lauan plywoods that had the thickness of 21 mm (7-ply), and the surface density of 12.6 kg/m^2. The dimensions of the room were 3 m by 3 m by 3 m (a cube), and which were equal to them of the semi-anechoic test room, as results given in this room had to be the comparable ones with them given in previous sections.
In a general way, the form of the reverberant room is not rectangular, and surfaces of it are not parallel to each other. But, such rooms cannot be built easily, and thus those forms are not suited for the aim of this investigation.

Plywoods were fixed among steel angle frames with bolts and nuts, and small openings were stopped up with paste. The floor made of concrete mortar was not changed the surface with any other materials. For sound measurements, no other obstacles were taken into the reverberant test room than the sound source, the microphone, the microphone stand and the extention cable.

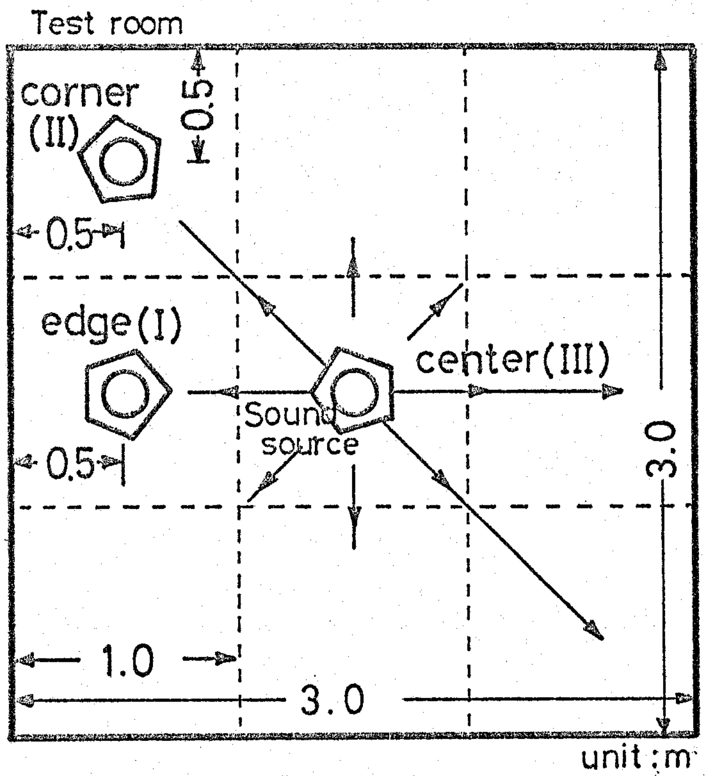
2.4.3. Qualification of the test room

An isotropic sound source was set on the one of three positions of the floor. Source positions and directions that sound pressures were measured were shown in Fig. 2-4-1 (left). The line that the microphone was traced on was parallel to the floor. The height of the source was 1.0 m or 1.4 m from the floor, and the microphone was traced with the same height as the source. See Fig. 2-4-1 (right).

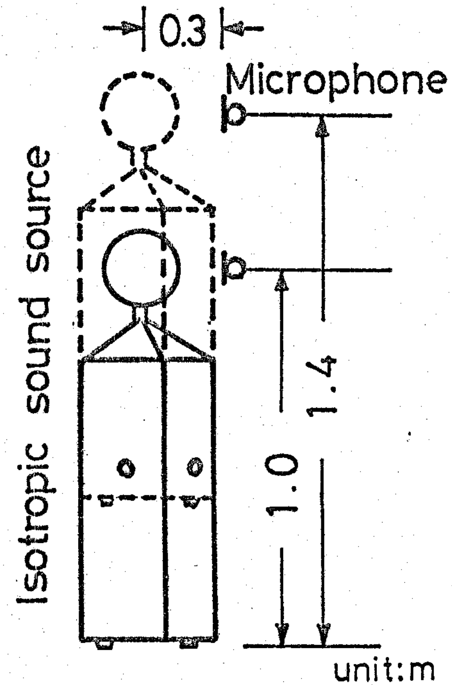
To see the acoustic characteristics of the reverberant test room, the reverberation time was measured with the same method as was used in previous section (Sec. 2.3). (See App. 3.1.) Results were shown in Fig. 2-4-2 about each 1/3-octave band, together with values given in previous two test rooms. Each value is the average. It can be seen from this result that reverberation times becomes especially long among 250 Hz- to 1 kHz-bands in this test room. Average Sabine absorption coefficients ($\bar{\alpha}_{sab}$) were shown in Fig. 2-4-3 compared with ones of the original room for each band. In the reverberant test room, values of them is below 0.1 for all bands measured, and the boundary walls is much reflectable.

If the sound is diffused well in the room, the sound pressure-squared will be same in any positions of the room. This assume was used for evaluating the state of diffusion of the test room, that is, the sound pressure level distribution was measured in the test room and the uniformity of the pressure-squared with changes of position in it was examined to evaluate the degree of diffusion.

When the sound source (an isotropic sound source)



Sound source positions
and measured directions(plan view)



Source and microphone
height

Fig. 2-4-1 The source positions and the measuring directions (left).
The height of the source and the microphone (right).

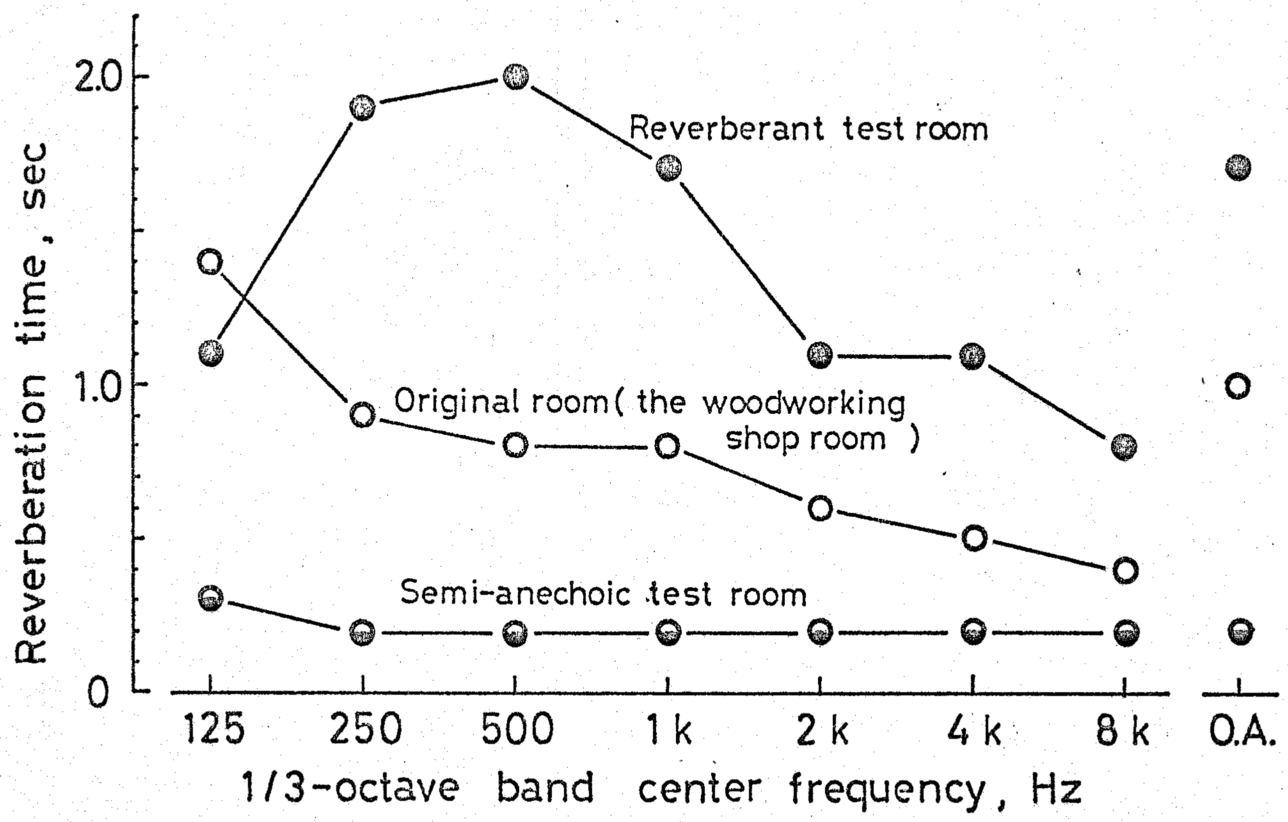


Fig. 2-4-2 The reverberation time versus frequency (1/3-oct. band frequency) among three test rooms (the original room, the semi-anechoic test room and the reverberant test room).

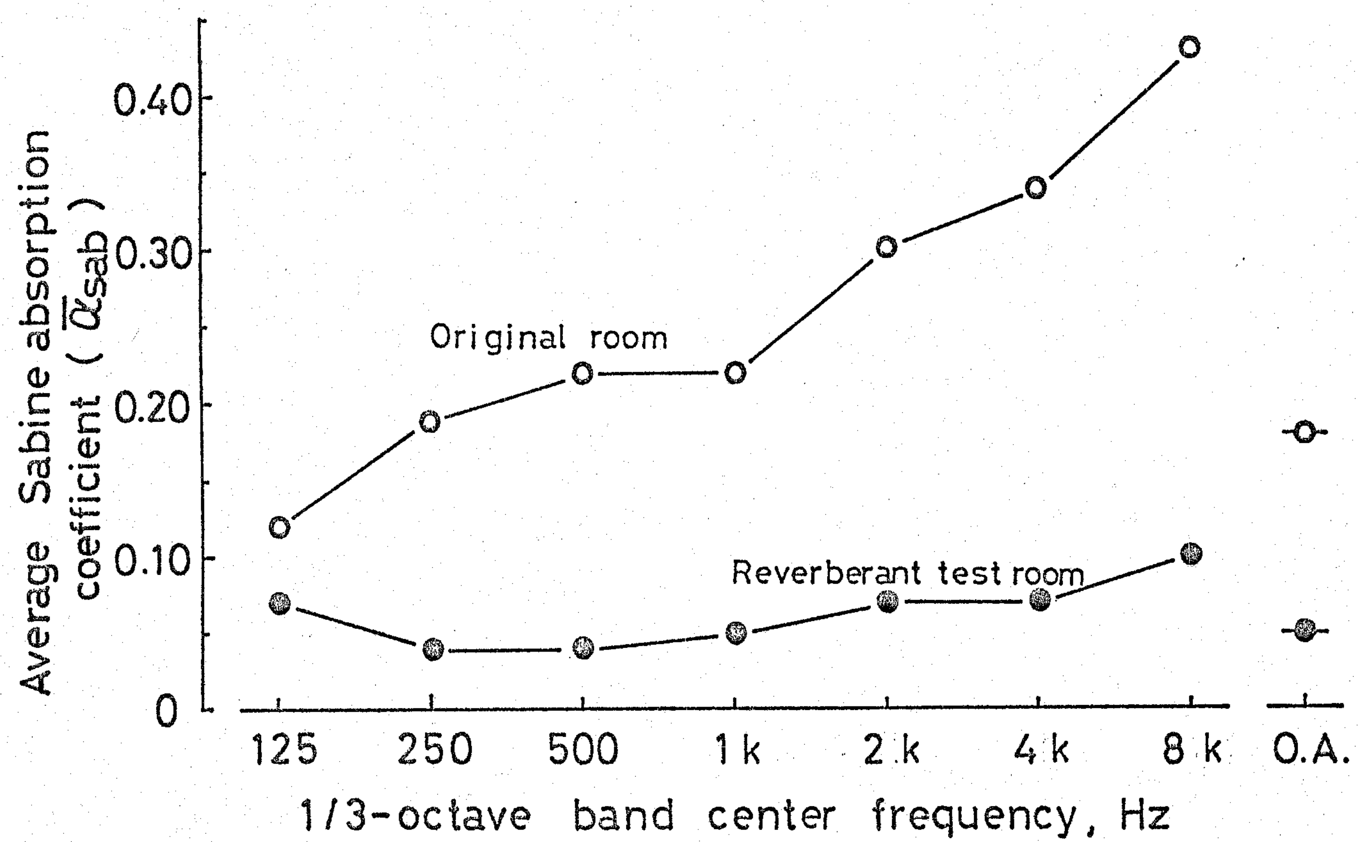


Fig. 2-4-3 The average Sabine absorption coefficient ($\bar{\alpha}_{sab}$) versus frequency (1/3-oct. band frequency).

emitting broad band random noise was placed at the center (III), the sound pressure level was measured along 8 lines in directions of A, B, C, D, A-B, B-C, C-D, and D-A.* Results were expressed in Tables 2-4-1, 2-4-2 and 2-4-3 with quantities of standard deviation. The standard deviations (SD) of O.A. sound pressure levels were shown in Table 2-4-1. In it, the value at each distance from source was the one calculated from 8 values measured at the same distance from source in 8 directions.

* See Sec. 2.3.1, Fig. 2-3-4 center (III).

The value of SD is not more than 0.7 dB and thus the sound field in this reverberant test room is considered to be diffused comparably well for the "broad band" noise.

Results of 1/3-octave band levels, which were also given with the same method as was written above, were shown in Tables 2-4-2 and 2-4-3. Table 2-4-2 represents the result of 250 Hz-band sound pressure levels measured as an example of low frequency band levels, and Table 2-4-3 shows the one given at 8 kHz-band as an example of high frequency bands. In low frequency bands, it can be thought that sound pressures distribute differently in A, B, C, D directions with in A-B, B-C, C-D, D-A directions as SD_3 is much larger than SD_1 or SD_2. In other words, the sufficient diffusion would not be given in the room in low frequency bands. In between 500 Hz- and 2 kHz-band, the standard deviation calculated with same methods were not so different from the one at O.A. But, in high frequency bands above the center frequency 4 kHz, SD was large near the source as one could see in Table 2-4-3. These results were thought to be caused as an isotropic sound source had some directivity in higher frequencies,[52)] and therefore, the

Table 2-4-1 The standard deviation (SD) of SPLs (O.A. levels) given at each distance from source.

r^* (m)	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
SD (dB)	0.7	0.3	0.5	0.5	0.4	0.5	0.5	0.7	0.3	0.4	0.4	0.7

* r: The distance from source.

Above values were calculated from eight data given at the same distance from source in eight measurement directions. Broad band random noise was radiated from source, and O.A. sound pressure level was measured.

Source position: Center (III), The height of the source and the mic.: 1.0 m from the floor.

Table 2-4-2 The standard deviation (SD) of SPLs (1/3-oct. band levels, center freq. 250 Hz) given at each distance from source in each set of measurement directions.

r (m)	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
SD_1* (dB)	0.6	0.8	0.6	0.8	1.1	0.8	0.8	0.3	0.6
SD_2* (dB)	0.7	0.8	0.2	0.4	0.9	0.2	0.3	0.5	0.9
SD_3* (dB)	0.7	0.8	0.6	1.1	1.9	2.0	2.0	2.0	1.6

* SD_1: SD of directions A, B, C, and D

SD_2: SD of directions A-B, B-C, C-D, and D-A.

SD_3: SD of above all directions

Broad band random noise was radiated from source, and 1/3-oct. band (C.F. 250 Hz) SPL was measured.

Source position: Center (III), The height of the source and the mic.: 1.0 m from the floor.

Table 2-4-3 The standard deviation (SD) of SPLs (1/3-oct. band levels, center freq. 8 kHz) given at each distance from source.

r (m)	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
SD (dB)	3.3	2.7	2.2	1.8	1.5	1.3	0.9	0.9	1.0	0.8	1.0	0.8

Above values were calculated from eight data given at the same distance from source in eight measurement directions.
Broad band random noise was radiated from source, and 1/3-oct. band (C.F. 8 kHz) SPL was measured.
Source position: Center (III), The height of the source and the mic.: 1.0 m from the floor.

sufficient diffuse field was not formed near the source. In regions far from source, SD is small in those frequency bands as the sound field is diffused well.

When the source is set near the boundary wall, one can get plenty of space for measurements in a narrow room putting off the near field. In that case, though, it must be considered that the sound energy reflected from the wall near the source might give influence to the sound field, and the total sound pressure might be different from the result given at the source location of center of the room. This question was discussed in the latter part of this section.

In the following, one can see the sound pressure level distribution results when the source was located at the corner or the edge of the floor.

The result of O.A. levels were shown in Fig. 2-4-4 about in two source positions (I and II). The value plotted with circle represents the result given at the source height of 1.0 m, and the one plotted with black spot is the result given at the source height of 1.4 m from the floor. The sound pressure levels distribute similarly and constantly through distance from source exclude near the source and near the boundary wall in both source positions and in both source heights, though levels are slightly different in between two source positions. (There exists the difference of 2 dB at mean values.) The standard deviation calculated from values within regions of the arrow shown in the figure was 0.7 dB at the source position of $I_{1.0m}$, and was 0.3 dB at the source position $I_{1.4m}$. When the source was located at II, SD was 0.6 dB in both source heights.

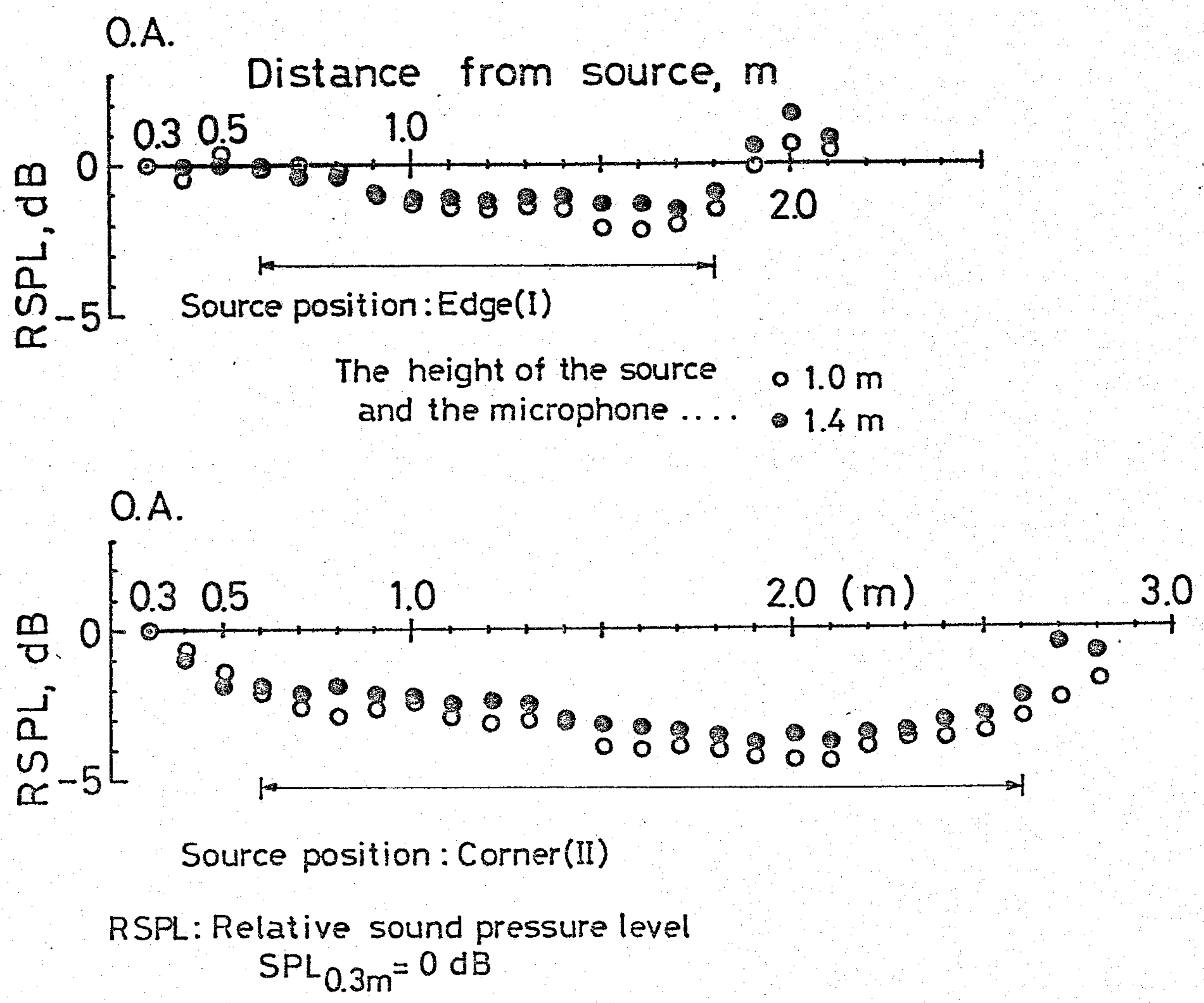
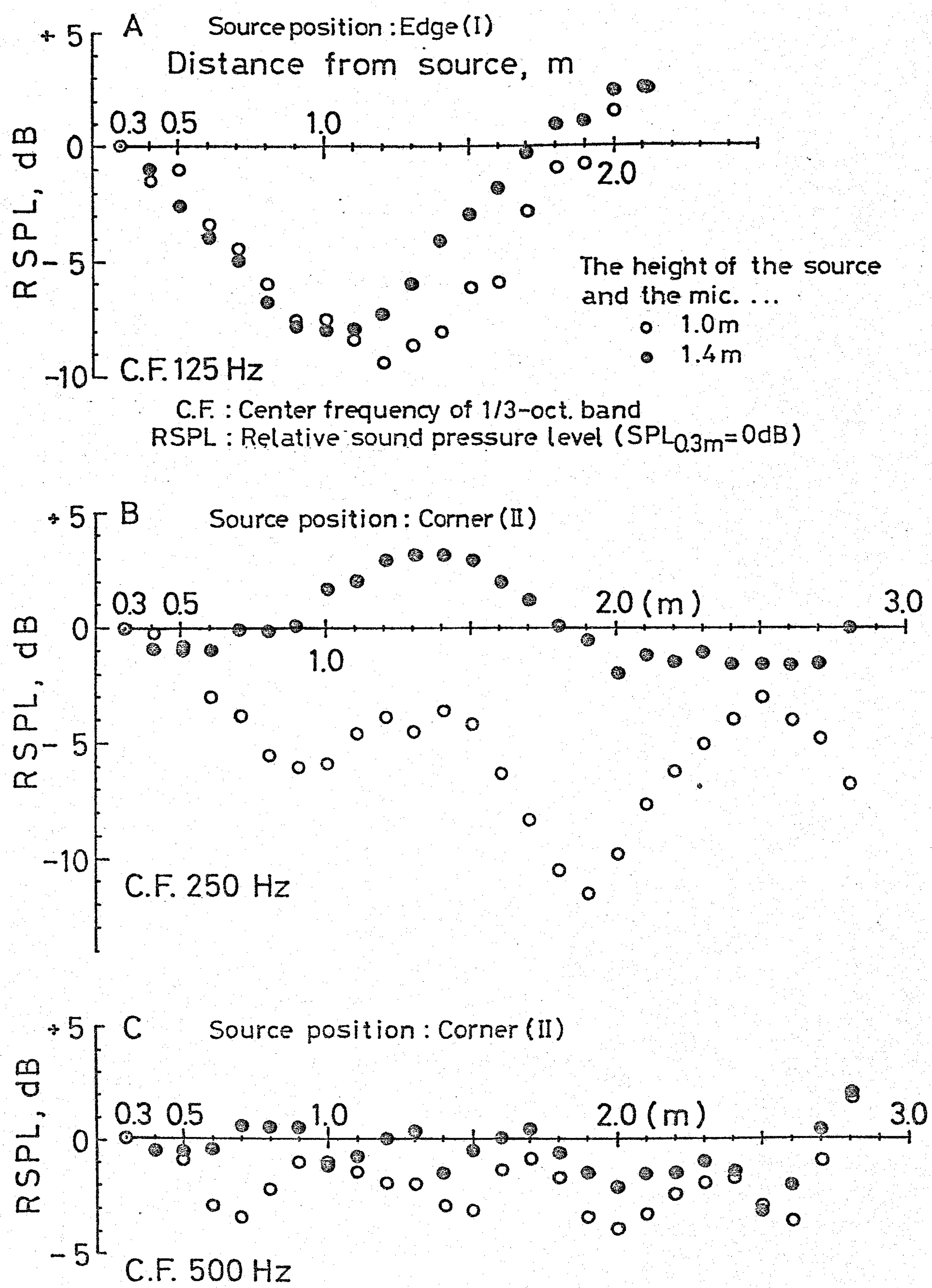


