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Environmental acoustics update

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This is the oral paper of a plenary lecture presented at the opening ceremony of the Joint meeting of the Acoustical Societies of Japan and America. The paper has briefly reviewed the update of both public and personal aspects of "Environmental acoustics." Although it has interdisciplinary or multidisciplinary nature, it is limited arbitrarily to those aspect related to people's daily lives, particularly those in which the author has an interest. The environment can be defined as the interface between human beings and everything surrounding them, *i.e.* the human Psycho-physiological factors and surrounding Physical factors. Therefore it seems to be imperative to promote Psycho-physiological research for developing environmental acoustics.

Keywords: Noise, Propagation, Barrier, Active, Control, Survey, Soundscape, Concert hall, Handicapped, Fluctuation

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1. INTRODUCTION

More than twenty years before, the invited lectures on "Environmental acoustics" at the 8th ICA Congress in London in 1974 were skewed toward "Public aspects" as shown in Table 1. At that time I had felt some dissatisfaction with this weighting, though there was a reason for being concerned with noise-nuisance as a social problem in all developed countries. As far as I remember, it was the first time that the term "Environmental acoustics" was used officially.

Today, I would like to correct such an imbalance by offering additional comments on the "Personal aspects" of "Environmental Acoustics."

As is well known, "Acoustics" has interdisciplinary or multidisciplinary nature. "Environmental Acoustics" is naturally related to every branch of acoustics, however, I would like to limit arbitrarily my remarks to those related to people's daily lives and in which I have interest, since it is difficult to give a rigorous definition. I am going to present current topics regarding "Environmental Acoustics" which have caught my eye recently, mainly for general acousticians.

2. PUBLIC ASPECT OF THE ENVIRONMENTAL ACOUSTICS

2.1 Noise Sources

The most common and significant noise source in the human environment is that of transportation, especially the noise of road vehicles. The International INCE (Institute of Noise Control Engineering) has reported a draft of the Working Party in the quarterly news magazine "Technical Assessment of the Effect of Regulations on Road Vehicle Noise."[1] Figure 1 shows a part of this report regarding a history of noise emission limits over the past 25 years. It is clear that every country has been continuing to make a successful effort to reduce noise emission from the sources, though the levels are not directly comparable since the measuring methods differ between every countries. Further efforts to reduce tire-noise are being made not only with the manufacture of vehicles but with the porous elastic pavement of road surface. The situation is very similar regarding the noise emission of aircraft.

These efforts are most essential not only for traffic noise but also for every noise source, because if noise-emissions from all noise sources could be

Table 1 Invited lectures at 8th ICA Congress (London 1974).

R. H. Bolt (USA)	Public aspects of environmental acoustics
J. E. Ffowcs-Williams (UK)	Physics of sound creation
Z. Maekawa (Japan)	Environmental sound propagation
H. E. von Gierke (USA)	Noise—how much is too much ? The measurement and rating of environmental noise with respect to its effects on man
L. Cremer (Germany)	Stand des Schallschutzes im Wohnungsbau
F. Ingerslev (Denmark)	Strategies for controlling and Planning against transportation noise

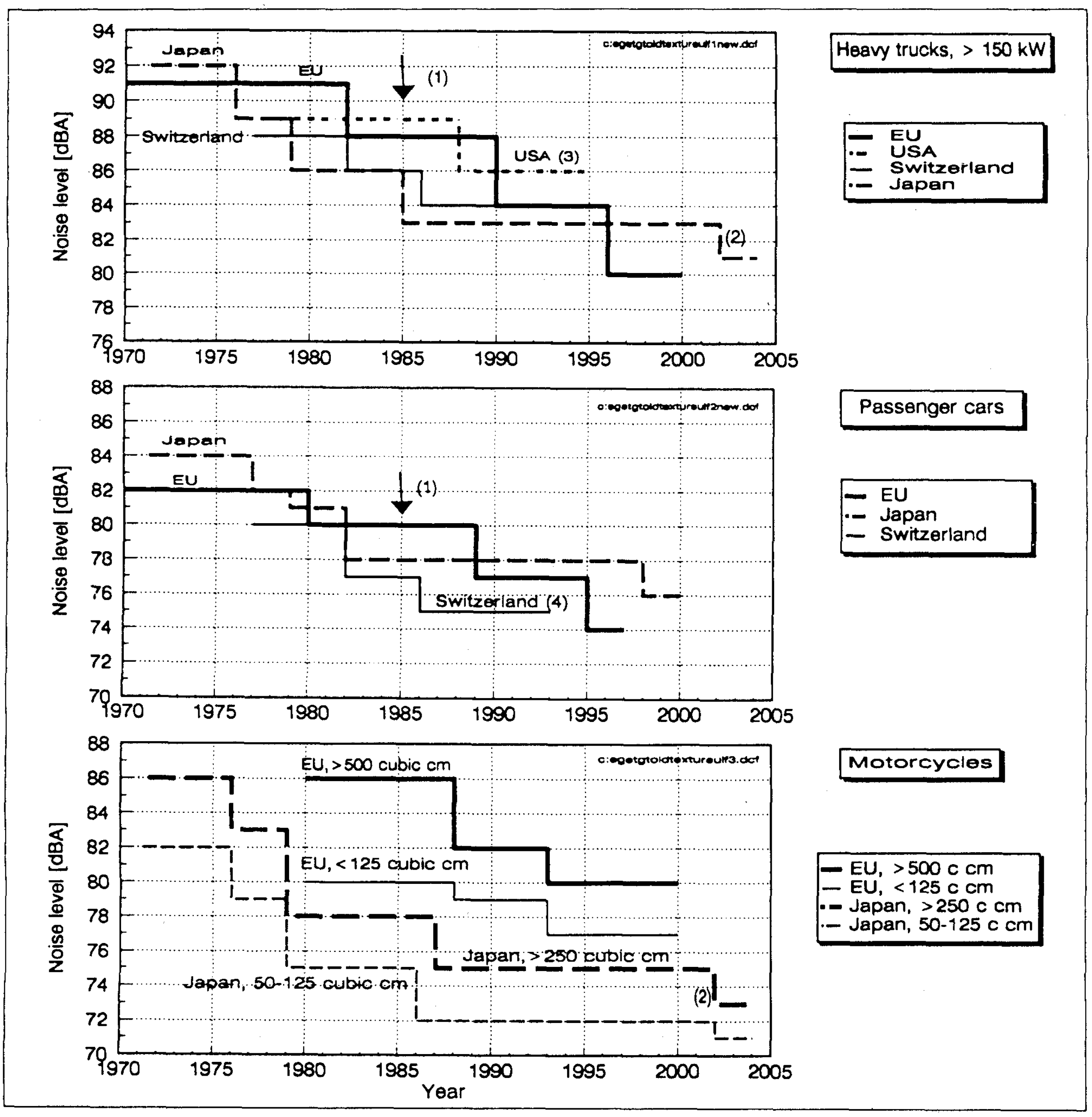


Fig. 1 Development of Vehicle Noise Emission Limits over the Years (Draft of the Working Party of the International INCE).

suppressed to acceptable levels no other means would be needed for noise control. When that day would come, it might be a happy one for people in general but not for us, since acousticians would lost their jobs. However, not to worry. The tremendous increase in the number of vehicles and aircraft continues to overcome efforts to reduce noise emission. We shall have to continue to make effort for sufficient noise control probably for ever.

2.2 Sound Propagation Outdoor

A very nice tutorial paper on this title has been presented by Dr. Tony Embleton this July in our Journal.[2] All factors related to sound propagation are reviewed and arranged so as to be easily understood. Further theoretical works on long range sound propagation in the atmosphere have developed practical methods such as cold the FFP (fast field program)[3] and the PE (parabolic equation) model[4] for a computer. These methods show the remarkable progress of research, but calculate with a simplified model of multi-layered steady atmosphere. They must be valid under the assumed condition of the vertical profile of sound speed in the atmosphere which is steady and constant between the source and the receiver. However, such a meteorological condition is not likely to exist in the natural atmosphere, even though taking into account the air turbulence, but it must be different from place to place and changing every moment. Therefore, it is a very complicated chaotic condition, the varying details of which it is almost impossible to catch or predict.