Fig. 2-4-4 SPL (O.A.level) versus distance from source. Broad band random noise was radiated from an isotropic sound source located at the edge (I) or the corner (II) at the height of 1.0 m or 1.4 m from the floor.

The distributions of 1/3-octave band sound pressure levels were shown in Fig. 2-4-5. In it, (A) is the result at 125 Hz-band. In this figure, one can see the wavy-formed pattern of sound pressures distributed along distance from source. The discripancy in levels amounts to 12 dB in this figure. The same tendency on distributions of sound pressures is seen in the result at 250 Hz-band. See Fig. 2-4-5 (B). Diffusion of sound in this test room might not be sufficient as the "reverberant" room in those low frequencies.

In 500 Hz-band, sound pressures are also distributed wavy along distance from source, but the gap of irregularity in levels is not more than 5 dB (see Fig. 2-4-5 (C)). The standard deviation calculated from values shown in the figure was 0.9 dB at the source height 1.0 m, and was 1.0 dB at the source height 1.4 m.

On the other hand, in 1/3-oct. bands above the center frequency 1 kHz, sound pressures were distributed almost same levels along distance from source, and in both heights of the source and in both locations of the source, levels were not different to each other. As an examle of results given in those frequency bands, the result at 2 kHz-band was shown in Fig. 2-4-5 (D). When values measured near the source (within a distance of 0.6 m from source) and near the boundary wall (within a distance of 0.6 m from the nearest wall) were exclude, mean sound pressure level ($\overline{SPL}$) at the source height of 1.0 m was 75.0 dB and the standard deviation (SD) was 0.7 dB, and at the height of 1.4 m these were 74.7 dB ($\overline{SPL}$) and 0.6 dB (SD). And more, standard deviations of 1 kHz- and 4 kHz- band sound pressure levels calculated with the same method were shown in



A
Source position : Edge (I)
Distance from source, m
0.3 0.5
1.0
2.0
+5
0
-5
-10
RSPL, dB
The height of the source and the mic. ...
1.0m
1.4m
C.F. 125 Hz
C.F. : Center frequency of 1/3-oct. band
RSPL : Relative sound pressure level ($SPL_{0.3m}$=0dB)
B
Source position : Corner (II)
0.3 0.5
1.0
2.0 (m)
3.0
+5
0
-5
-10
RSPL, dB
C.F. 250 Hz
C
Source position : Corner (II)
0.3 0.5
1.0
2.0 (m)
3.0
+5
0
-5
RSPL, dB
C.F. 500 Hz

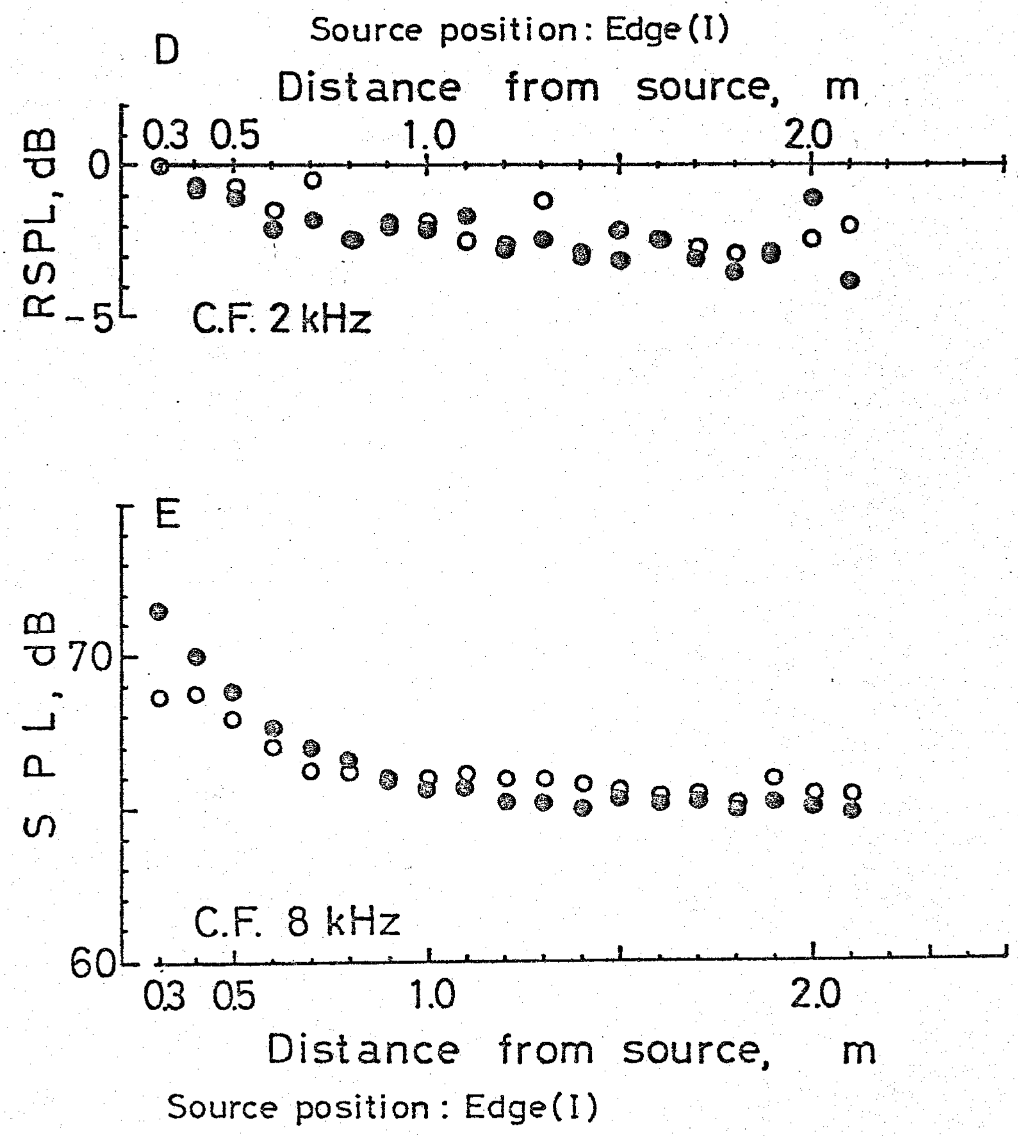


Fig. 2-4-5 One-third oct. band (center freq. 125 Hz, 250 Hz, 500 Hz, 2 kHz and 8 kHz) SPL versus distance from source located at the edge (I) or the corner (II). Broad band random noise was radiated from an isotropic sound source.

Table 2-4-4. Those results represent that neither the height of the source nor the location of the source to be tested influence to the sound pressures resulted in this reverberant test room in those high frequency bands. One, however, must have attention to the result at 8 kHz-band. As it is seen in Fig. 2-4-5 (E), the range where the sound pressure levels distributed is dependent on the distance from source is wider than in other frequency bands. The reason is that the absorption coefficient of the boundary is higher in this band than in other bands as it was already known in Fig. 2-4-3. In Fig. 2-4-5 (E), not the relative sound pressure level but the sound pressure level was plotted to be able to be seen the differences of levels near the source, and these would be caused by the directivity characteristics of the source.

From these results, one may say that sufficient diffusion is able to be given in this reverberant test room at least above 1 kHz-band if the room is excited by "broad band" noise more than 1/3-octave bandwidth.

To see the effect of narrow band noise, the test room was excited by 500 Hz- and 4 kHz-pure tones. For, there would be often containd narrow band frequency components in machinery noises. Results were shown in Fig. 2-4-6 (A) and (B). The height of the source was 1.0 m from the floor. Even in high frequency ranges, sound pressure levels are, apparently, fluctuated. It should be necessary to practice some counter-plan to narrow band noises or pure tones.

The effect of the source location on the average sound pressure levels given in the test room was examined as follows: One-third octave band sound pressure levels were measured at

Table 2-4-4 Standard deviations of 1 kHz- and 4 kHz-band SPLs measured at the source heights of 1.0 m and 1.4 m at two source positions (I and II).

	I	II	I	II	
S.H.* 1.0m	0.6	0.9	0.4	0.3	(dB)
S.H. 1.4m	1.0	0.9	0.3	0.4	(dB)
C.F.*	1 kHz		4 kHz		

* S.H.: Height of the source.

C.F.: Center frequency of 1/3-oct. band

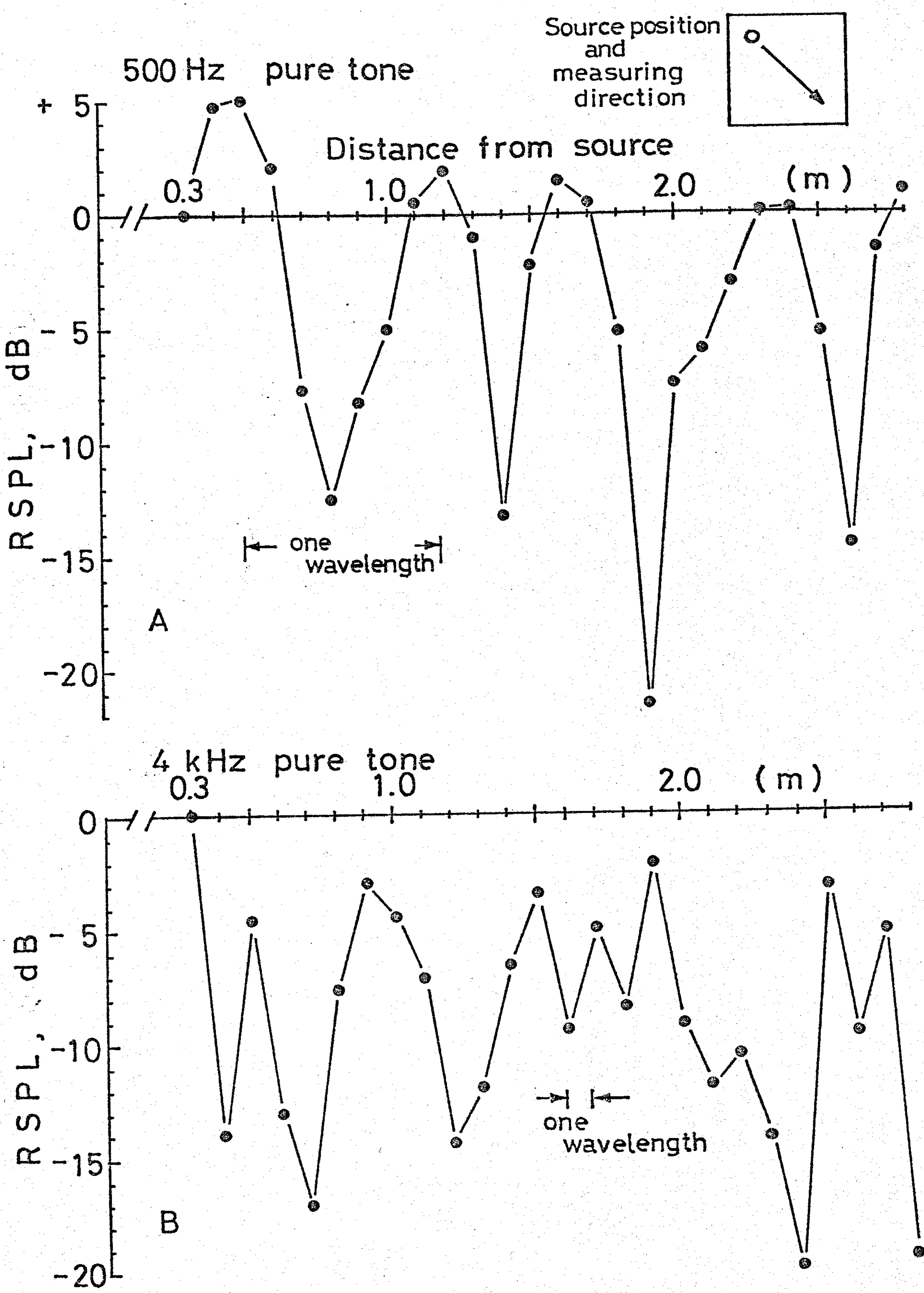


Fig. 2-4-6 SPL versus distance from source. The reverberant test room was excited by 500 Hz or 4 kHz pure tone.

arbitrary 20 points excluded the region near the source and the wall. The sound source was located at the one of three source positions (I, II or III) and at the one of two source heights (1.0 m or 1.4 m) and the mean sound pressure levels were compared to each other. The mean sound pressure level at the source position $III_{1.4m}$ was decided, in this case, as the reference sound pressure level, that is, 0 dB, and others were represented as differences from this level. Results were seen in Table 2-4-5. The mean sound pressure levels ($\overline{SPL}$) and the standard deviations (SD) given from 20 values at the source position $III_{1.4m}$ were also shown in Table 2-4-6 for each frequency band to compare them with ones measured through lines. From this table (Table 2-4-6), it can be recognized that the SD calculated from levels measured at 20 points is few large in low frequencies compared with the value calculated from data measured through lines. The cause of this is thought as follows: The standard deviation given with the former manner contains the dispersion in vertical directions, while it is not contained in results given with the latter manner. At the frequency bands above 1 kHz-band, however, the value of SD is not more than 1.5 dB, and therefore, the test room is thought to be in well diffused condition.

In the 1/3-octave band frequencies above the center frequency 500 Hz, the influence of source location on the average sound pressure level is almost not seen in Table 2-4-5, and these results would be given as the test room was in well diffused conditions in those frequency bands.
When the source was placed at the corner, the value of $\overline{SPL}$ below 250 Hz-band have the difference of few levels compared

Table 2-4-5 Comparison of the average sound pressure levels given at various source positions.

Source position	Center frequency of 1/3-oct. band, Hz							
	O.A.	125	250	500	1 k	2 k	4 k	8 k
	$\overline{SPL}_{dif.}$*, dB							
$III_{1.0m}$	-0.3	-0.1	-0.8	-0.4	-0.3	-0.4	-0.4	-0.3
$I_{1.0m}$	0.4	3.2	-0.2	0.1	0.2	0	-0.4	-0.3
$I_{1.4m}$	0.7	1.3	0	0.9	0.5	0.4	0.1	0.3
$II_{1.0m}$	0.8	5.5	-3.3	0.5	0.3	0.2	0.2	0.6
$II_{1.4m}$	-0.1	-4.0	-2.4	0	-0.6	-0.7	-0.6	-0.4

* Above values represent the difference in levels between $\overline{SPL}$ in each source position and $\overline{SPL}$ in the reference source position ($III_{1.4m}$), that is,

$$\overline{SPL}_{dif.} = \overline{SPL} - \overline{SPL}_{ref.}$$

Table 2-4-6 The average level ($\overline{SPL}$) and the standard deviation (SD) of SPLs measured at arbitrary 20 mic. positions. The sound source was placed at the reference source position ($III_{1.4m}$).

C.F.* (Hz)	O.A.	125	250	500	1 k	2 k	4 k	8 k
$\overline{SPL}$ (dB)	84.2	66.2	73.7	72.3	68.2	70.2	71.8	62.8
SD (dB)	0.8	3.3	1.9	1.7	1.2	0.8	0.6	0.9

* Center frequency of 1/3-oct. band.

with the one at other source positions. The reason is thought as follows, that is, almost all the region where the sound pressure levels are measured corresponds to the near field in case of the source positions I and III, and adequate diffusion is not given in this sound field. While in case of the source position II, the sound field is thought to be composed of few amount of near field region and large amount of far field region if one consider the wavelength of sounds. Therefore, the mean sound pressure levels given at the source position II is much different from others. One may say that the test room is not in well diffused condition in those low frequency bands, and this is caused as the room is relatively small compared with wavelengths of those frequency band noises.

2.5. Installation of Diffusing Equipment in the Reverberant Test Room

2.5.1. Introductory remarks

The reverberant test room built as the place to determine the sound power of the source was in well diffused condition on band noises above the center frequency 1 kHz. (The standard deviation of sound pressure levels calculated from 20 data was not more than 1.5 dB.) However, especially below 250 Hz-band, the sound field was in not so sufficient condition as the "reverberant" test room because of poor diffusion. One should have any ways to achieve diffusion in those low frequency ranges in the test room. Of cource, the negative effect* that will be caused by the narrowness of the room must be considered in the examination.

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* Shults[57] said as follows: In a statistical sense, the number of modes in a bandwidth is dependent only on the volume of the room, the frequency, and the width of the band.

Some methods[57] are existed to achieve diffusion in a room, but in this experiment, the methods to change the shape or to exchange the dimensions of the room were excluded as these are out of the aim of this study. To exchange the acoustic characteristics of the room surfaces with thin aluminum plates or to hang diffusing panels from the ceiling were examined in this study as ways of adding diffusion. Methods and results were written in following two sections.

2.5.2. Diffusing equipments and their effects

a. thin aluminum plates

To exchange the characteristics on **reflections** of sound at boundaries, inner surfaces except the floor part were covered with thin aluminum plates (a thichness of them: 0.5 mm). Plates were nailed on the boundary wall at the intervals of 10 cm as was seen in Fig. 2-5-1.

As one can see in Fig. 2-5-2, the average reverberation times are exchanged in most of 1/3-oct. band in the case of adding plates on the boundary wall. In this figure, values plotted with circles represent the results given in the reverberant test room that the aluminum plates are not added on walls. The reverberation time in the test room whose walls was covered with plates became longer by about 1.0 sec in 125 Hz-band. On the contrary, it was diminished as much as about 0.3 sec to 0.4 sec in 500 Hz- to 4 kHz-band. This result represents that the average absorption coefficient of the boundary in this test room was reduced to the quantity of 1/2 in 125 Hz-band, and it was added by 30 % in above 500 Hz- to 4 kHz-bands.