When we had to perform an environmental impact assessment of our new developing airport on an artificial island, we measured noise propagation in long range of 5 km over sea continuously for 14 months, in order to know how the noise reduction from source to receiver varied in time and from season to season. Technical data have been presented at the Conference "Inter-Noise 96,"[5] an example of the results for one month is shown in Fig. 2. As you see, the noise reduction shows one day's periodic change with large amplitude of 50 dB or more. Some times, it changes 20–30 dB quickly within several minutes. Our major interest is when it becomes small, because, then the receiving noise becomes high level. At what time and for what percentage of time does noise level exceed the acceptable level ? It must obviously be a statistical problem. And we hope to find any relation with meteorological conditions in order to predict noise behavior. If we can forecast that the noise level will be higher than the acceptable level, we shall be able to control the flying of aircraft in order not to occur social noise problems.

The meteorological conditions at the site were, of course, observed simultaneously, in order to obtain any correlation with the noise reduction. It is, however, not easy to get a favorable result with simple statistical analysis, though some results were presented at the "Inter-Noise 96."[6] Now, we are continuing to analyze in order to publish more details of it in the near future.

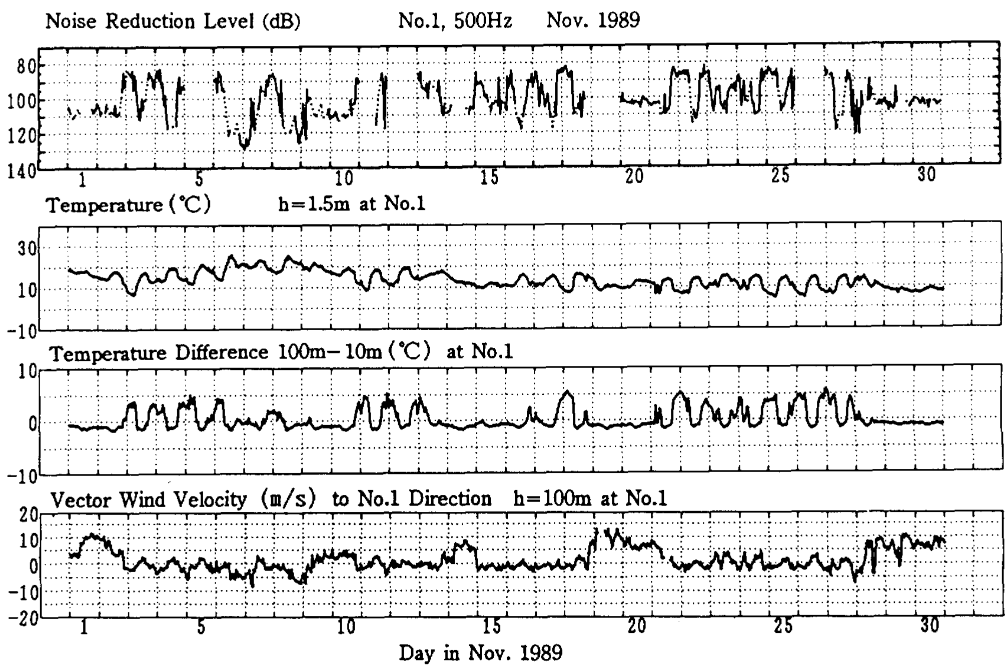


Fig. 2 Fluctuation of Received Noise Reduction Levels and some weather conditions.

2.3 Noise Barriers

Noise barriers are a very common device for noise control in the open air. Some rigorous exact solutions for refracted sound field by a screen had been presented, however, a simple chart shown in Fig. 3 which I compiled 30 years before[7] is still useful for designing a noise screen in practice. The chart is very simple and easy to use and also gives results with reasonable accuracy even without any computer. On the other hand the rigorous solution requires more or less troublesome computation with simple and pure conditions which rarely exist. Consequently there are some discrepancies with the real situation. In addition, resulting interference patterns are not always important. However, where the effects of ground surface and meteorological conditions might not be negligible with some distance, not so close to the source, we must use the exact theory. For example, Fig. 4[2] shows influence of the ground surface by the exact solution. Here, I have added the curve (M2), it shows the result of addition of the intensity of ground reflection by my method neglecting its phase, since the curve (M) shows only the value of my chart without any reflection. Regarding the distribution pattern of diffracted sound pressure level by the exact solution we must keep in mind that it depends on the position of receiving point.

Barriers are almost the only one device in use in

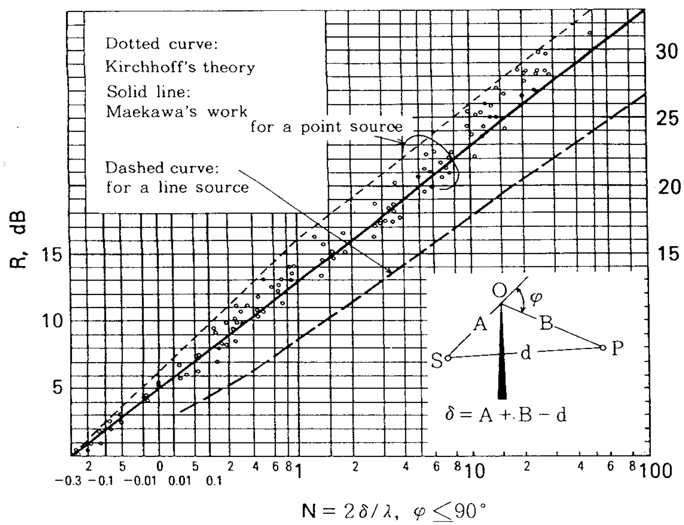


Fig. 3 Noise reduction by a semi-infinite screen in free space.[7]

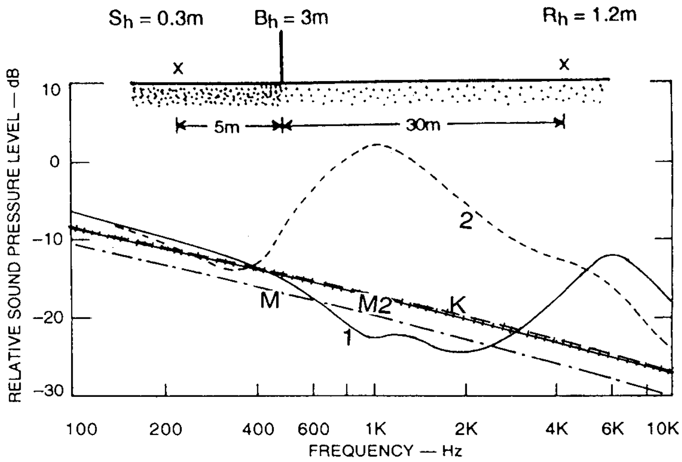


Fig. 4 Predicted Insertion Loss for a Roadside Barrier.[2] Curve 1 & 2, due to Isei *et al.*; Curve 1, both side of barrier is hard, agree with K, M & M2; 2, behind the barrier is grass-covered; Curve K, due to Kurze & Anderson; M, due to Maekawa (neglecting the ground); M2, due to Maekawa (added with the ground reflection).