The degree of diffusion in the test room at 125 Hz-band was compared with decay curves of sound pressure level versus time measured in between conditions of the boundary walls. As reverberation curves recorded with level recorders are changed the scale of irregularity by taking different recording conditions[58] (such as the writing speed of recording pen, or paper speed), one cannot compare the curve with the one measured in

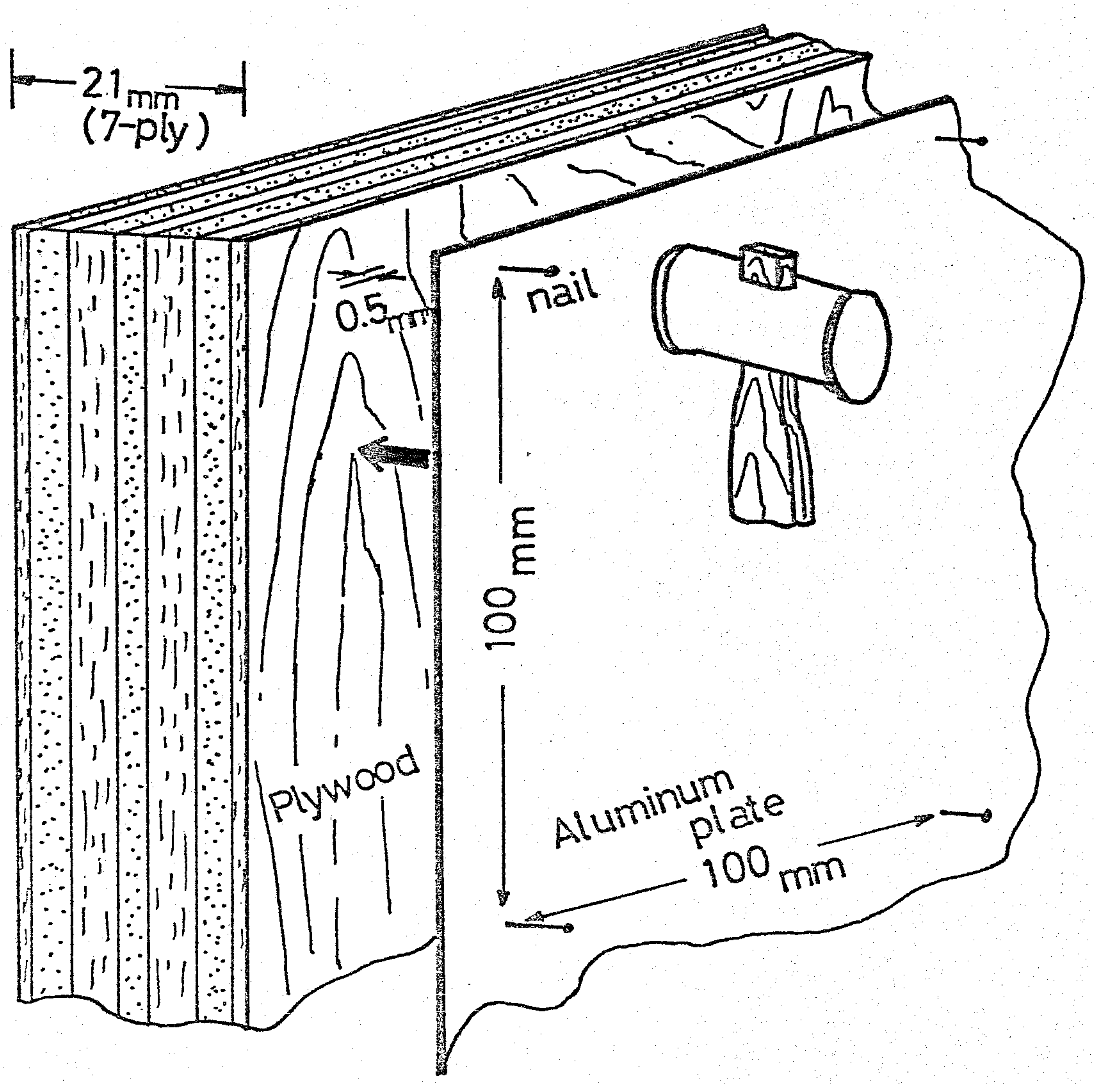


Fig. 2-5-1 An illustration of nailing of thin aluminum plates on the plywood's wall.

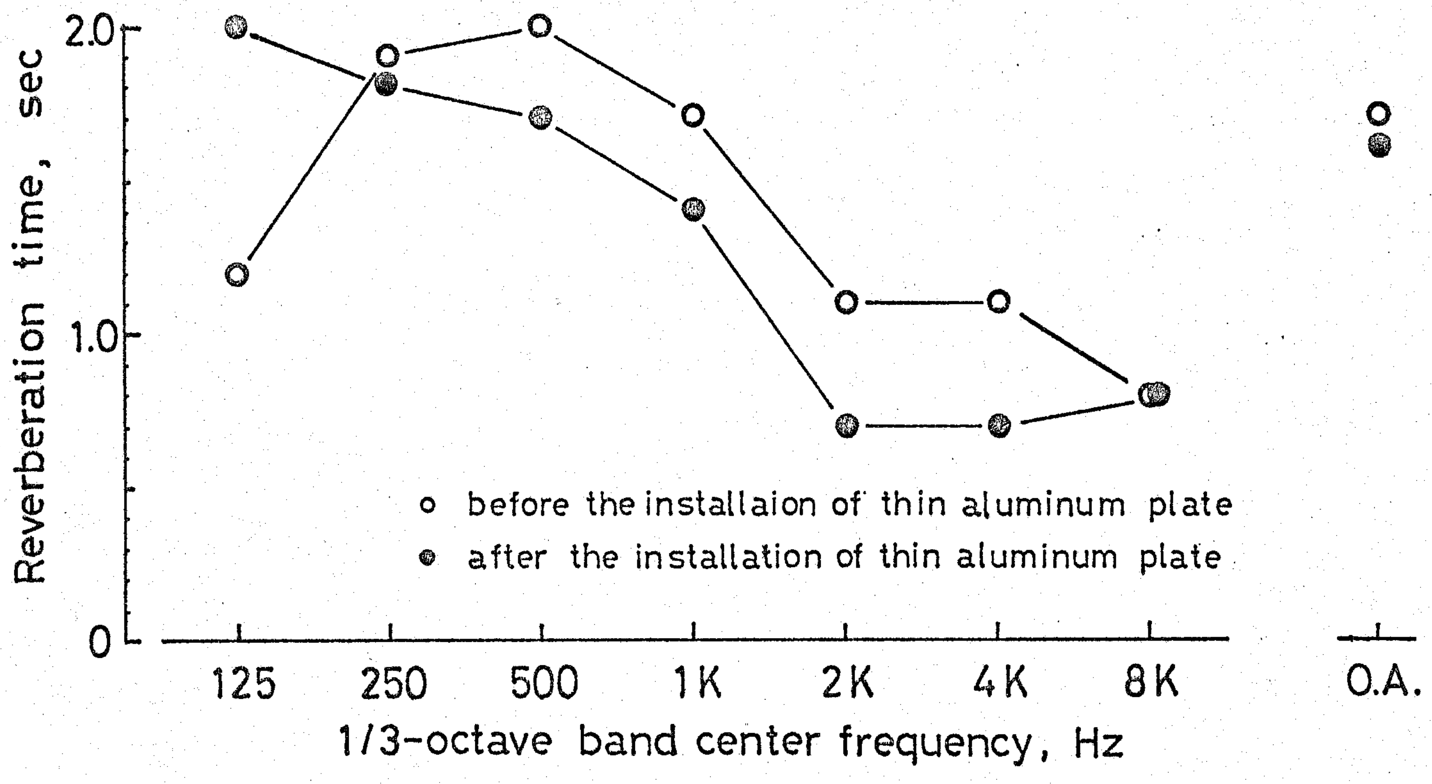


Fig. 2-5-2 The reverberation time versus frequency (1/3-oct. band frequency) in the reverberant test room with different conditions on wall-surface.

another recording conditions. If, however, the condition of recording is same, decay curves are able to to be compared to each other.

Typical decay curves at each two condition of walls were shown in Fig. 2-5-3. These were given at the same recording conditions (Writing Speed: 400 mm/sec, Paper Speed: 30 mm/sec) using B&K Level Recorder, and these curves were chosen from 20 data at each condition of walls. The state of diffusion is thought to be better if the irregularity seen in curves is smaller and if the curves becomes more linear.[59] When we judge results according to these assumptions, the room whose walls are covered with thin aluminum plates is thought to be in more diffused condition in this band. In high frequency bands above this band, no differences were seen in decay curves in both conditions of walls.

Unfastend parts of thin plates nailed to walls would be vibrated[60] by radiated sounds at frequencies above 500 Hz, therefore, sound energies of those frequency sounds would be absorbed. Perhaps, this is the reason why the reverberation time was diminished between 500 Hz- and 4 kHz-band.

The sound pressure level distributions after adding thin aluminum plates on walls were shown in Fig. 2-5-4 with black dots. The value plotted with circle represents the result in the room whose walls were not covered with plates. These results were given when the sound source was located at the edge (I) and the height of 1.0 m from the floor. In this figure, 1/3-octave band sound pressure level distributions at four frequency bands--125 Hz-, 500 Hz-, 1 kHz- and 8 kHz-band--are seen. The horizontal axis represents the distance

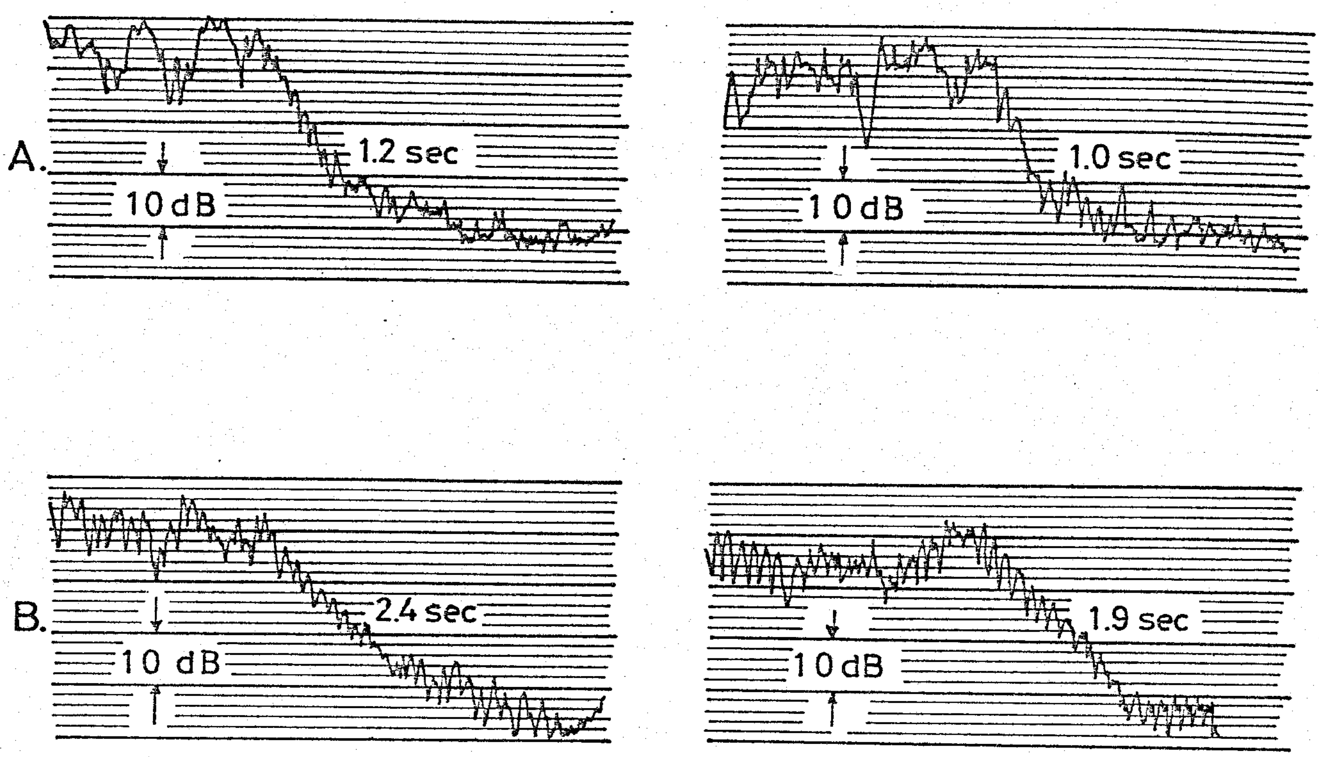
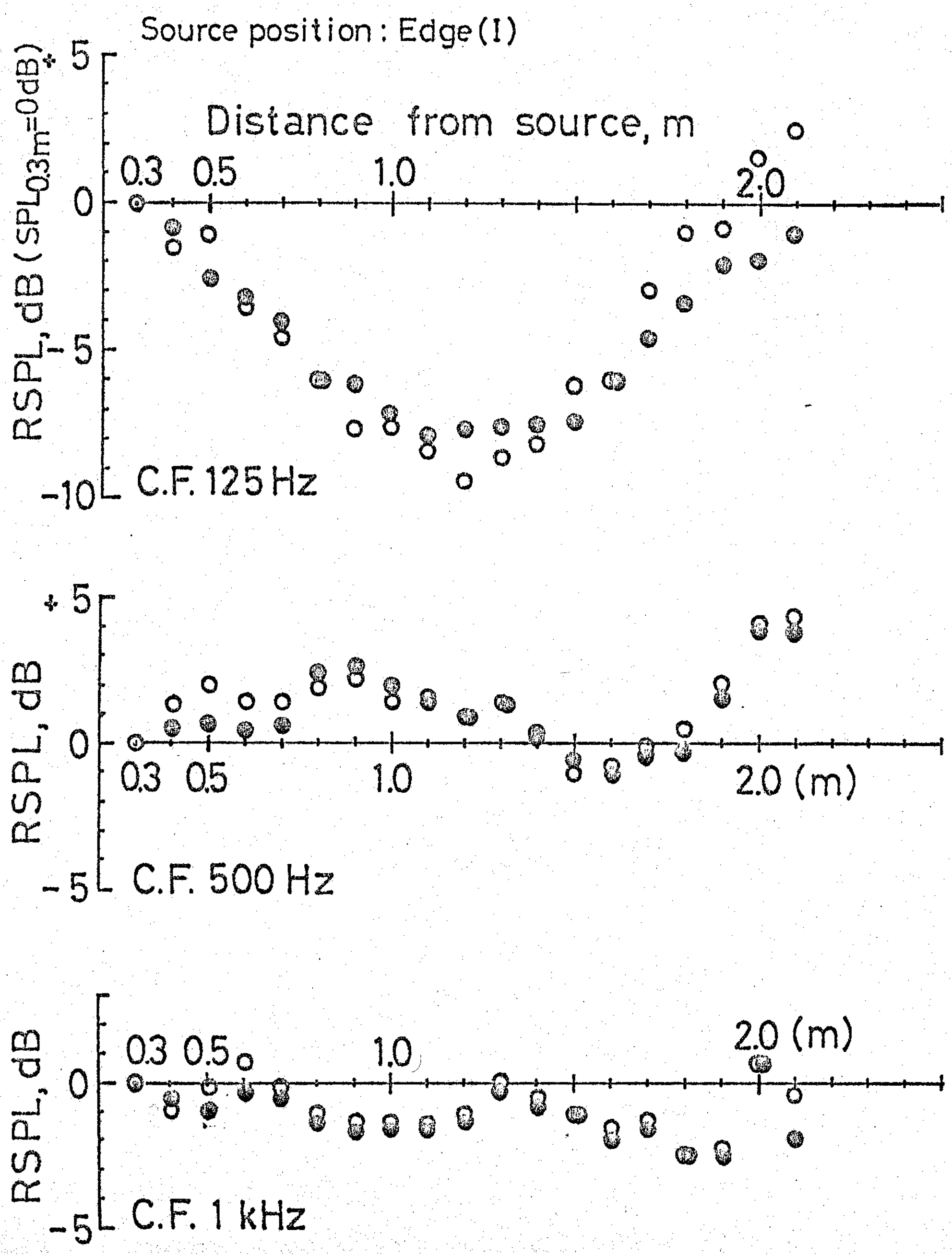


Fig. 2-5-3 Typical decay curves at 125 Hz-1/3 oct. band, given in different surface conditions: A...before the installation of thin aluminum plates, B...after the installation of them.



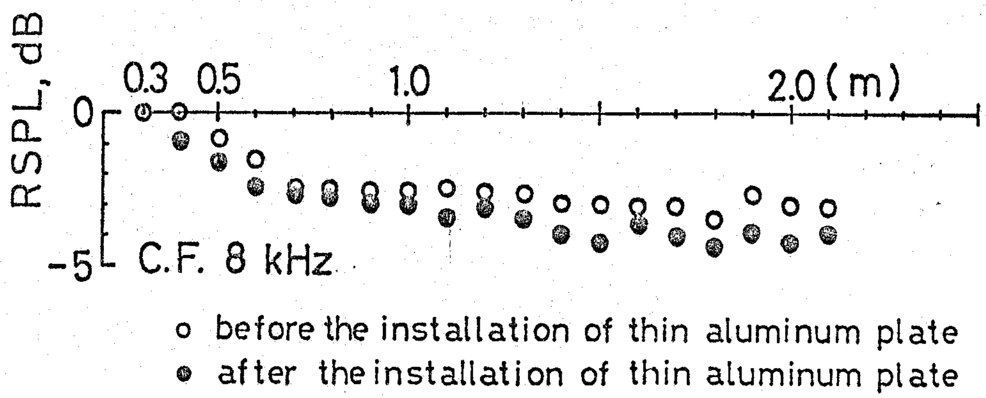


Fig. 2-5-4

One-third oct. band (center freq. 250 Hz, 500 Hz, 1 kHz and 8 kHz) SPL versus distance from source. Broad band random noise was radiated from an isotropic sound source located at the edge (I) and the height of 1.0 m from the floor.
The symbol o represents the result that the wall is not covered with aluminum plates, and the symbol • represents the one that the wall is covered with them.

from source with logalithmic scale, and the vertical axis represents the relative sound pressure level (RSPL) in dB. The sound pressure level at the distance of 0.3 m from source was decided as 0 dB, and levels at other distances were plotted as the differece from the value at this position.

As one can recognize from this figure, almost no disparity is seen in between two results even in 125 Hz-band, and these results would be given as so much reflections of sound could not be given in the test room by additions of aluminum plates as was expected. In conclusion, it may be said that the experiment used the thin aluminum plates had not appeare good effects on achieving adequate diffusion in the room.

b. stationary diffusers made of hard boards

In order to give adequate diffusion in the test room, the method that to introduce the stationary diffusers, i.e., to hang panels was examined in this section.

As diffusing elements, mainly in U.S. acoustical test laboratolies, moving vanes, or rotating diffusers were used for experiments to enhancing diffusion.[35) 61) 62)] They might have apparent effects as auxiliary devices to determine the sound power in reverberant rooms. But, those devices are large and expensive, and therefore, it is improper for us to add them in this reverberant test room. Another method to achieve diffusion in rooms was to add fixed diffusers.[63) 64) 65)] These methods were popular in Europe, especially in Germany. Such panels were often used when the sound absorption coefficient of absorptive samples were measured with the reverberation-room method.[66)] The diffusion of the room would be affected by the size or the number of the panel, so that it would be necessary to be found out the proper condition of them. However, this method was easy to practice and not so expensive. Therefore, in this examination stationary diffusers were used as diffusing elements.

As the material of diffusing panels the hard board, which had the dimensions of 0.9 m by 0.9 m by one unit, and had the thickness of 5 mm, was used. The weight of it was 4.2 kg, and therefore, the surface density was calculated at 5.2 kg/m^2.

In general, besides the wood materials, thin metal plates such as the iron plates were often used as materials of diffusers. But, it is necessary for one to add the vibration isolation such as to coat vibration isolation paints or to grue different sorts of metals, if one use those matal plates. And more, as they are comparatively heavy, it is improper to suspend them so many numbers.

On the contrary, plywoods are lacking in weight compared with hard boards. Therefore, if plywoods have the same surface density as that of hard boards, they must increase their own volume inevitably. They are bulky. These are reasons why hard boards were used for materials of diffusers.

The dimension of the diffuser was decided according to following assumptions: The test room has poor diffusion in below 500 Hz-band. To have the effect in those low frequency bands, the size of diffusers must be as large as the wavelength of the sound concerned.[67] The dimension 0.9 m is equal to about one wavelength of 380 Hz, and the panel whose size is 0.9 m by 0.9 m by one unit would have the ability to act to the lowest frequency sound wave of 500 Hz-1/3 octave band. And more, the diffuser whose dimensions were 1.8 m by 0.9 m was also used in the test. It is the one that two unit panels are linked tightly. The dimension 1.8 m is equivalent to about one wavelength of 190 Hz, and the panel whose size is 1.8 m by 0.9 m would be able to reflect the lowest frequency sound waves of 250 Hz-1/3 octave band.