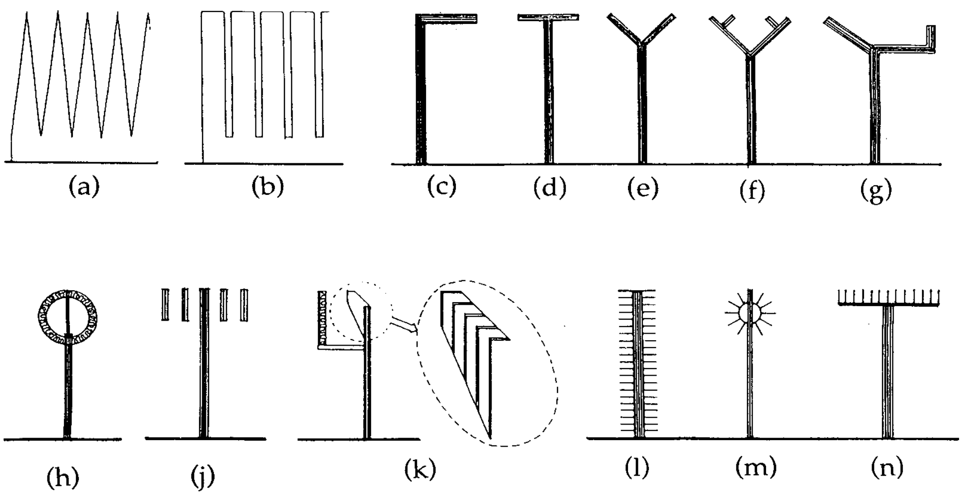


Fig. 5 Special Shapes or Treatment for Noise Barriers. (a), and (b) show elevations, the others show cross-sections. A noise source is right hand side of the sections at (g) and (k).

the open air for blocking noise propagation. And they block also wind, sunshine and sight or the nice view, *i.e.* they destroy almost all environmental elements except noise. The higher the barrier the greater the noise reduction, it is true, but these adverse effects are unavoidably introduced. We have been continuing to make effort to reduce these adverse effects within the environment of human life. When a barrier is required to be lower in height and to have greater noise reduction, special devices or treatment must be added to it. Figure 5 shows various inventions from the past. The drawings (a) and (b) are elevations designed for reducing the adverse effects. And others are cross sections designed for increasing the shielding effect with many adaptive shapes at the head of the barriers. They have been invented as shown in (c∼g), various overhang with hard materials, (h); absorbing, and (j) have multiple-edges, (k); interfering with a reactive-type head. The devices (*l*, *m*, *n*) have acoustical soft surface, *i.e.* honeycomb layer of a quarter wavelength thickness, so that the sound pressure of the incident sound wave becomes zero at the surface. One of these will be presented at this afternoon session. Especially the last one will probably obtain great noise reduction for wide range of frequency. Figure 6 shows the detail of its design and results of theoretical calculation with Boundary Element Method.[8] This research is still

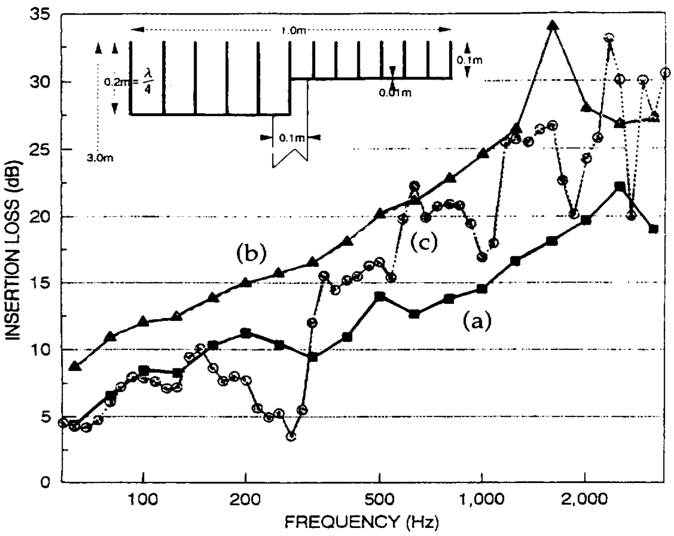


Fig. 6 Insertion loss spectra of a T-shaped barrier, containing wells tuned to frequencies of 420 and 840 Hz on the upper surface, computed by BEM method. (a) Rigid flat surface, (b) Ideally soft for all frequencies, and (c) With tuned wells of 420 and 840 Hz.

advancing, and BEM computation is a powerful tool for theoretical investigation.

2.4 Active Noise Control

As is well known, superposition of a negative phase wave on the original one can cancel the original wave provided that both the amplitude and the wavelength are the same and the phase is inverse to the original one. Owing to development of the digital computer, its first application has been successful in a closed narrow space such as in an earmuff or in an air conditioning duct. Now, attempts are being made to increase the shielding effect of a noise barrier in the open air.[9,10] Here, the sound pressure at the top of the barrier should be canceled.

Although it is necessary to have equipment, a power source and maintenance for the facility, the application of active control technique is gradually spreading for various kind of noise control especially in the low frequency range for our environmental comfort.

2.5 Community Noise Survey

The social survey on noise problems is quite an essential procedure for compiling basic data on noise control, since the noise problems that exist depend on the subjective evaluation of the citizenry. Such surveys have been performed in almost every country.

In Japan, the Committee for the Social Survey on Noise Problems has proposed fundamental items in our Journal,[11] to be used in the survey in order to make them comparable to each other. And two groups are active in cross-cultural study between foreign countries as shown in Fig. 7.[12,13]

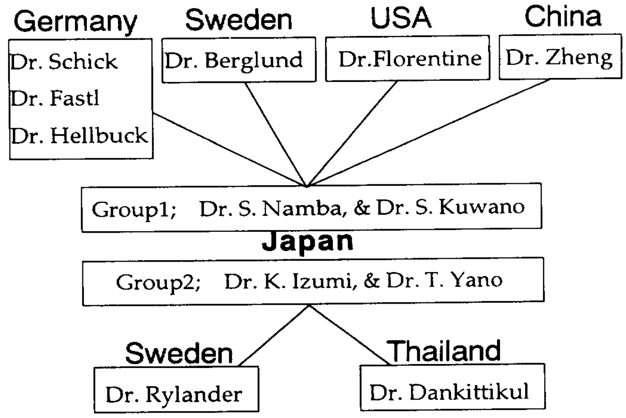


Fig. 7 Cross-Cultural Study Groups on Environmental Noise.

The "International Commission on Biological Effects of Noise (ICBEN)" is now discussing how to make "the common questions for survey."[14] It is essential to have a common international questionnaire transcending language barriers. Also in the ISO, a committee is going to start with the similar target. When it has been put into operation we shall be able to compare the results of surveys performed anytime and anywhere with a common measure.

On the other hand, an intensive survey in relation to community response to noise is emphasized in order to obtain more detailed information on people's response with smaller amount of data than the usual extensive methods.[15] It seems that both intensive and extensive surveys should be organized with proper balance, according to the purpose of investigation.

A new method for analysis of personal reaction to environmental noise with a membership function of the fuzzy theory as well as the quantification theory and a neural network has been reported.[16,17] It can be expected that such analysis will become a new tool to deal with a indistinct problem like a psychological response or a social survey.

This field is intimately related to the hearing research in Psycho-acoustics. It is our pleasure to have a Festschrift for Dr. S. Namba "Recent Trends in Hearing Research" authored by 14 authorities.[18] It contains almost all items of psycho-acoustics related to environmental acoustics.

2.6 Effect of Regulation on Environmental Noise and Soundscape Movement

It has been a quarter century since the Japanese Government established the Environment Agency and determined Environmental Quality Standards for noise in 1971. The effect of regulation is not yet sufficient. Places which satisfied the standard all day are only 13% of areas which had observed the environmental noise level continuously.

Being at their wit's end, the Environment Agency published this June the list of "100 selected soundscapes in Japan" to be conserved.[19] Ideally, if people give attention to sounds surrounding them, and assess them good or bad, and necessary or unnecessary for their environment, they might become aware of the importance of silence. And it might lead to satisfying Environmental Quality Standards for noise. It may really be the most important to improve the surrounding environment so that the soundscape can be enjoyed forever.

3. WHAT IS GOOD ACOUSTICS IN THE PERSONAL ENVIRONMENT

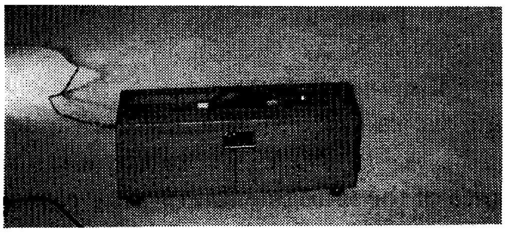
3.1 Noise Control in Buildings

This evening we will have a "Tutorial Lecture on sound transmission through structures-protecting occupants from exterior noise." The first step for good acoustics in the personal environment is of course obtaining quiet. Exterior noise shows yearly increase, owing mainly to the growth of transportation everywhere. Locally, near a airport, along a highway or a high speed train line, and in the vicinity of a bombarding site for military practice, there are serious problems in low frequency airborne sound insulation, as a protecting technique. Especially for high energy impulsive sound contained in very low frequency range we must develop some new effective devices. It is our obligation, for example, to solve such acoustical problems in Okinawa, though a new device for increasing the sound insulation of a double-window by using the active control technique is being studied and will be presented in this meeting.[20]