In the following, the panel whose dimensions were 0.9 m by 0.9 m was denoted by "A" panel, and the one which has the dimensions of 1.8 m by 0.9 m was denoted by the name of "B" panel.

The diffusing panels were suspended from the ceiling by fine threads as it was seen in Figs. 2-5-5 and 2-5-6. In the experiment, the number of plates hung in the test room was 12 by the number of "A" panels, and this numbers were decided after taking following two terms into consideration, that is, the total weights of panels and the quantity of reverberation-time changing with the numbers (and the total surface areas) of them. The combinations of panels and their symbols were collected in Table 2-5-1 together with the total surface areas of them.

If the room were in well diffused condition, the values of reverberation-time measured would not be different in any point of the room.[68] To think them contrariwise, the degree of diffusion in the test room is able to be decided by dispersions of reverberation-time values measured in it. This was used for qualifications of the test room.

The isotropic sound source emitting random noise was set on the corner (II) as almost all normal modes were

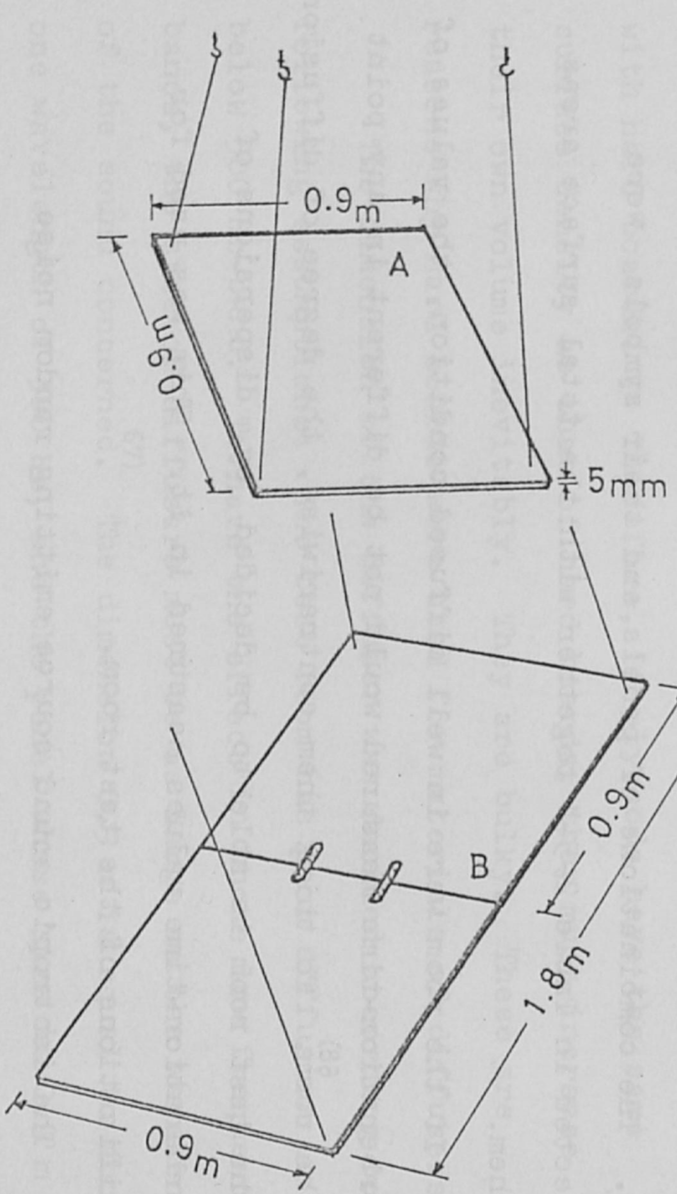


Fig. 2-5-5

A sketch of two types of diffusing panels.

Fig. 2-5-6

A photo taken when the diffusing panels were being hung in the test room.

Table 2-5-1 The conditions of diffusers installed in the reverberant test room.

Symbol	The number of diffusers		Surface areas, m^2
	A^*	B^*	
A_3	3	0	4.9
A_6	6	0	9.7
B_3	0	3	
A_9	9	0	14.6
A_3B_3	3	3	
A_{12}	12	0	19.4
B_6	0	6	
A_6B_3	6	3	

* A: "A" panel, dimensions 0.9m x 0.9m

B: "B" panel, dimensions 1.8m x 0.9m

excited by this position of source.[50) 51)] Results were shown in Table 2-5-2 about at 125 Hz, and 250 Hz-band. The conditions that the total surface areas became same were selected. The values ($\overline{T}$) shown in it are average of 20 data.

In 125 Hz-band, the standard deviation (SD) is slightly larger in the conditions A_{12} and A_6 than in the condition "no diffuser". Except them, however, the quantity of SD is tends to diminish with addition of diffusing panels, and the smallest value is given in the case that only "B" panels are used.

The same tendency is seen in values of average reverberation time. That is, the longest value is given in condition of only "B" panels, and the shortest value in the condition of only "A" panels and this value is almost same as in "no diffuser" condition. When both "A" and "B" panels were used, an intermediate value was obtained.

As above results were given under conditions of the same surface areas on panels, the effect of areas on reverberation times may be neglected.

The reason that the reverberation time was decreased and therefore, the total room absorption was increased in 125 Hz-band by addition of "B" panels is thought as follows: The panel "B" that has the dimension of 1.8 m and which is equivalent to about one wavelength of 125 Hz sound wave would have work on those frequency band noises as obstacles, and it would have been vibrated* by the sound energies of those band noises, and thus, it would absorbed the energies of sound in those frequency bands.

---

* From the measurement, it was found that the panel "B" had the resonance frequency at 82 Hz.

Table 2-5-2 The mean value ($\overline{T}$) and the standard deviation (SD) of 20 data of reverberation time.

	Center freq. of 1/3-oct. band			
	125 Hz		250 Hz	
	$\overline{T}$, sec	SD, dB	$\overline{T}$, sec	SD, dB
A_{12}	2.0	0.3	1.8	0.2
A_6B_3	1.6	0.2	1.6	0.2
B_6	1.2	0.1	1.6	0.2
A_6	1.9	0.5	1.7	0.1
B_3	1.3	0.1	1.6	0.1
N.D.*	2.0	0.2	1.8	0.3

* N.D.: No diffuser condition

Decay curves of sound pressure level versus time were also compared with in conditions of A_{12}, B_6 and A_6B_3 that had the same surface areas. Results were shown in Fig. 2-5-7. Obviously, differences in curves would be seen from the figure.

In 250 Hz-band, the value of reverberation-time is not different in each diffuser's condition including "no diffuser" condition. However, the value of SD becomes smaller with addition of panels. Moreover, though one could not see from tables, the value of reverberation-time was not different in any condition of diffusers (T = 1.6 sec to 1.7 sec), and the value of SD was not more than 0.1 sec in high frequency bands above 500 Hz-band. The reason is thought as follows, that is, adequate diffusion was already given in the test room before installing diffusing elements, and therefore the effect of the addition of them was not come out.

To evaluate the state of diffusion in the test room installed the diffusers, sound pressure level distributions were also measured at each diffuser's condition. The isotropic sound source was placed at the corner (II) with the height of 1.0 m from the floor, and broad band random noise was radiated from it and each 1/3-oct. band SPL was measured including the O.A. levels. The sound pressure levels were measured at arbitrary 20 points in the test room and the standard deviations were calculated. Results were given in Table 2-5-3 for all conditions of diffusers tested.

The standard deviation at 125 Hz-band is about 3 dB and this value is few larger than that in other bands. And, at the condition of only "A" panels, the quantity of SD tends to become large compared with that of "no diffuser" condition. However,

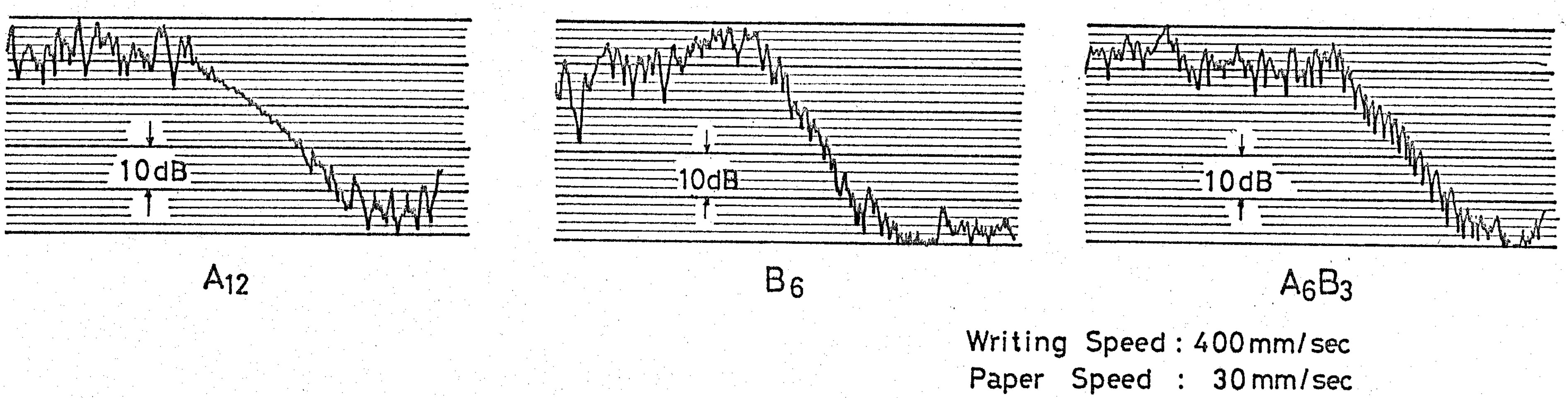


Fig. 2-5-7 Examples of 125 Hz-1/3 oct. band noise decay curves at three different conditions on diffusers.

Table 2-5-3 The mean value ($\overline{SPL}$) and the standard deviation (SD) of SPLs (1/3-oct. band levels) measured at arbitrary 20 mic. positions at every test conditions of diffusers.
The sound source was located at the corner (II), and the height of 1.0 m from the floor.

		Center frequency of 1/3-oct. band, Hz						
	O.A.	125	250	500	1 k	2 k	4 k	8 k
A_{12}	86.5	71.2	71.8	75.3	70.1	70.2	72.1	65.0
	(0.9)	(2.9)	(2.0)	(1.2)	(0.9)	(1.1)	(0.7)	(0.9)
A_9	86.4	71.6	71.9	75.3	70.3	69.9	72.0	65.4
	(1.1)	(3.5)	(1.5)	(0.8)	(0.6)	(1.0)	(0.8)	(1.0)
A_6	86.7	72.0	72.0	75.5	70.1	69.8	72.3	65.5
	(0.8)	(4.0)	(1.5)	(0.9)	(0.7)	(1.1)	(0.9)	(1.0)
A_3	86.5	71.9	71.9	75.3	70.5	70.3	72.1	65.5
	(1.0)	(3.3)	(2.1)	(1.3)	(0.7)	(0.9)	(0.9)	(1.0)
B_6	85.9	71.6	71.6	74.4	69.9	70.0	71.3	64.3
	(0.8)	(2.2)	(1.5)	(1.7)	(0.7)	(1.1)	(1.0)	(0.9)

B_3	86.1	71.1	72.1	75.4	70.0	70.0	71.7	64.9
	(1.0)	(2.6)	(1.8)	(1.5)	(0.9)	(0.7)	(0.8)	(0.9)
A_6B_3	86.0	69.8	71.1	75.8	69.6	70.1	71.9	64.9
	(1.0)	(2.9)	(1.5)	(1.3)	(0.6)	(1.0)	(0.7)	(1.1)
A_3B_3	86.0	70.0	71.7	74.9	70.4	70.4	71.9	65.1
	(0.9)	(2.6)	(2.3)	(1.0)	(0.7)	(0.7)	(0.9)	(0.7)
N.D.	86.7	72.7	71.6	76.8	70.0	71.0	72.4	66.0
	(1.1)	(2.7)	(2.2)	(1.6)	(0.8)	(0.7)	(0.9)	(0.8)

Unit: dB

( ) is the standard deviation value.

it can also be seen that "B" panels work to diminish the degree of dispersion of sound pressures, and this results prove that "B" panels act on 125 Hz-band noises. But, the value of SD in condition of only "B" panels is not so different as that in " no diffuser" condition. These would be caused as the dimensions of the test room was not so long against the wave-length of those low frequency sounds that the sound field became not well diffused condition, and thus, the "B" panel represented the sufficient effect as a result.

In 250 Hz- and 500 Hz-bands, the standard deviation of sound pressure levels becomes small by adding panels. Especially at the condition of A_9, good values of SD could be given.

Above 1 kHz-band, the value of SD was almost same (about 1.0 dB) at any diffuser's conditions containing "no diffuser" condition. The reason is thought as follows, that is, as it was written before, sufficient diffusion was already given in this test room for random noise at least above 1 kHz-band, and therefore the effect of diffusers could not be realized apparently in results.

ISO 3740[69] had given the uncertainty in determining sound power levels at the largest value of the standard deviation in dB. These values in reverberant test circumstancies were shown in Table 2-5-4 (3741[20], and 3742[21]--reverberation room meeting special requirements; 3743[22]--special test room). Though these values are standard deviations of sound power levels, it thought to be nearly equivalent to ones of sound pressure levels as sound power levels should be calculated from sound pressure levels measured in the room.

Table 2-5-4 Uncertainty in determining sound power levels, expressed as the largest value of the standard deviation in dB as given by ISO 3740.

Oct. bands (Hz)	125	250	500	1 k to 4 k	8 k	A
1/3-oct. bands (Hz)	100 to 160	200 to 315	400 to 630	800 to 5 k	6.3 k to 10 k	
3741, 3742	3	2	1.5		3	-
3743	5	3	2		3	2

Judging from values given in this table, this reverberant test room is thought to be in allowable condition as the place for the determination of sound power levels of the source.

3. SOUND PRESSURE LEVELS AND SOUND POWER LEVELS OF THE WOODWORKING MACHINERY

3.1. Introductory Remarks

The methods for constructing some test rooms which were given readily and cheaply according to the aim of this study, and the experiments for evaluating those rooms were described in Chapter 2. Examinations were done with techniques of architectural acoustics using broad band random noise. However, we cannot conclude that test rooms were qualificated completely if results of the machinery noise sources had not been given. The reason is that the machinery emits narrow band noises and the results given from them will make appear the practical merits or demerits of those test rooms.

In this chapter, the sound distribution results given in previous test rooms excited by usual woodworking machinery noises were described. And more, the sound power levels of those machinery sources were calculated with values of sound pressure levels measured in each test room and they were compared to each other.

3.2. In the Semi-anechoic Test Room

A single surface planer, a router machine and a circular saw bench were used as the sound source. Specifications of those machines were written in App. 1. Noises of those machines were analyzed by constant percentage (3%) frequency analyzer and results were already shown in Figs. 2-1-10 and 2-1-11 on single surface planer noise and circular saw noise, and the result of router machine noise was shown in Fig. 3-2-1. From those results, it can be recognized that the single surface planer radiates low frequency and narrow band noise (main two peaks exist at frequencies 250 Hz and 500 Hz), and the router machine has the main peak at the frequency 200 Hz, but it has, also, many peaks of similar levels in comparatively broad frequency range, and the circular saw radiates high frequency and too narrow peak noise (main peak exists at the frequency 4 kHz).

Those machines were set on near the edge or near the corner of the floor in turn in the test room, and the sound pressure levels were measured with the same method as was written in previous sections. Results were shown in Figs. 3-2-2, 3-2-3 and 3-2-4. The horizontal axes of these figures represent the distance from source with logalithmic scale, and values represented by circles are the results given in the original room space, i.e., in the woodworking shop-room. The straight lines drawn in figures represent the theoretical decrease of sound pressure level according to inverse square law.

In the case that a single surface planer was used as the source and it was set on the corner (II), sound pressure levels

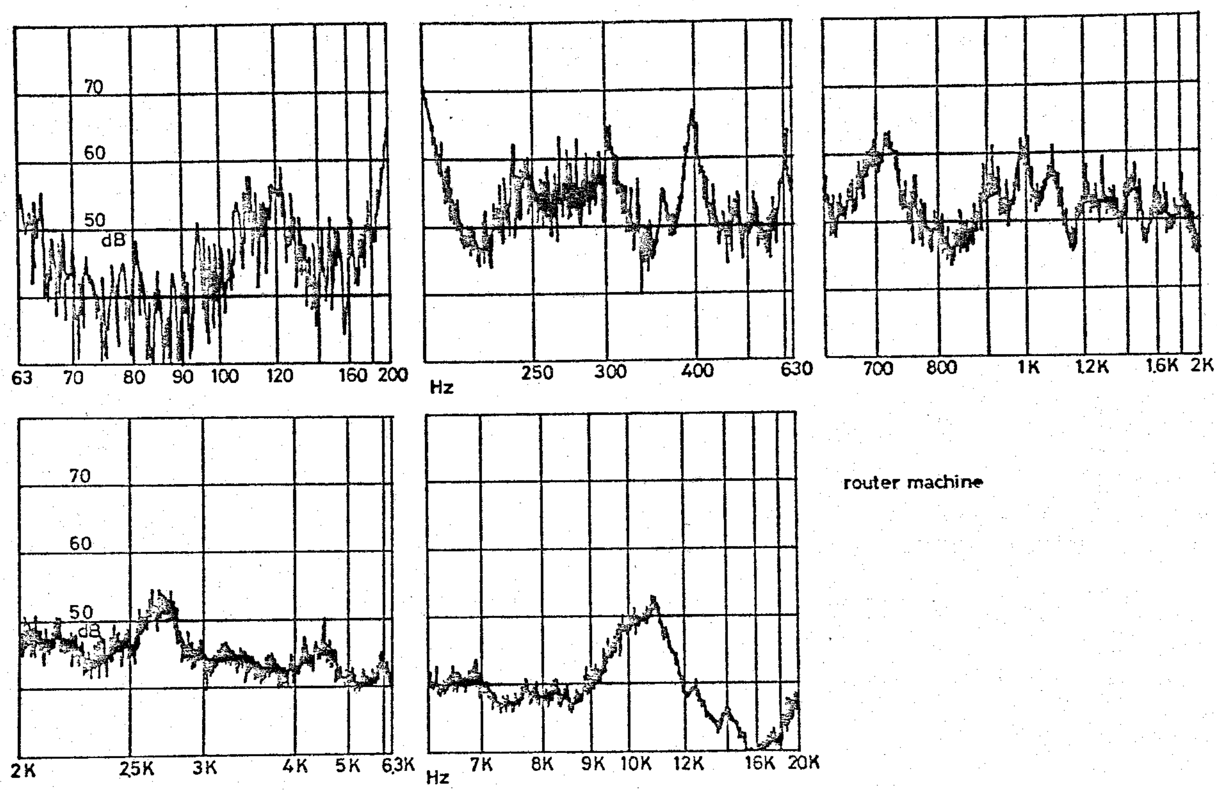


Fig. 3-2-1 Frequency analysis of router machine noise.

measured in the semi-anechoic test room were plotted with black dots in Fig. 3-2-2. The O.A. sound pressure level was measured at the side of infeed opening of the planer, and the height of the microphone was 0.9 m from the floor. From this figure, it can be seen that the sound pressure decreases the level almost theoretically and the wavy-form pattern in distribution curves might be disregarded, while this wavy pattern is obviously seen in the original room space. The similar result was seen in Fig. 3-2-3. It was the result given in the case that a router machine was used as the sound source and it was located at the edge (I). The height of the microphone was 1.1 m from the floor.

From these results given by low frequency noise sources, it was realized that the free field condition was able to be formed in the range from near the source to near the boundary wall in this semi-anechoic test room. On the other hand, in the case that a circular saw bench was used as the source, there was seen a violent fluctuation of levels in distributions as it was shown in Fig. 3-2-4. As was already mentioned in Sec. 2.3.4, this phenomenon was caused by reflected sound waves from the concrete mortar floor that was the only reflectable surface for high frequency sounds. Figure 3-2-5 represents the frequency analyses results given at distances of 1.4 m and 1.5 m from circular saw bench. One can see that the main peak at the frequency of 4 kHz was vanished in the underside figure. This phenomenon would be caused by the interference between direct sound waves and reflected sound waves. Especially high and narrow band noises such as circular saw noise, the sound field in the semi-anechoic test room is

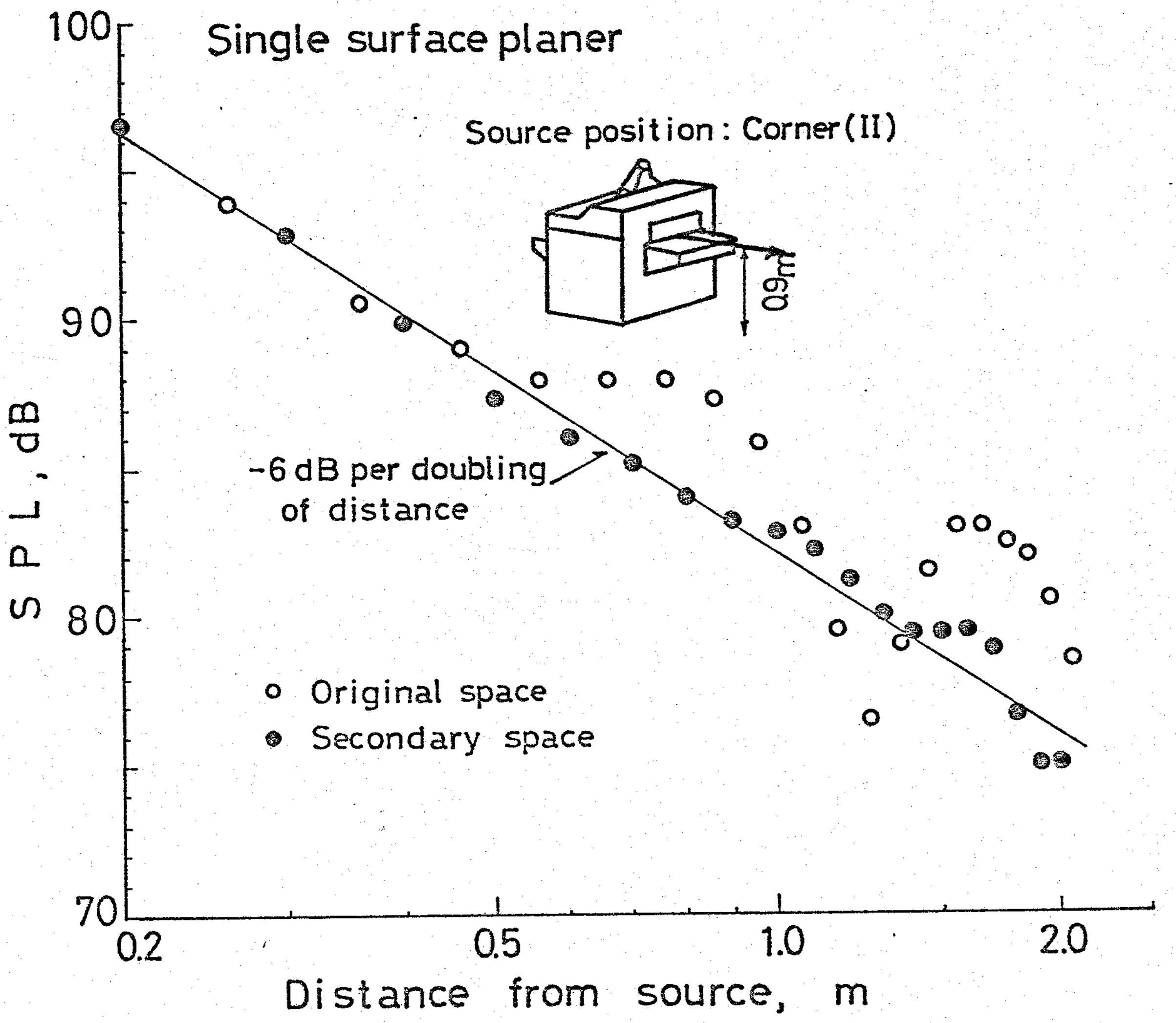


Fig. 3-2-2 SPL versus distance from source. The test room (the semi-anechoic test room--the secondary space, or the woodworking shop room--the original space) was excited by single surface planer noise.

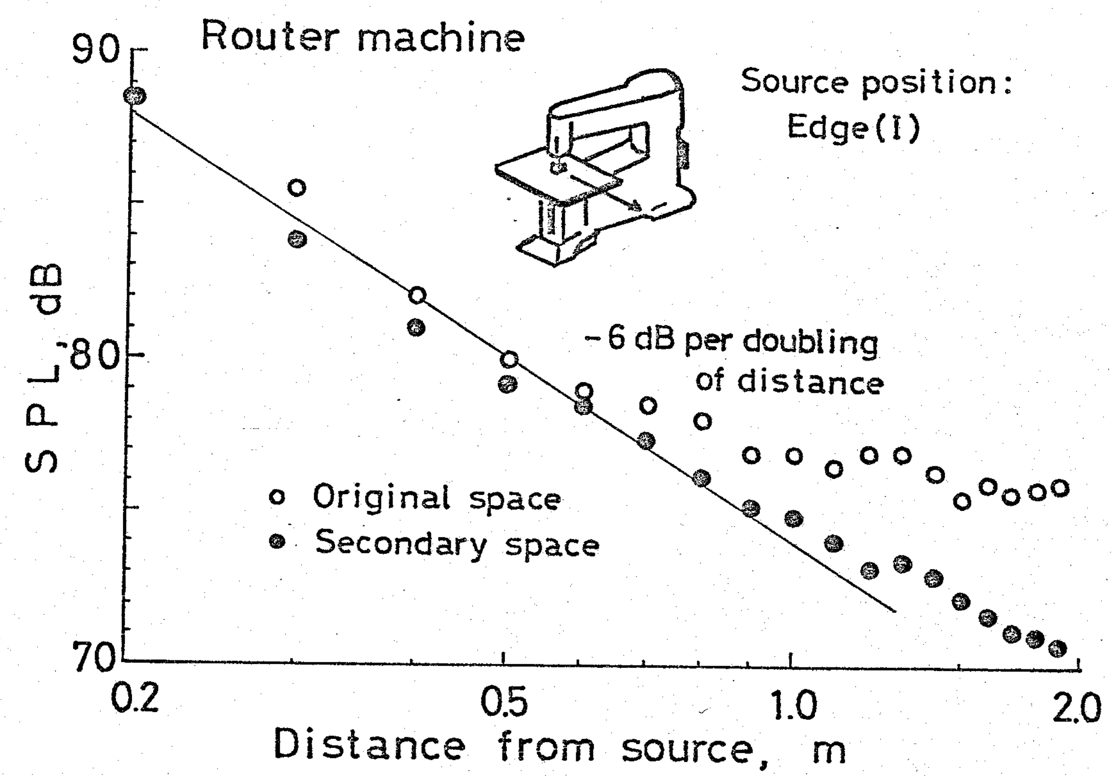


Fig. 3-2-3 SPL versus distance from source (the router machine) in different test rooms.

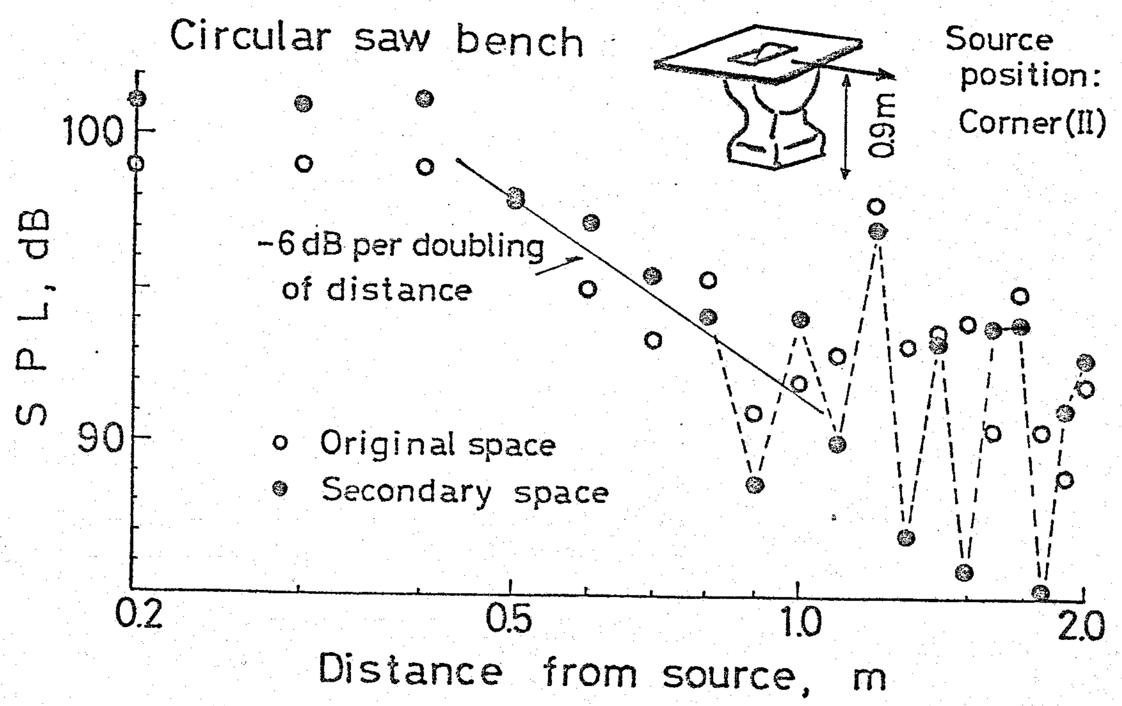


Fig. 3-2-4 SPL versus distance from source (the circular saw bench) in different test rooms.

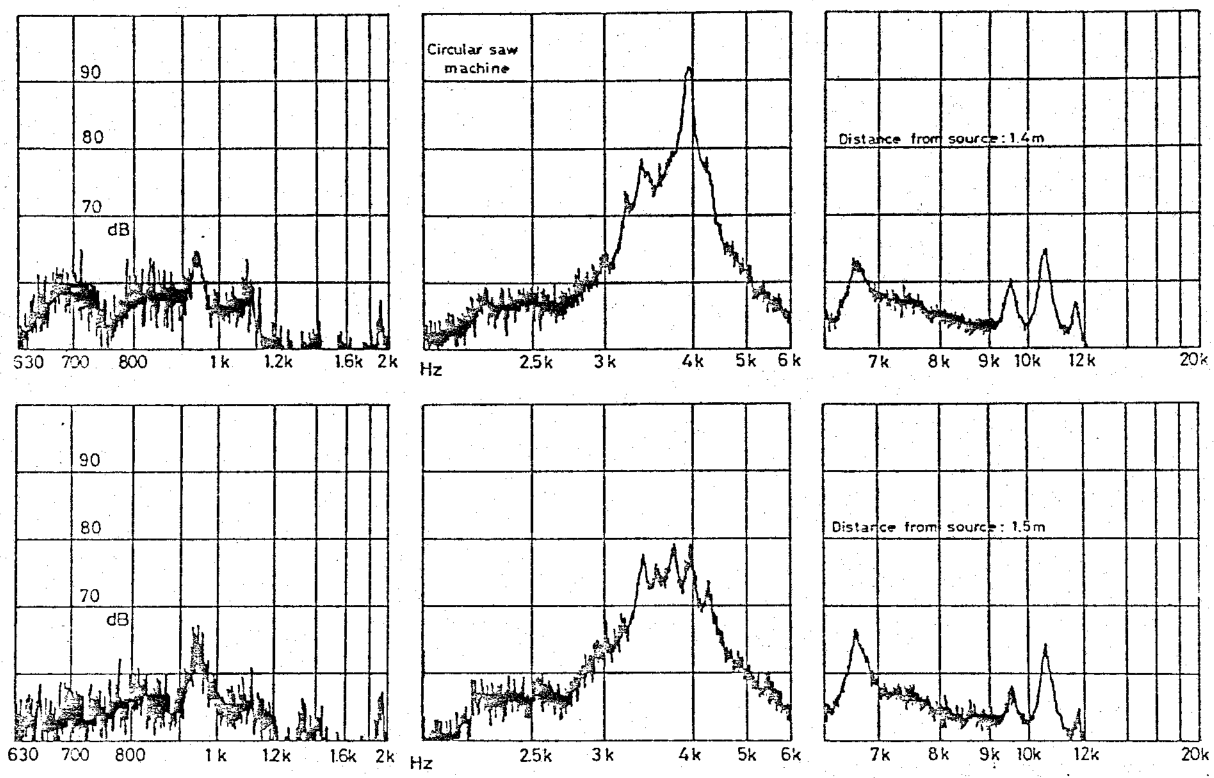


Fig. 3-2-5 Frequency analyses of circular saw noise given at the distance of 1.4 m and 1.5 m from source.

thought to be in improper condition as the place to determine the sound power of the source.

3.3. In the Reverberant Test Room

3.3.1. Without the stationary diffusers

In the reverberant test room, as was already stated, sufficient diffusion was not formed by low frequency band noises or narrow band noises. These low frequency noises are often emitted by woodworking machinery. Therefore, it is necessary to know what distributions of sound pressures are seen in this test room by excitations of those machinery noises.

The result given from single surface planer noise was shown in Fig. 3-3-1 comparing with the one at the semi-anechoic test room. The value plotted with circle represents the one given in the semi-anechoic test room. The sound source was placed at the corner (II). The height of the microphone was 0.9 m from the floor. Some fluctuations of levels were seen in the reverberant test room. The mean sound pressure level ($\overline{SPL}$) calculated from values in the range between 0.5 m and 2.0 m from source was 92.6 dB and the value of the standard deviation was 2.6 dB. On the other hand, average sound pressure level given from arbitrary 20 data measured at the same test room with various mic. heights was 87.3 dB and the standard deviation was calculated at 3.4 dB. The reason that the difference arose between values of $\overline{SPL}$ calculated from each data given by different measurements (which is 5.3 dB) is thought as follows, that is, the sound source radiated the sound energy much to the direction of infeed side from opening , and therefore, levels measured through lines in this direction inevitably became higher than values chosen throughout the room,

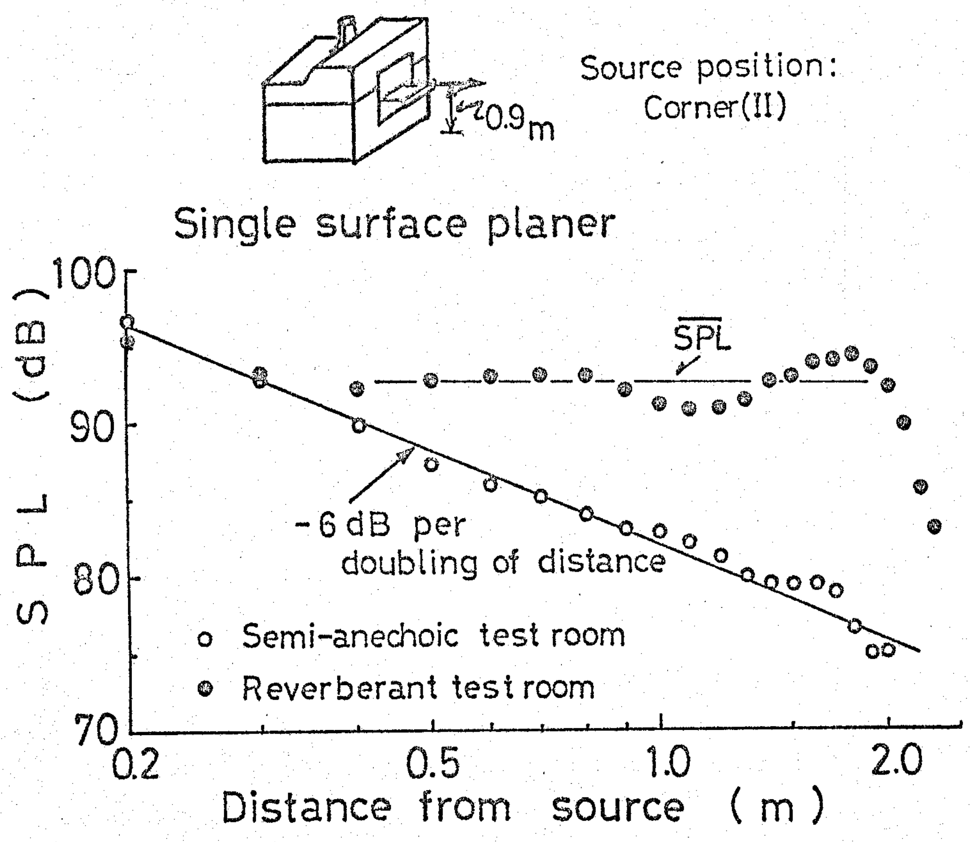


Fig. 3-3-1

SPL versus distance from source (single surface planer) in the two test rooms (in the semi-anechoic test room, and the reverberant test room). The sound source was placed at the corner (II).

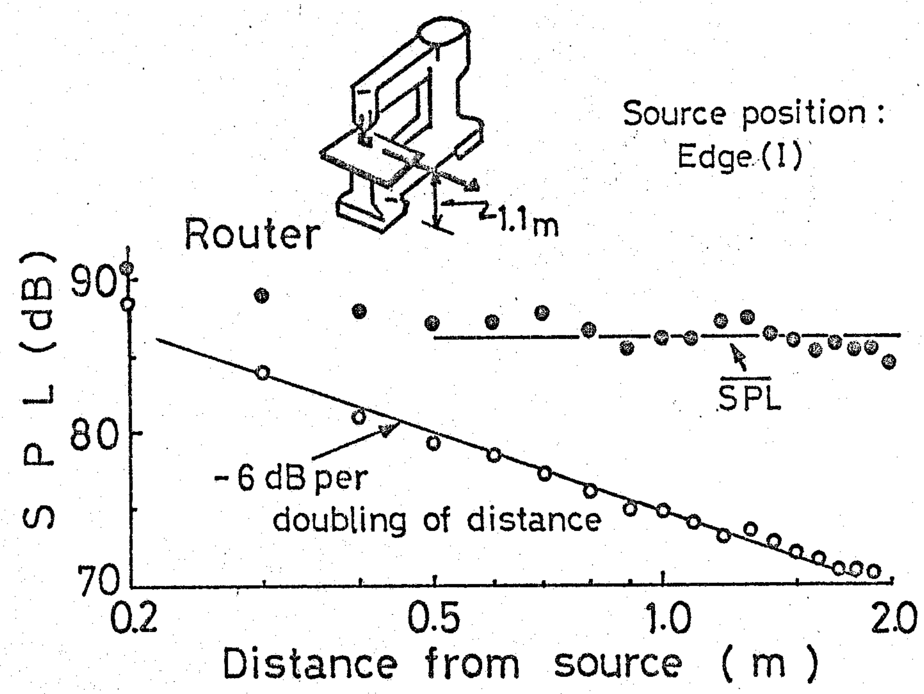


Fig. 3-3-2

SPL versus distance from source (router machine) in two test rooms (in the semi-anechoic, and the reverberant test rooms). The sound source was located at the edge (I).

i.e., measured at arbitrary 20 points. In other words, sufficient diffusion was hard to be formed in this test room excited by low frequency and narrow band noise, especially in the case that the sound source has the strong radiation directivity.

As another example of low frequency noise source, a router machine was used as the source. The result was shown in Fig. 3-3-2. The values plotted with circles were given in the semi-anechoic test room. The sound source was located at the edge (I), and the height of the microphone was 1.1 m from the floor. Though sound pressure levels are slightly fluctuated in this test room, the descripancy is small and thus the test room is in comparatively well diffused conditions. The mean value calculated from levels plotted in the figure was 86.1 dB (values near the source were excluded). The standard deviation was calculated at 0.9 dB. The average sound pressure level calculated from 20 values measured arbitrarily in the same test conditions was 86.8 dB and the standard deviation was 1.5 dB. The noise of this machine is radiated from comparatively small bit (60 mm x 60 mm, flat-plate-like) and the noise generated by rotating bit is radiated non-directly. And more, frequency spectra of its noise is distributed in comparatively wide ranges. Perhaps, these are the reason that the values of both $\overline{\text{SPL}}$s were not so different.