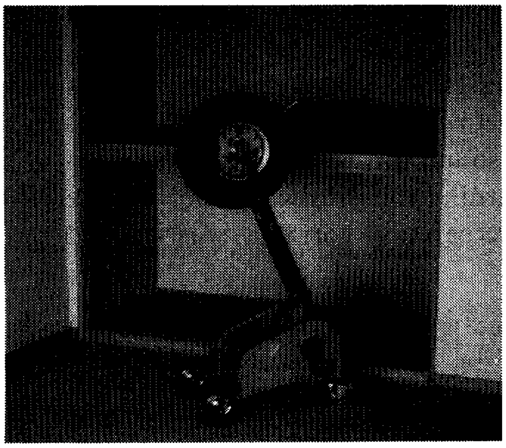
Various methods for measurement and evaluation of airborne-sound insulation have been proposed for national and international standards. Although relationships among many single-number indices for sound insulation of building walls has been reported,[21] no one treated the lower frequency range under 100 Hz.

Thursday afternoon we are going to have a session on "Floor Impact Sound," which is the most common problem of structure-borne noise in apartment houses. In Japan, we have our own testing method *i.e.* in addition to the standard method of using ISO tapping machine a heavy and soft impact source (specified in JIS A 1418), have being used.[22] That is the process of simulating noises such as those of children's jumping and running. Figure 8 shows both sources, and you can listen to each sound by playing back of a recorded tape. The ISO Committee is now discussing methods for measuring and rating of the structure-borne sound problem in frequency extending below 100 Hz, according to the proposal from Japan. Many papers will be presented in the session.

Consequently, both air-borne and structure-borne sound problems in buildings are insulation in fre-



(a) Tapping Machine (ISO).



(b) Heavy Impact Source (JIS).

Fig. 8 Floor impact Sound Sources.

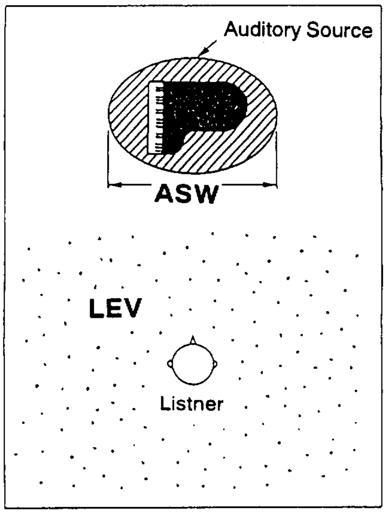


Fig. 9 Concepts of two components in an auditory space. ASW: Auditory (Apparent) Source Width; the width of a sound image fused temporally and spatially together with a direct sound and early reflections. LEV: Listener Envelopment; the fullness of sound images around a listener, composed of the later arriving lateral reflections.

quency range lower than 100 Hz, in which frequency range we have not enough data for practice. Since the wavelength is so long that it must be difficult to solve both theoretically and experimentally, some special invention is to be hoped for.

Regarding the subjective evaluation or perception in very low frequency range, we have also many unclear problems. For example, we have had a peculiar experience. When we were in a good insulated room near a highway, we felt shock to our bodies and had a strong oppressive feeling because of a passing heavy truck. However, this sense was reduced by a little opening of the window! What had happened? Why was the poor sound insulation able to relieve our feeling? From now on we intend to study this problem with psycho-acoustical experiment.

3.2 In a Concert Hall

Dr. J. S. Bradley gave a brief article "Listener envelopment: An essential part of good concert hall acoustics" as an "ACOUSTICS 1995" in the Journal of our Society.[23] It is a very nice review of recent research for evaluation of concert hall acoustics.