In Fig. 3-3-3, results of circular saw noise was shown. The sound source was set on the edge (I). The height of the microphone was 0.9 m from the floor. One can see that interference pattern of levels is almost vanished in this test room, while this phenomena is obviously seen in the semi-anechoic room (shown with the symbol of circle). The standard deviation cal-

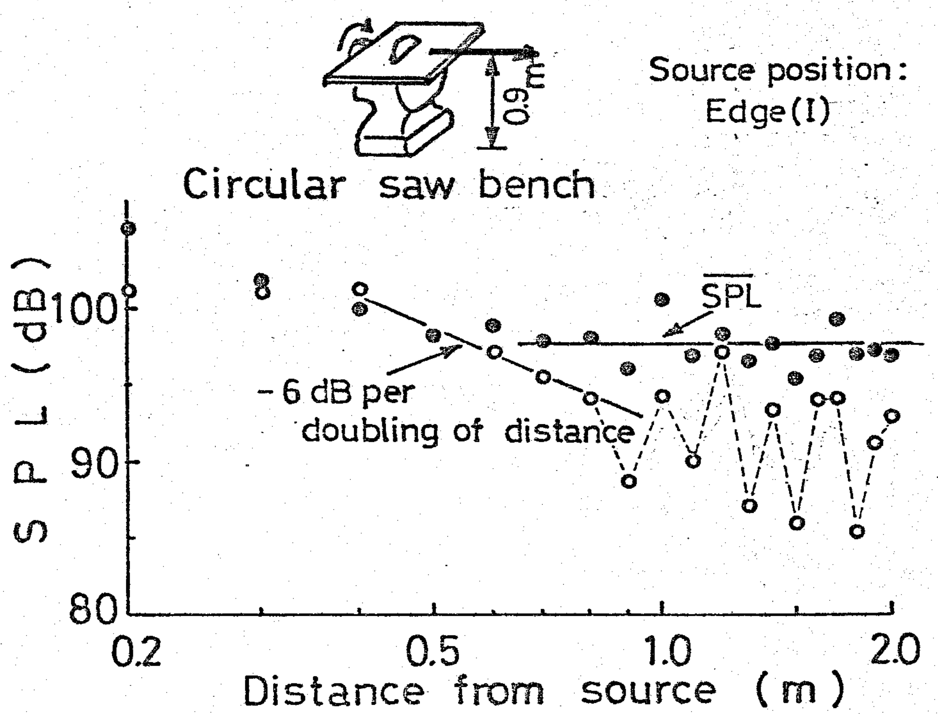


Fig. 3-3-3 SPL versus distance from source (circular saw bench) in the different test rooms (in the semi-anechoic test room and the reverberant test room). The source was placed at the edge (I).

culated from values plotted in the figure was 1.3 dB (values near the source were excluded). The average sound pressure level was calculated at 97.5 dB, and this value was almost the same as was given from 20 data arbitrarily chosen in the same test room (The difference was only 1.4 dB). These results represent that this test room is more usuable as the environment of sound measurements than the semi-anechoic test room for high and narrow frequency band noise sources.

And more, a vacuum cleaner was used for the test. It is often used as the broad band noise source in acoustical examinations. The frequency spectrum of this cleaner, which was given with constant percentage (3%) frequency analyzer was shown in Fig. 3-3-4. The sound pressure level distribution was shown in Fig. 3-3-5. The location of the source was the edge (I), and the height of the microphone was 0.5 m from the floor. In the range about 0.6 m away from the source, sound pressures were distributed with almost the same levels (the standard deviation was calculated at 0.3 dB in these regions). Near the source, the levels were slightly high as this range was close to the inlet or the outlet of air and thus results measured there were, perhaps, affected much by flow of air. At any rate, it is evident that the adequate diffuse field can be formed in this test room exclude the near of the source, and therefore, the test room is able to be used as the "reverberant" room if the source to be tested emits broad band noises.

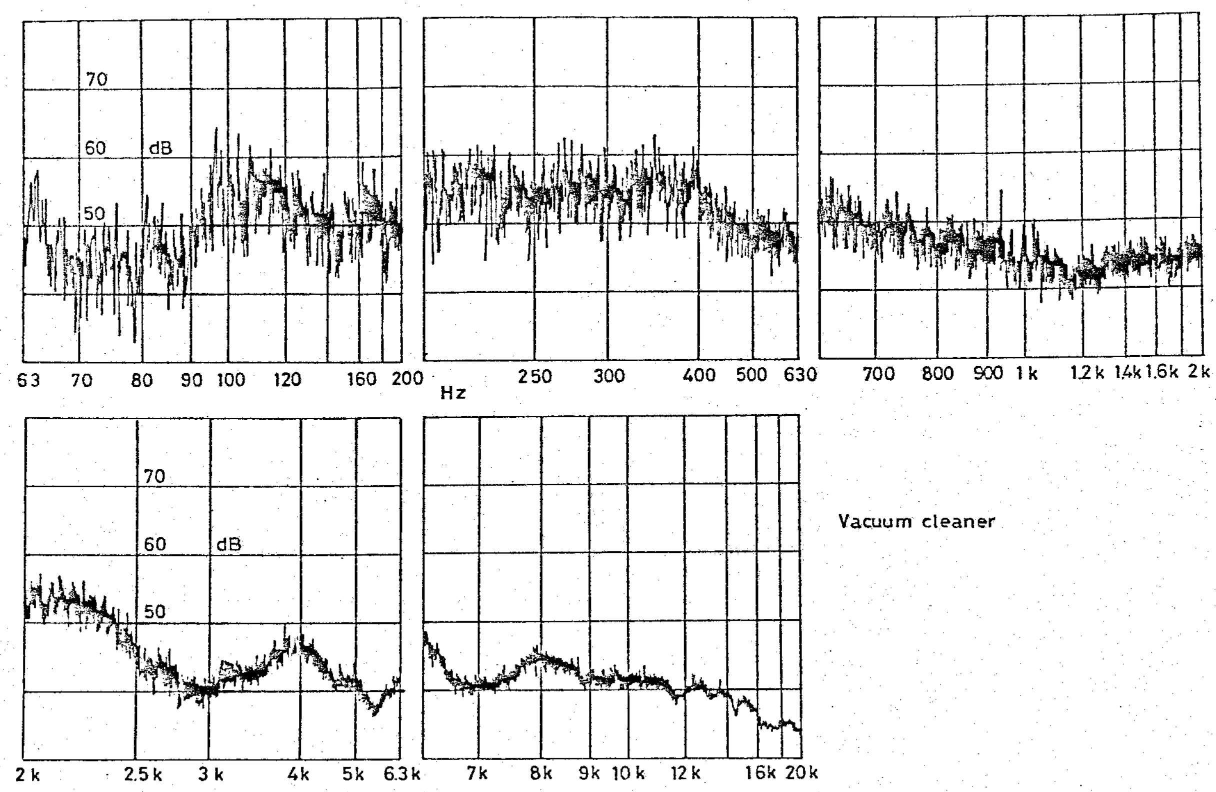


Fig. 3-3-4 Frequency analysis of vacuum cleaner noise.

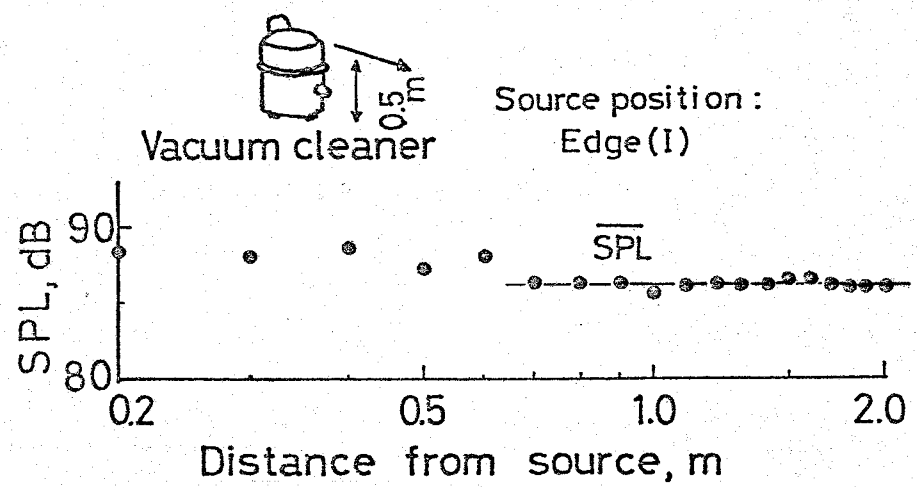


Fig. 3-3-5 SPL versus distance from source (vacuum cleaner) in the reverberant test room. The sound source was located at the edge (I).

3.3.2. With the stationary diffusers

To give adequate diffusion in the test room, fixed diffusers were hung from ceiling arbitrarily. In the experiment, the sound pressure level measurements on machinery noises were practiced with the most effective condition of diffusers chosen in accordance with the results of Table 2-5-3 (see Sec. 2.5.2 b), that is, the conditions A_9 and A_6B_3 were selected. The best value on the standard deviation was given at the condition "A_9" in 250 Hz- and 500 Hz-band. Almost the same value was shown at the condition "A_6B_3", and more, under this condition, there existed "B" panels which were effective to 125 Hz-band noises. Therefore, these two diffuser's conditions were used in examinations.

A single surface planer, a router machine, a circular saw bench and a vacuum cleaner were used as the noise sources. These were the same machines as were used in previous tests. The sound source was located at the edge (I) or the corner (II), and the sound pressure levels were measured at arbitrary 20 points.

Table 3-3-1 represents the results of single surface planer noise. In it, over all (O.A.) sound pressure level (averaged) and 250 Hz-1/3 octave band sound pressure level (averaged), and the standard deviations (SD) calculated at above two frequency bands were shown together with the results in "no diffuser" condition. (In 250 Hz-band, the main peak of this planer noise was contained.) It can be recognized from this table that the value of the standard deviation was larger than that given from random noise about 1 dB to 2 dB in each

Table 3-3-1 The mean value ($\overline{SPL}$), and the standard deviation (SD) of SPLs (O.A., 250 Hz-1/3 oct. band levels) measured at arbitrary 20 points.

The test room was excited by single surface planer noise (source position: I or II). The conditions of diffusers were following ; A_9, A_6B_3, and N.D.*

		O.A.		C.F.* 250 Hz	
		SPL (dB)	SD (dB)	SPL (dB)	SD (dB)
I	A_9	89.2	4.2	86.4	5.9
	A_6B_3	91.4	3.9	89.0	4.6
	N.D.*	90.7	3.3	88.2	4.4
II	A_9	89.9	3.0	86.0	5.2
	A_6B_3	89.0	3.7	84.9	5.7
	N.D.*	88.5	3.8	83.9	7.0

* N.D.: No diffuser condition.

C.F.: Center frequency of 1/3-oct. band.

band. This may be due to the bandwidth of noise radiated by the planer is narrow, and therefore, diffusion in the test room is not so adequate as the case of band noise. Though the effect of diffusers was not found evidently in the value of SD, it is worthy of notice that almost the same average sound pressure level ($\overline{SPL}$) was given in between two source positions, especially at the condition "A_9".

In the case that a circular saw bench was used as the sound source, results were given in Table 3-3-2. Sound pressure levels were measured at O.A. and 4 kHz-band in which the main peak spectrum was contained. It would be recognized from the result given at the source location I that the value of the standard deviation was decreased about 1 dB by the addition of diffusers. And, the average sound pressure levels ($\overline{SPL}$) had almost the same value at two different source positions (I and II) by adding diffusers (both "A_9" and "A_6B_3").

Results from router machine noise is seen in Table 3-3-3 for several frequency bands. Similar results were obtained in case of vacuum cleaner noise as were seen in Table 3-3-4. The results at the source position II and at the diffuser's condition "A_9" were omitted from these two tables, as the values of $\overline{SPL}$ and SD were almost same as ones shown in tables. From these results, the difference in quantities of $\overline{SPL}$ or SD cannot be seen by the difference of conditions on diffusers, that is, in cases between "with" and "without" diffusers. Noises radiated from above machines have comparatively broad bandwidth in both cases. And, for these types of noises, adequate diffusion had been formed in this test room before adding diffusing panels. There would be the reason why above

Table 3-3-2 The mean value ($\overline{SPL}$), and the standard deviation (SD) of SPLs (O.A., and 4 kHz-1/3 oct. band levels) measured at arbitrary 20 points.
The test room was excited by circular saw noise (source position; I or II).
The conditions of diffusers: A_9, A_6B_3, and N.D.*

		O.A.		C.F.* 4 kHz	
		$\overline{SPL}$ (dB)	SD (dB)	$\overline{SPL}$ (dB)	SD (dB)
I	A_9	97.2	2.0	95.5	2.5
	A_6B_3	97.5	2.0	95.5	2.1
	N.D.	97.1	2.9	95.0	3.4
II	A_9	97.6	2.7	95.7	3.0
	A_6B_3	97.7	2.8	95.7	3.4
	N.D.	96.4	2.4	94.4	3.0

* N.D.: No diffuser condition.
C.F.: Center frequency of 1/3-oct. band.

Table 3-3-3 The mean value ($\overline{SPL}$), and the standard deviation (SD) of SPLs (main frequency band levels) measured at arbitrary 20 points. The test room was excited by router machine noise. The source position: I. The conditions of diffusers: A_6B_3, and N.D.*

	Center frequency of 1/3-oct.band, Hz									
	O.A.		200		400		630		1 k	
	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD
A_9	86.0	1.1	73.8	3.6	77.3	3.3	78.9	1.8	74.9	1.4
N.D.	86.1	1.3	72.1	4.1	77.3	3.1	79.5	1.5	73.7	1.1

unit: dB

* N.D.: No diffuser condition.

Table 3-3-4 The mean value ($\overline{SPL}$), and the standard deviation (SD) of SPLs (main frequency band levels) measured at arbitrary 20 points. The test room was excited by vacuum cleaner noise.
The source position was the edge (I), and the conditions of diffusers were A_6B_3, and N.D.*

	O.A.		Center frequency of 1/3-oct. band, Hz 125		250		500		1 k	
	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD	$\overline{SPL}$	SD
A_9	83.9	0.7	69.3	2.2	72.3	2.2	73.1	1.1	74.2	1.7
N.D.*	84.4	0.8	69.1	3.9	73.0	1.9	74.1	1.4	72.5	0.9

unit: dB

* N.D.: No diffuser condition.

results were given.

It is necessary to know whether the measurement results are different too much or not if data are decreased in number for saving troubles in measurements. To examine this problem, five values were picked up at random from 20 data measured in above tests, and $\overline{SPL}$ and SD were also calculated. (As untrouble numbers to do measurements, five in number were thought to be proper.) Results were shown in Table 3-3-5 a, b, c, d and e. From the test done with all cases shown in tables, it was found that the average sound pressure levels of 5 data had no bias to the mean value of the population with the level of significance of 5 %.

From above results, it could be recognized that better environment for sound measurements was able to be formed in this reverberant test room especially for high frequency noises or comparatively broad band noises, and the trouble existing in the collection of data was also able to be saved in it. And more, the standard deviation about 5 dB, which was the largest value measured in this test room for narrow band machinery noise, would seem to be in allowable limits , even if one made reference to the recommendation value in ISO 3740 (see Table 2-5-11).

Table 3-3-5 The mean value ($\overline{SPL}$), and the standard deviation (SD) of SPLs of each machinery noises calculated from 5 data took out at random from 20 values arbitrarily measured. The condition of diffusers is A_6B_3, and the location of the source is the edge (I)

a. Single surface planer noise

	O.A.	C.F. 250 Hz
$\overline{SPL}$ (dB)	90.9	88.6
SD (dB)	3.5	3.7

b. Circular saw noise

	O.A.	C.F. 4 kHz
$\overline{SPL}$ (dB)	97.2	95.8
SD (dB)	1.9	2.0

c. Router machine noise

		C.F., Hz			
	O.A.	200	400	630	1 k
$\overline{SPL}$ (dB)	85.4	72.9	77.1	79.4	74.9
SD (dB)	1.4	1.8	2.1	2.4	1.4

d. Vacuum cleaner noise

		C.F., Hz			
	O.A.	125	250	500	1 k
$\overline{SPL}$ (dB)	84.1	70.7	73.0	73.1	75.0
SD (dB)	0.3	1.8	1.6	1.1	1.2

3.4. Determination of Sound Power Level in Several Test environments

Various experiments and considerations had been carried out to evaluate the utility of test rooms constructed for this study.

In this section, the sound power levels of the machines used for the experiment were calculated and compared mutually. The sound pressure level data used for the calculations were the same ones presented in previous sections except for values given in the original space.

The test environments the sound power level was compared were; a. the semi-anechoic test room, b. the reverberant test room in which diffusing panels were installed, and c. the original room (woodworking shop-room).

To determine the sound power from sound pressure values measured, one must use the equation suitable for the environment that the measurement was done. These equations were described in follows.

a. In the semi-anechoic test room, the sound power level (PWL) is determined according to the next formula, that is,

$$PWL = SPL + 20 \log_{10} r + 8 - DI, \quad (dB) \qquad (3.4.1)$$

where

PWL is the sound power level

SPL is the sound pressure level.

This formula is derived as fillows: Under the free-field condition the sound power is related to the sound pressure by the equation

$$P = \frac{4\pi r}{Q\rho c} p_m \qquad (3.4.2)$$

where P is power in watts

r is the radius of the sphere in meters

ρc is the characteristic impedance of air in mks rayls

p_m is the mean sound pressure in N/m^2

Q is the directivity factor defined later.

For a point source Q takes the values 1, 2, 4, and 8 when the source is places in mid-air, on a hard floor, on an edge between two adjacent hard surface and in a corner of three hard surfaces respectively.

For hemispherical radiation of sound in a free-field, i.e., Q = 2, the sound power level is given by

$$10 \log_{10}\left(\frac{P}{P_o}\right) = 20 \log_{10}\left(\frac{p_m}{p_o}\right) + 10 \log_{10}\left(\frac{2\pi r^2}{S_o}\right) \qquad (3.4.3)$$

where P_o is the reference sound power 10^{-12} Watts, and p_o is the reference sound pressure of 2×10^{-5} N/m^2. That is,

$$PWL = \overline{SPL} + 10 \log_{10}\left(\frac{2\pi r^2}{S_o}\right) \qquad (3.4.3')$$

where $\overline{SPL}$ is the mean sound pressure level and S_o is a reference surface area of 1 m^2, and therefore,

$$PWL = \overline{SPL} + 20 \log_{10} r + 8,$$

and where DI (Directivity index) = SPL - $\overline{SPL}$, so that

$$PWL = SPL + 20 \log_{10} r + 8 - DI. \qquad (3.4.1)$$

From the result measured at r = 0.9 m (r is the distance from source), DI was calculated at 1.3 dB for the single surface planer. For the router machine, DI was decided to be 0 dB (non-directional). The sound power level of the circular saw bench was determined from sound pressure level values given in the semi-anechoic test room whose floor was covered with woodfiber mats. DI of this machine was 1.3 dB.

b. In the reverberant test room, following equation was used, that is,

$$10 \log_{10}\left(\frac{P}{P_o}\right) = 20 \log_{10}\left(\frac{p_m}{p_o}\right) - 10 \log_{10}\left(\frac{T}{T_o}\right) + 10 \log_{10}\left(\frac{V}{V_o}\right) - 14, \text{ (dB)} \qquad (3.4.4)$$

i.e.,

$$PWL = \overline{SPL} - 10 \log_{10} T + 10 \log_{10} V - 14 \quad \text{(dB)} \qquad (3.4.4')$$

where
T is the reverberation time of the room in sec
V is the volume of the room in m^3
T_o is the reference reverberation time 1 sec
V_o is the reference volume 1 m^3.

This formula is given as follows: In a diffuse field, the steady state sound energy in the room is equal to the

Table 3-4-1 The reverberation time (T) of the reverberant test room in which diffusers were added with the condition of "A_6B_3".

		Center frequency of 1/3-oct. band, Hz						
	O.A.	125	250	500	1 k	2 k	4 k	8 k
T (sec)	1.5	1.6	1.6	1.6	1.3	0.6	0.7	0.7

Router machine noise... T = 1.6 sec was used as the value at 200 Hz-, 400 Hz-, and 630 Hz-band.

Circular saw noise ... T = 0.7 sec was used as the value at 3.2 kHz-, and 5 kHz-band.

difference between the sound energy transmitted by the source and that absorbed by the room boundaries. Since the sound energy is directly proportional to the sound pressure squared, the relation between the sound power emitted and the reverberant sound pressure level can be shown to be

$$P = \frac{R}{4\rho c} p_m^2 \qquad (3.4.5)$$

where R is the room constant (a function of frequency) defined as $R = S\bar{\alpha}/(1-\bar{\alpha})$, where S is the area of the room boundaries and $\bar{\alpha}$ is the average absorption coefficient in the room. The room constant is simply $R = S\bar{\alpha} = A$ where A is a measure of the total absorption in the room. The quantity A can be determined indirectly with the aid of the Sabine formula

$$T = 0.16\ V/A \qquad (3.4.6)$$

by measuring the reverberation time of the room, T. Substitution of equation (3.4.6) in (3.4.5) for R = A gives equation (3.4.4).

The value used for calculations were shown in Table 3-4-1 (Diffuser's condition was "A_6B_3").

c. In the woodworking shop, the sound power level was determined with the next formula, that is,

$$PWL = \overline{SPL} = 10\log_{10}\frac{2\pi r^2}{S_o}, \qquad (3.4.3')$$

or

$$PWL = \overline{SPL} - K + 10 \log_{10} \frac{S}{S_o} \qquad (3.4.7)$$

where S is the measurement surface area

K is the environmental correction in dB determined from the curve[70] given in Fig. 3-4-1.

As it was already shown in a., above formulae are able to be used in a free-field. On the other hand, the sound field in the woodworking shop room is "semi-reverberant*".

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* As it was already found from previous tests, the woodworking shop room is in semi-reverberant sound field condition. Therefore, for this condition, the following formula is adapted, that is,

$$PWL = \overline{SPL} - 10 \log_{10}\left(\frac{Q}{4\pi r^2} + \frac{4}{f(a)}\right) \qquad (3.4.8)$$

where f(a) is the valid measure of the absorption in the room. It is prefered to use $f(a) = S\bar{\alpha}_{sab}$, where $\bar{\alpha}_{sab}$ is the average Sabine absorption coefficient.

Therefore, in the woodworking shop, the sound pressure levels of the machinery were measured in a free-field part of the semi-reverberant sound field (within the radius of 1 m from the surface of the source, and exclude the area close by the source).

The mean sound pressure level ($\overline{SPL}$) written in eqs. (3.4.3') and (3.4.7) was evaluated from sound pressure levels measured according to so-called "measurement surface" method.[71][72]

Dimensions of the hemisphere* or the rectangular parallelepiped* were shown in Figs. 3-4-2, 3-4-3-, 3-4-4 and 3-4-5 for each sound source.

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*1 The 6-point array[73] was used for SPL measurements of vacuum cleaner noise (see Fig. 3-4-2), and the sound power level was calculated with eq. (3.4.3') at r = 1 m.

*2 A rectangular parallelepiped was used for the SPL measurement of single surface planer noise, router machine noise or circular saw noise (see Figs. 3-4-3, 3-4-4, and 3-4-5). The equation (3.4.7) was used for calculations of PWLs of those machines. The value of K and S were shown in figures for each frequency band concerned.

The sound power levels calculated with previous equations were collected in Tables 3-4-2 to 3-4-5 for all test machines.

For almost all cases, the sound power level had the largest value in the original room space, i.e., in the wood-working shop-room, and had the smallest value in the semi-anechoic test room.* In the reverberant test room, the value of PWL was mostly smaller than the one given in the original room space in any frequency band concerned. And the difference between them was large in low frequency bands. The examples are seen in case of single surface planer noise or router machine noise (see b. and c. in tables). On the other hand,

---

* As the sound pressure level in the semi-anechoic test room was calculated from only one measurement value (at the distance of 0.9 m from source), some questions may exist on the comparison with others.

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in high frequency range, the difference of levels were not so

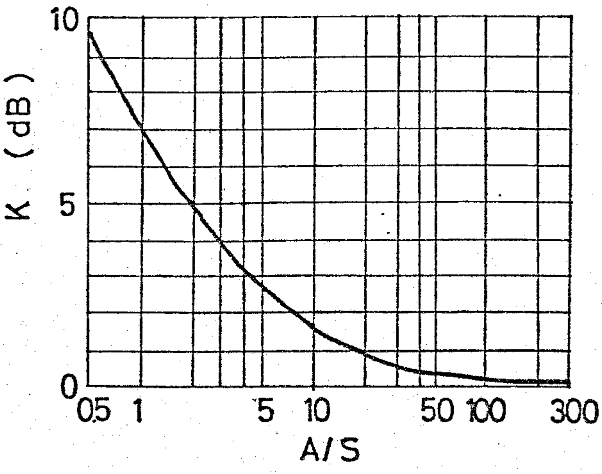

Fig. 3-4-1 The environmental collection K in dB, by Ref. 70.

6-point array

	X	Y	Z
1	0.89r	0	0.45r
2	0.28r	0.85r	0.45r
3	-0.72r	0.53r	0.45r
4	-0.72r	-0.53r	0.45r
5	0.28r	-0.85r	0.45r
6	0	0	r

In the test, r=1.0m was sellected.

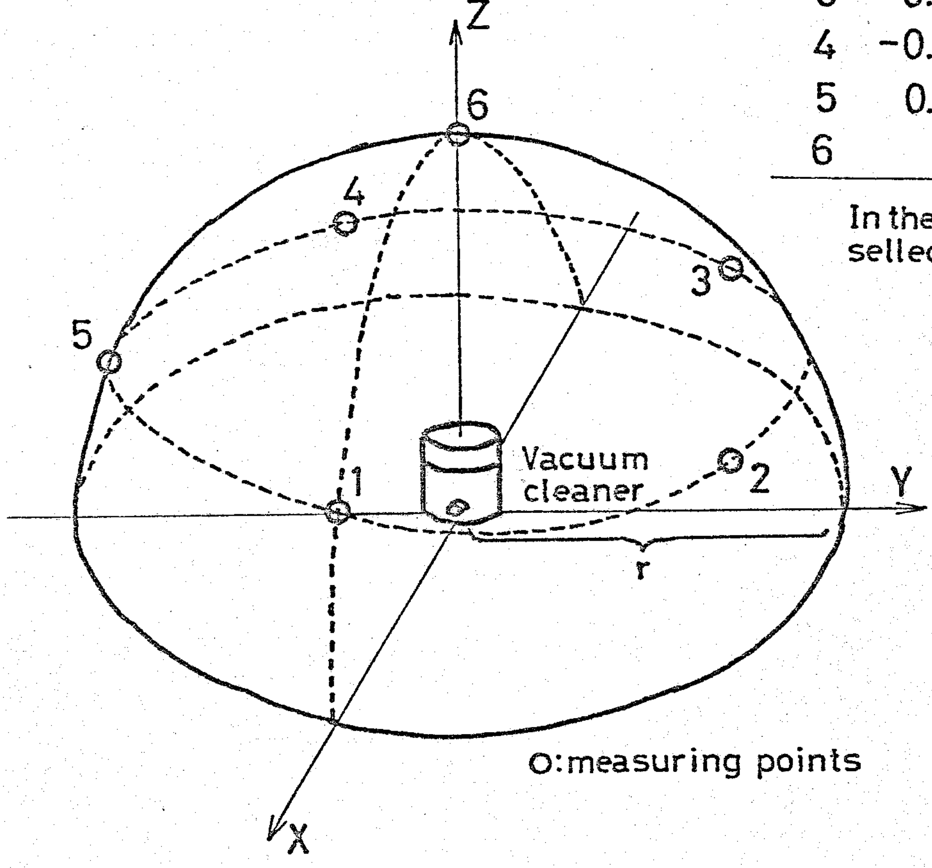

Fig. 3-4-2 Distributions of 6 measuring points over a hypothetical hemisphere surrounding the source (the vacuum cleaner).

S: Measurement surface area. ≒ 18.0 m^2

	K_{dB}
O.A.	3.5
125 Hz	4.5
250 Hz	3.3
500 Hz	3.0
1 kHz	3.0
2 kHz	2.5

K: Environmental correction

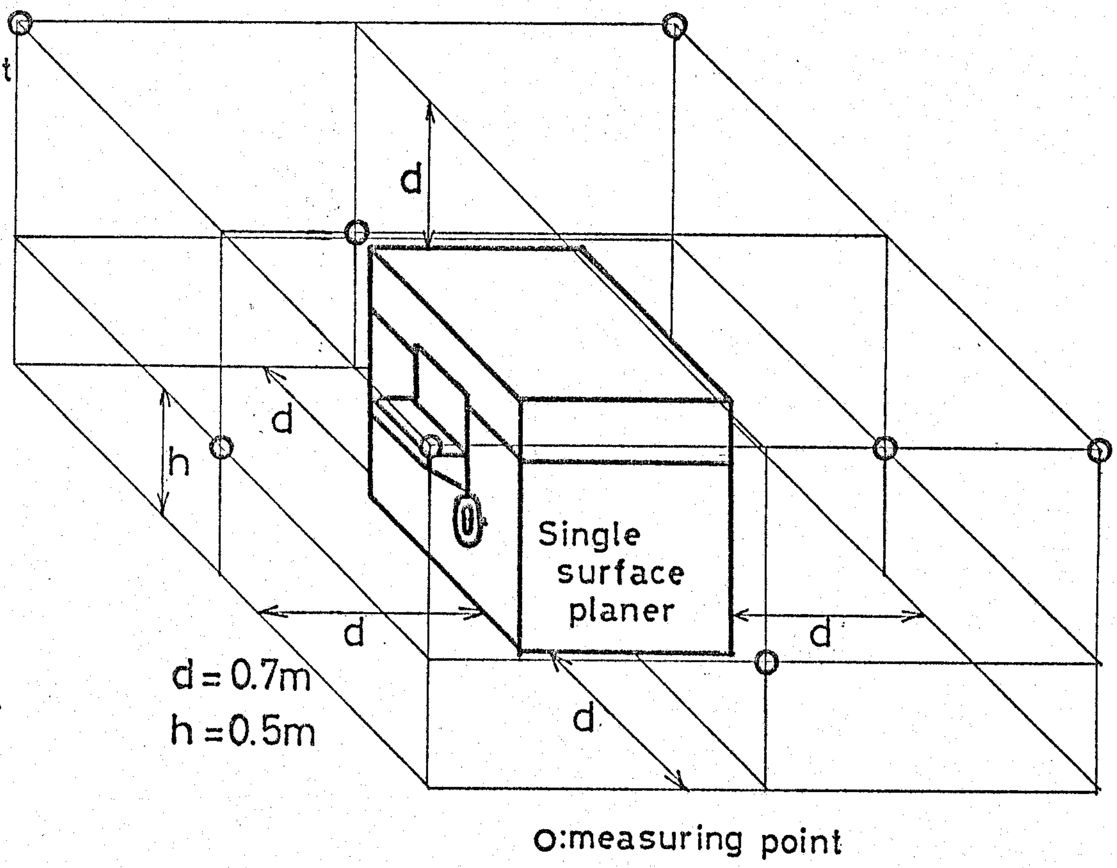

Fig. 3-4-3 Distributions of measuring points over a rectangular parallelepiped surrounding the source (the single surface planer).

$S \doteqdot 21.8m^2$

	K^*_{dB}
O. A.	4.0
125 Hz	3.8
250 Hz	3.6
500 Hz	3.3
1k Hz	3.3

*In 200Hz-band... 3.6 dB, in 400Hz- and 630Hz-band... 3.3 dB were used

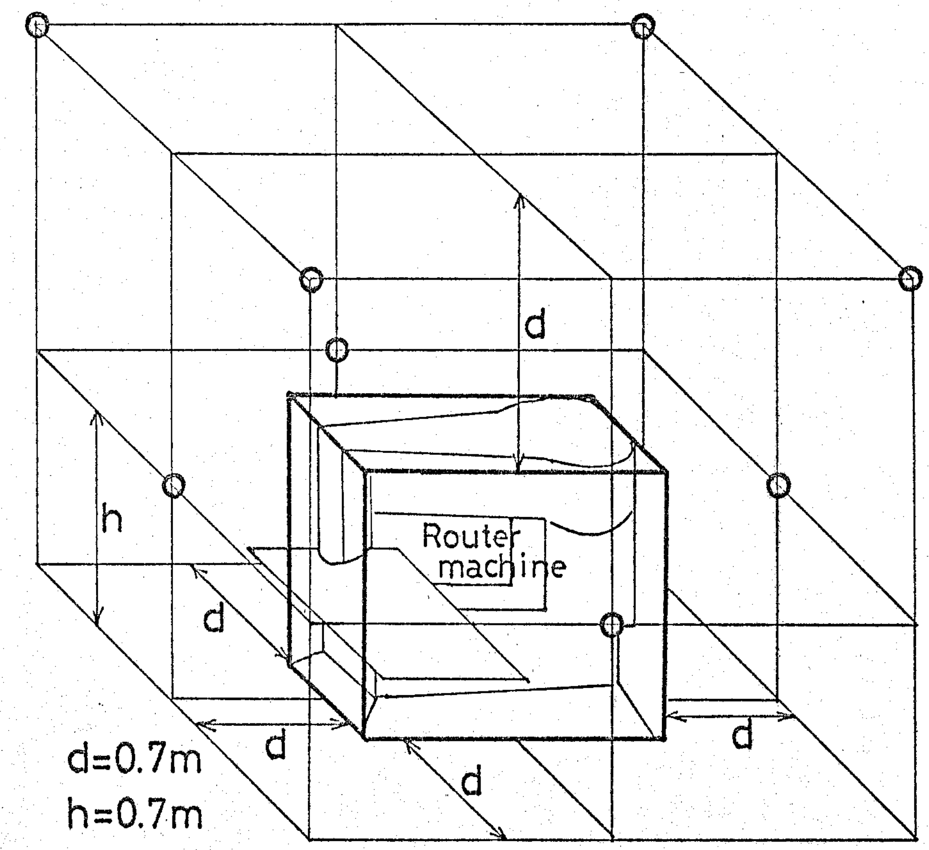

Fig. 3-4-4 Distributions of measuring points over a rectangular parallelepiped surrounding the source (the router machine).

$S \fallingdotseq 12.6 m^2$

	K^* dB
O.A.	2.5
2 k	1.7
4 k	1.5
8 k	1.3

*In 3.2 kHz-, 4 kHz-, and 5 kHz-band ... 1.5 dB was used for K value.

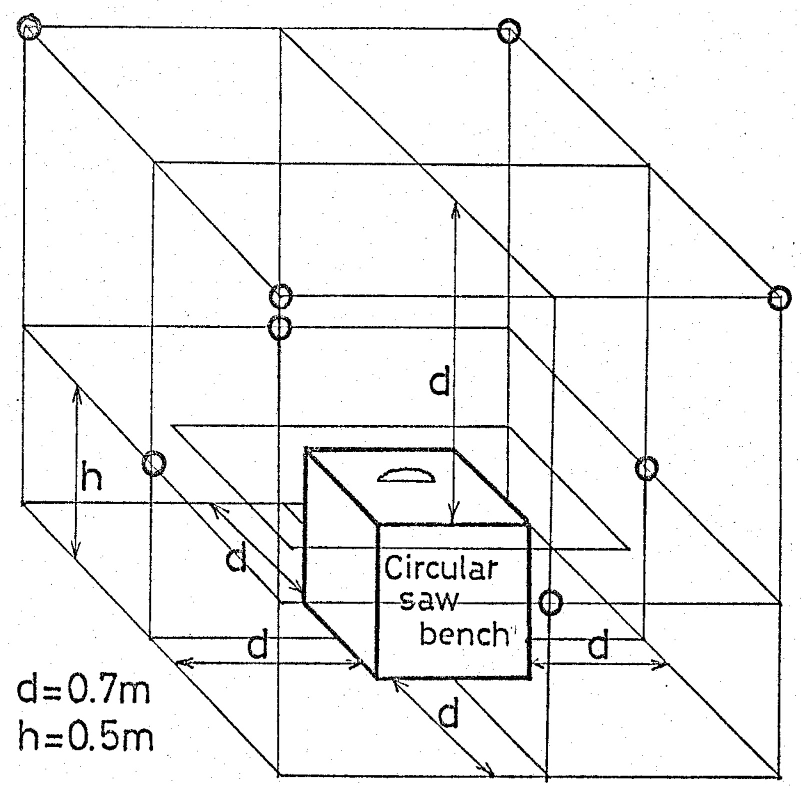

Fig. 3-4-5 Distributions of measuring points over a rectangular parallelepiped surrounding the source (the circular saw bench).

large as was seen in case of circular saw noise result. The reason is thought to be as follows, that is, especially at low frequencies there are only a limited number of normal modes (see Sec. 2.1 note) in a room of limited size and furthermore these mode have different damping. When a sound source emits noise in the room in the range where there are few normal modes, only a part of the frequency range would be represented in the diffuse field, especially the frequency regions lying near the resonance frequencies. At frequencies away from the resonancies the excitation is reduced and the contribution to the total sound pressure would be little. As a result the sound pressure level measured, and the sound power determined, would be low as compared to the case of free field where the contribution from the individual frequencies emitted by the source to the total sound pressure is independent of the room.[33)]

In a free-field, the directivity of the sound source must be known exactly to determine the sound power. If one want to omit this quantity, one must take many data on sound pressure levels to calculate the mean sound pressure level truly. However, much labor would be necessary to do them. And more, the desirable free-field is not given easily in rooms as was shown in this study. On the other hand, the diffuse field is able to be given with allowable limits in the reverberant test room. In this test environment, the measurement positions are able to be chosen arbitrarily if the areas close by the source are excluded, and the data need not be taken at so many positions. The sound power level estimated in this test room, furthermore, has only a few differeces of levels compared with the value calculated

Table 3-4-2 The sound power level of the vacuum cleaner calculated at each room condition.

C.F.*	a.*	b.*	c.*
125 Hz	-**	69.0	74.9
250 Hz	-	71.3	73.2
500 Hz	-	71.4	72.5
1 k Hz	-	74.2	69.2
2 k Hz	-	68.8	72.3
O.A.	-	82.7	86.2

unit: dB

* C.F.: Center frequency of 1/3-oct. band.
a.: In the semi-anechoic test room
b.: In the reverberant test room
c.: In the original room (in the free-field part)

** In the semi-anechoic test room, the vacuum cleaner noise levels were not measured.

Table 3-4-3 The sound power level of the single surface planer calculated at each room condition.

C.F.	a.	b.	c.
125 Hz	-*	67.3	74.0
250 Hz	-	86.9	89.6
500 Hz	-	76.2	78.2
1 k Hz	-	71.9	74.7
O.A.	88.8	89.5	91.7

unit:dB

* Unmeasured.

Table 3-4-4 The sound power level of the router machine calculated at each room condition.

C.F.	a.	b.	c.
200 Hz	-*	71.1	77.1
400 Hz	-	75.4	81.1
630 Hz	-	77.7	78.2
1 k Hz	-	74.1	74.7
O.A.	82.3	84.0	87.2

unit: dB

* Unmeasured.

Table 3-4-5 The sound power level of the circular saw bench calculated at each room condition.

C.F.	a.*	b.	c.
3.2 kHz	-**	89.8	91.0
4 kHz	-	97.7	97.8
5 kHz	-	89.2	90.7
O.A.	92.3	95.8	98.5

unit: dB

* SPL used for the calculation was given in the test room the floor of which was covered with woodfiber mats.

** Unmeasured.

in the free-field condition.

4. CONCLUSION

The following may be concluded from the experiment described above.

In a common room such as a factory-room or a woodworking shop-room, the theoretical sound field is hard to be formed. Especially in a region distant from the source, a fluctuant distribution of sound pressure levels were often recognized in the woodworking shop-room tested as one of common test rooms, in the case that noises containing low frequency components were emitted there. Perhaps this phenomenon is related to room resonancies, and caused mainly by sound waves reflected from boundaries.

To remove the cause of it from sound field, two methods were considered; one was to make the sound field more anechoic by omitting the reflection from boundaries, and the other was to make sounds more diffusible in a room by increasing the reflection from boundaries.

The first method was examined by making new test space surrounded by cloth curtains or woodfiber mats. As this test room was aimed to be built in any room space, the volume of it inevitably had to be small. But it had the negative effect on making the room "anechoic". And more, materials used for boundaries did not have better absorption to the low frequency noises. The hard floor, which was not covered with absorption materials for setting machines, had the undesirable effect on the measurement field espacially in case of high frequency and narrow band noises.

The other method was examined by making the reverberant test room whose walls were made of lauan plywoods in the same woodworking shop-room. To give adequate diffusion in low frequency ranges, thin aluminum plates were nailed on the surface of plywood's walls, and then stationary diffusers were installed in the room. The former improvement did not take so good effect, but the other had better influence to those frequency noises. If the state of diffusion in rooms can be expressed by the standard deviation, the value of it is not more than 1.5 dB for band noises above the center frequency 250 Hz and about 5 dB at the worst case on machinery noises. These values ought to be in the limits recommended in ISO Standard if the nature of this room is taken into consideration.

The sound power levels of machinery sources calculated from pressure levels measured under several test conditions were slightly different to each other. Especially, the value obtained in the reverberant test room was smaller than the one in the free-field part of the woodworking shop-room in almost all the case. But the difference in levels was small, and therefore, one may conclude that if one consider the labor on collecting data for the determination of sound powers of sources, the reverberant test room built in this study is the most suitable place for the test.

In general, it is not necessary to consider the shape (such as a cube or a rectangle) of rooms in the case that anechoic rooms are constructed. Under the reverberant-room-condition, however, it becomes a matter of concern as the normal modes of the room decrease the number in a cubic room compared to that in a rectanglar room (see Sec.2.1.3 note). But, judging from results of this study, above disadvantage is not so great, and therefore, even in the cubic test room, the measurement is practiced well. Thus, if the form of the test room would be not a cube but such a rectangle that has recommended ratio[20][74] $1:\sqrt[3]{2}:\sqrt[3]{4}$ or 2:3:5 for height:width:length, more accurate results might be obtained.

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REFERENCES

1) N.Edamatsu, M.Mori: "Seizai to Mokko," Morikita Shuppan, (1970) p 334

2) R.P.Cristman, H.H.Jones, R.E.Bales: Noise Control, Sep. (1956) 33-38, 72

3) H.Sugihara, S.Kitayama: Mokuzaikenkyu, 39, 35-40 (1966)

4) G.Pahlitzsch, E.Liegmann: Holz als Roh- und Werkstoff, 14, 121-135 (1956)

5) B.Thunell: Reprint from Paper och Trä nr 4a (1957)

6) Brüel & Kjaer: "Accustic Noise Measurement," p 146

7) G.Pahlitzsch, W.Meins: Holz-Zentralblatt, 14, 64-71 (1960)

8) H.Sugihara: Mokkokikai, 64, 19-22, & 65, 11-14(1965)

9) Woodworking Machinery Manufacturers of America: "Test Cord for Evaluating the Noise Emittion of Woodworking Machinery," April (1973)

10) JIS B 0114-1976: "Measuring Method of Noise Emitted by Wood Working Machinery"

11) H.Sugihara: Mokkokikai, 88, 11-14(1978)

12) W.C.Sabine: "Collected Paper on Acoustics," Dover Reprint, (1964)

13) C.F.Eyring: J. Acoust. Soc. Am., 1, 217 (1930)

14) G.Millington: J. Acoust. Soc. Am., 4, 69 (1932)

15) W.J.Sette: J. Acoust. Soc. Am., 4, 193 (1933)

16) L.L.Beranek: "Noise and Vibration Control," McGraw-Hill, (1977) p 226

17) Y.Ogawa: J. Acoust. Soc. Jap., 21 (3), 137-140 (1965)

18) M.J.Crocker, A.J.Price: "Noise and Noise Control, Vol. 1," CRC Press, (1975) p 187

19) D.A.Bies: Noise Contrl Eng., Nov-Dec., 154-163 (1976)

20) ISO 3741: "Precision method for broad-band sources in reverberation rooms."

21) ISO 3742: "Precision method for discrete-frequency and narrow-band sources in reverberation rooms."

22) ISO 3743: "Engineering methods for special reverberation test rooms."

23) ISO 3744: "Engeneering methods for free-field conditions over a reflecting plane."

24) ISO 3745: "Precision methods for anechoic and semi-anechoic rooms."

25) ISO 3746: "Survey method."

26) M.Koyasu: J. Acoust. Soc. Jap., 32 (2), 172-177 (1976)

27) P.A.Mansbach: Inter Noise 78, 269-276, May (1978)

28) R.E.Gardinier: ibid., 967-970, May (1978)

29) O.L.Angevine Jr., C.E.Ebbing: J. Acoust. Soc. Am., 54, 930 (1973)

30) P.K.Baade: J. Sound Vib., 16 (1), 131-135 (1971)

31) R.Watherhouse: J. Acoust. Soc. Am., 54, 931-934 (1973)

32) C.E.Ebbing, G.C.Maling Jr.: J.Acoust. Soc. Am., 54, 935-949 (1973)

33) P.V.Brüel: Brüel & Kjaer, Tech. Rev., No.3 (1978)

34) D.Lubmann: J. Sound Vib., 16 (1), 43-58 (1971)

35) C.E.Ebbing: J. Sound Vib., 16 (1), 99-118 (1971)

36) T.J.Schltz: J.Sound Vib., 16 (1), 119-129 (1971)

37) W.W.Lang: J. Acoust. Soc. Am., 54, 960-966 (1973)

38) T.J.Schultz: J. Acoust. Soc. Am., 54, 982-984 (1973)

39) G.M.Diehl: J. Acoust. Soc. Am., 61, 449-455 (1977)

40) R.J.Wells, F.M.Wiener: Noise Control, Jan.-Feb., (1961) 21-29

41) J.B.Moreland: J. Acoust. Soc. Am., 61, 476-483 (1977)

42) JIS Z 8731-1966: "Methods for Measurement of Sound Level."

43) M.J.Crocker, A.J.Price: "Noise and Noise Control, Vol. 1," CRC Press, (1975) p 182

44) JIS Z 8106-1961: "Glossary of Acoustical Terms (General)."

45) Nippon Onkyo Zairyo Kyokai: "Kenchiku Onkyo Kogaku Handbook," Gihodo, (1963) p 236

46) M.J.Crocker, A.J.Price: "Noise and Noise Control, Vol.1," CRC Press, (1975) p 27

47) K.Kubo, M.Koyasu: Kobayashi Rigaku Kenkyusho Hokoku, 13 (3), 80-90 (1963)

48) J.Duda: Noise Control Eng., 9 (2), 60-67 (1977)

49) S.Yoshikawa, and et al.: J. Acoust. Soc. Jap., 24 (6), 343-354 (1968)

50) Brüel & Kjaer: "Architectural Acoustics," p 124

51) J.Maekawa: "Kenchiku Onkyo," Kyoritsu Shuppan, (1968) p 29

52) Brüel & Kjaer: Isotropic Sound Source, Type 4241, Manual, Naerum, Denmark (1974)

53) S.Yamakoshi, T.Nakano: Soon Seigyo, 2 (1), 27-32 (1978)

54) P.K.Baade: an ASME Publication, 69-WA/FE-30 (1970)

55) M.J.Crocker, A.J.Price: "Noise and Noise Control, Vol.1," CRC Press, (1975) p 33

56) J.Maekawa: "Kenchiku Onkyo," Kyoritsu Shuppan, (1968) p 34

57) T.J.Schultz: J. Sound Vib., 16 (1), 17-28 (1971)

58) J.T.Broch, V.N.Jensen: Brüel & Kjaer, Tech. Rev., No. 4 (1966)

59) J.Maekawa: "Kenchiku Onkyo," Kyoritsu Shuppan, (1968) p 47

60) Z.Fukuda, J.Okuda: "Soontaisaku to Soonsekkei," Kyoritsu Shuppan, (1973) p 264

61) E.D.Lauler: Sound Vib., Sep. (1968) 16-20

62) J.Tichy, P.K.Baade: J. Acoust. Soc. Am., 56, 137-143 (1974)

63) C.W.Kosten: Acustica, 10, 400-411 (1960)

64) U.Kath, W.Kuhl: Acustica, 11, 50-64 (1961)

65) F.Kolmer, M.Kršák: Acustica, 10, 357-371 (1960)

66) L.L.Faulkner: "Handbook of Industrial Noise Control," Industrial Press Inc., (1976) p 154

67) J.Maekawa: "Kenchiku Onkyo," Kyoritsu Shuppan, (1968) p 9

68) J.Maekawa: ibid. p 48

69) ISO 3740: "Acoustics-Determination of sound power levels of noise sources."

70) Brüel & Kjaer: "Acoustic Noise Measurements," p 142

71) ISO R 495-1966

72) A.Nakano: J. Acoust. Soc. Jap., 31 (4), 278-282 (1975)

73) G.M.Diehl: "Machinery Acoustics," John Wiely & Sons, Inc., (1973) p 72

74) K.Zaveri: Brüel & Kjaer, Tech. Rev., No. 3 (1971)

Appendix. Insruments and Techniques of Measurements

1. Sound sources

1.1. Isotropic sound source (Fig. 1)

B&K, Type 4241

Specifications

High frequency unit

Directional characteristic: Isotropic within 3 dB for frequencies below 3 kHz.[52)]

Diameter: 200 mm

Low frequency unit + High frequency unit

Directional characteristic: Isotropic within 3 dB for frequencies below 1 kHz.[52)]

Dimensions: Height (with HF unit)...1000 mm

Diameter: 400 mm

Accessaries: Power Amplifier B&K Type 2706

1.2. Woodworking machinery

a. Hand feed planer (Fig. 2)

SHODA Type HP 133

Dimensions: 660 (W) x 1910 (L) x 965 (H)

Specifications

Cutter-head*...Diameter: 200 mm

Length: 325 mm

The max. number of knives: 8

The rotation speed of the spindle: 2140, 3480 rpm

* This cutter-head is a special-made one, and 8 slots are opened for setting knives (see Fig. 3). These slots where knives are not set are able to be filled with plastic covers. The rotation speed of the cutter-head is able to be changed in 21 stages with 7 pullies.

b. Single surface planer* (Fig. 4)

IIDA Type SP-400N

Dimensions: 900 (W) x 700 (L) x 1100 (H)

* This machine is produced as one of "low-noise-type" machines by Dr. Sugihara and et al. The outside of this machine, therefore, is almost all covered with casting or thin steel plates excepting the infeed and outfeed openings.

Specifications

Cutter-head...Diameter: 100 mm

Length: 400 mm

The number of knives: 3

The rotation speed of cutter-head: 5050 rpm

c. Router machine (Fig. 5)

SHODA Type RO-116D

Dimensions: 800 (W) x 1100 (L) x 1300 (H)

Specifications

Bit...Dimensions: 60 mm x 60 mm (flat-plate-like)

The rotation speed of spindle: 5960 rpm*

* The max. speed is 20 000rpm, but, in the test this value were adopted.

d. Circular saw bench (Fig. 6)

SHODA Dimensions: 800 (W) x 600 (L) x 850 (H)

Specifications

Circular saw...Diameter: 255 mm (miter saw)

The number of teeth: 100

The max. blade width: 15 mm

The rotation speed of spindle: 4120 rpm

e. Vacuum cleaner (Fig. 7)

HITACHI Type CF-V 10081

Dimensions: 300 (Dia.) x 450 (H)

2. Measurement Instruments

Microphone (Fig. 8)

1/2-inch condencer microphone*	B&K	Type 4133
1-inch condencer microphone	B&K	Type 4145

* This microphone was used only for the measurement of reverberation times.

Sound level meter (Fig. 9) B&K Type 2209

One-third octave band filter (Fig. 10) JEIC Type BP-10A

Frequency analyzer* (Fig. 11) B&K Type 2120

* This analyzer is a constant percentage bandwidth analyzer, and have four selectable bandwidth, 1%, 3%, 10% and 1/3-octave. In this study, machinery noises were analyzed with a bandwidth of 3 % except for the hand feed planer noise analyzed with a bandwidth of 1 %.

Fig. 1 Isotropic sound source

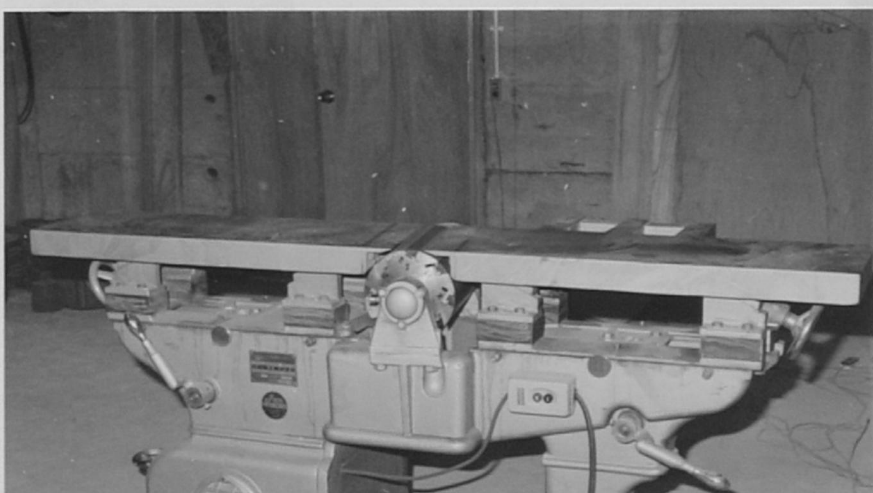

Fig. 2 Hand feed planer

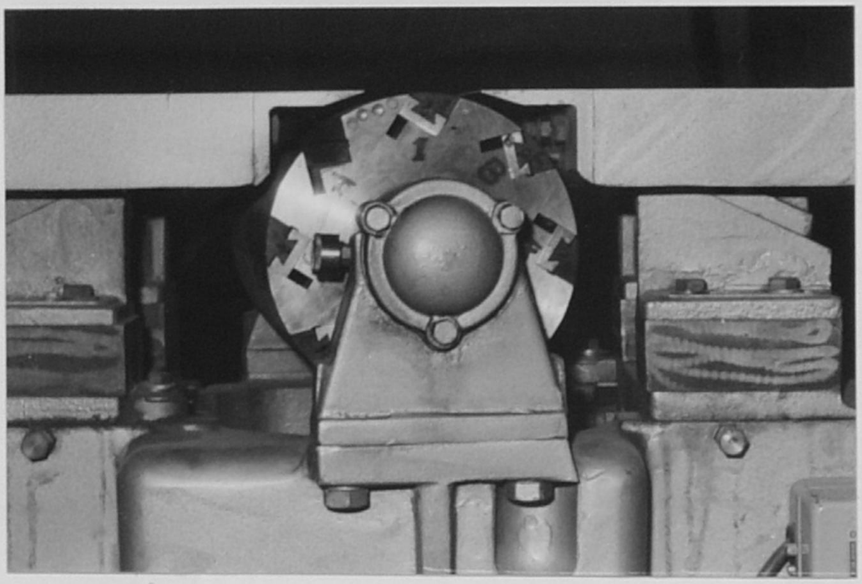

Fig. 3 The special-made cutter-head of the hand feed planer.

Fig. 4 Single surface planer

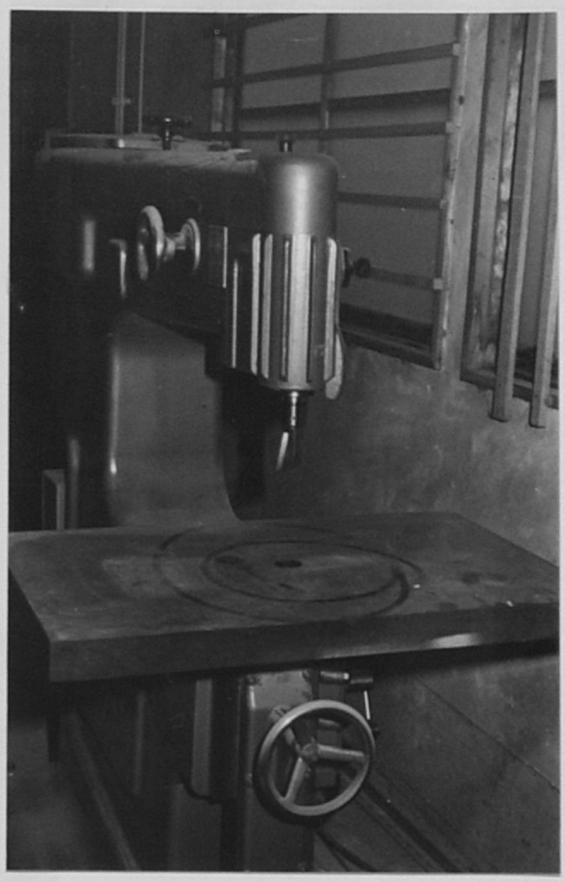

Fig. 5 Router machine

Fig. 6 Circular saw bench

Fig. 7 Vacuum cleaner

Fig. 8 Two kinds of condencer microphones

Fig. 9 Sound level meter

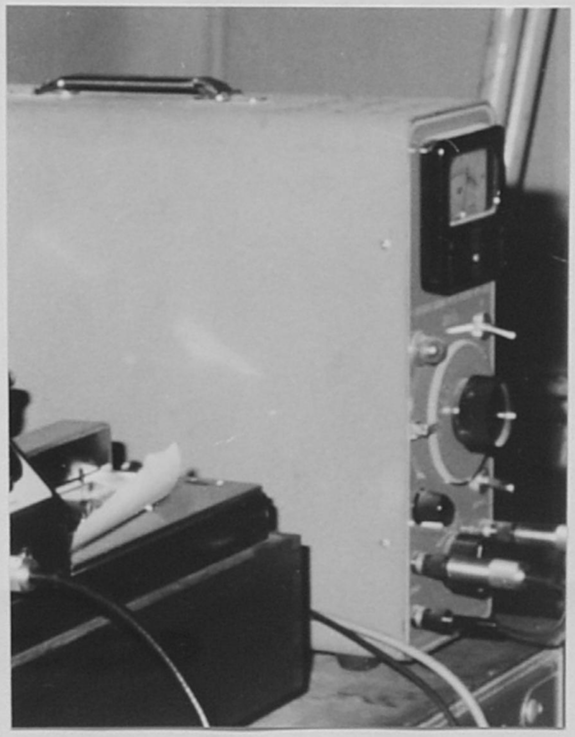

Fig. 10 One-third octave band pass filter

Fig. 11 Frequency analyzer

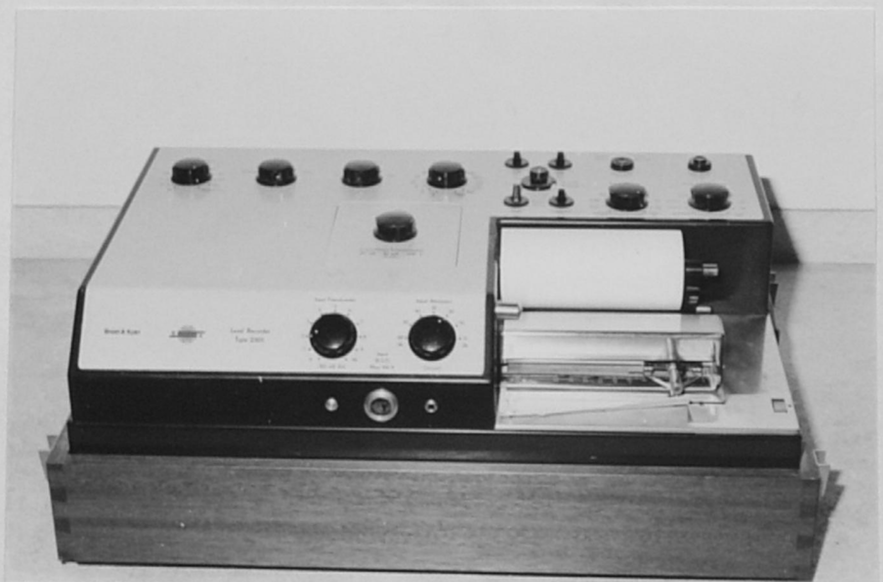

Fig. 12 Level recorder

Fig. 13 Noise generator

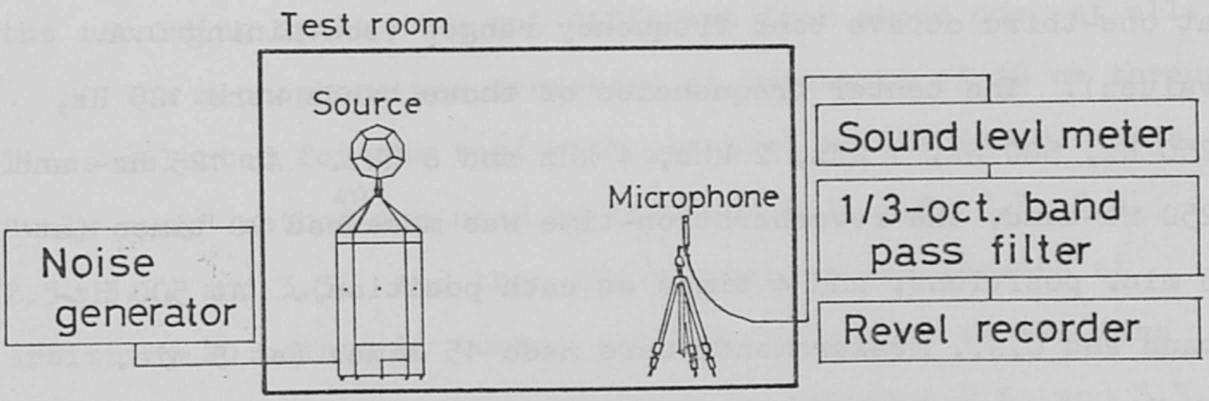

Fig. 14 Schematic diagram of instrumentation used in this study.

Level recorder (Fig. 12) B&K Type 2305

Noise generator* (Fig. 13) B&K Type 1402

* This noise generator produces a noise signal with uniform spectrum density in the frequency range 20 - 20 000 Hz with a true Gausian (normal) amplitude distribution.

3. Measurement Techniques

3.1. Reverberation time

The measurement set-up was illustrated in Fig. 14. The broad band random noise (pink noise was used in the test) was radiated from an isotropic sound source located at the corner of the test room, and the reverberation times were measured at one-third octave band frequency ranges (containing O.A. values). The center frequencies of those bands were 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. At 125 Hz- and 250 Hz-band, the reverberation-time was measured 20 times (at 5 mic. positions, and 4 times at each position). At 500 Hz-band and O.A., measurements were made 15 times (at 5 mic. positions, and 3 times at each position). At 1 kHz- and 2 kHz-band, 10 times of measurements were made (at 5 mic. positions, and 2 times at each position). above 4 kHz-band, measurements were made 5 times (at 5 mic. positions, and single time at each position).

The recording conditions of the recorder were as follows:

Potensiometer Range	50 dB
Potensiometer	50 dB
Rectifire	RMS
Low. Lim. Freq.	50 Hz
Writing Speed	400 mm/sec
Paper Speed	30 mm/sec

The decay curves recorded on papers were changed into numerical values, i.e., decay times in sec by the aid of the protractor (B&K, Type SC 2361).

3.2. Sound distribution

The same measurement set-up as was shown in Fig. 14 was used in the case that the test room was excited by broad band random noise. Even if the room was excited by machinery sources, the recording system was not different from above one at all.

The microphone was traversed at intervals of 10 cm through lines selected for the test with parallel to the floor. This "walk away" method[41] was used in Sections 2.1, 2.2, 2.3, 2.4, 2.5, 3.2, and 3.3. And then the microphone was located at arbitrary 20 points by turns, and sound pressure levels were also measured. This method was used in Sections 2.5, and 3.3.