It has been 25 years since the discovery by Dr. Barron of the importance of lateral reflections in a concert hall for listener spatial impression or spaciousness. Recent work has now revealed that there are two distinct components, one is a sense of 'listener envelopment,' and other is a sense of 'apparent broadening of the source.' Figure 9 shows these two components. He emphasize the importance of the later arriving lateral reflections for getting a sense of 'listener envelopment.'

Dr. Beranek also gave a tutorial review "Acoustics and musical qualities" in the same Journal.[24] That is Chapter 3 of his new remarkable book "Concert and Opera Halls" published by the A.S.A. He wrought the same theme *i.e.*, 'apparent source width' (ASW) is composed of the early sound. "The larger the better." I would like to comment against his description. When large amount of lateral reflections arrive early time after the direct sound we can really feel a source size is broadened. However, I would like to ask "Why is that better?"! If by shutting one's eyes, the sound of a violin would seem to be broadened to equal the size of a full stage, I can not be comfortable with the resulting queerness, unnaturalness or a sense of incompatibility that I would feel. It is most obvious at a solo performance. I think interaural cross-correlation coefficient (IACC), the measure of ASW, does not imply the lower value the better, but the IACC

J. Acoust. Soc. Jpn. (E) 18, 3 (1997)

should have the optimum value. Therefore, in my opinion, ASW is not the larger the better, though it's detail is still under investigation and will be presented in this meeting.[25]

Such and such discussions, the assessment or evaluation of concert hall acoustics still generate a lot of controversy, since the problem is deeply related to the subjective sense of the music arts. At every meeting of our acoustical societies many papers on concert hall acoustics used to be presented. In this meeting we also will have a full-day session "Acoustic Measurement and Assessment in Halls" on this Friday. Further, 'auralization,' the use of computer simulation, recently has been increasing. It must be an effective tool for designing a hall, since we can listen to the sound in the hall before construction, provided that the sound be completely the same as the real sound of the hall after completion. This afternoon, we are going to have a session of "Demonstration in Auralization," and tomorrow morning 8 papers on auralization will be presented in succession. Furthermore, next April an International Symposium on Simulation, Visualization and Auralization (ASVA 97) will be held in Tokyo. I've heard that more than 20 papers related to auralization have been submitted. We hope a reliable auralization technique will be accomplished as soon as possible.

On the other hand, some persons who are not satisfied with computer simulation are trying to have a new evaluation method for concert hall acoustics with real sound of music performance. For example of the first step, Fig. 10 shows two positions of a timpani on the stage. You can find the importance of source position by listening to the reproduced sound recorded at these positions. The music is the first page of the score of J. Brahms Symphony No. 1 as shown in Fig. 11. With comparing the sounds recorded at both positions of a timpani, we can recognize a missing fundamental at position A.[26] Then, we can understand the importance of the fundamental tone by playing with a contra-bass and by ensemble with an orchestra.

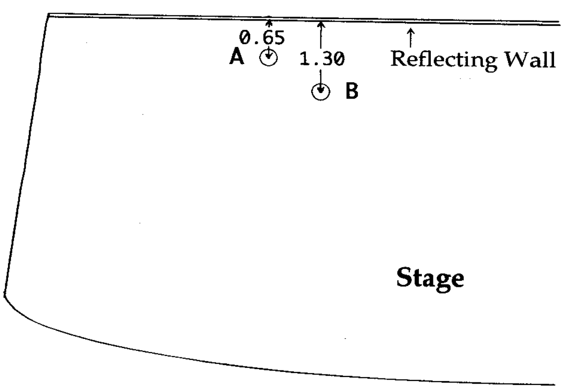


Fig. 10 Two positions of a timpani (Pauken) on a stage.

How to design a stage on which we have the same sound effect with the same instrument at every possible location? Although many studies on stage design have been reported, the design method is not yet accomplished. It seems necessary to clear up the sound diffusion on the stage.

Regarding the diffused sound field, even though the reverberation formula was derived under the

Fig. 11 A portion of 1st page of the score; J. Brahms Symphony No. 1, Op. 68.

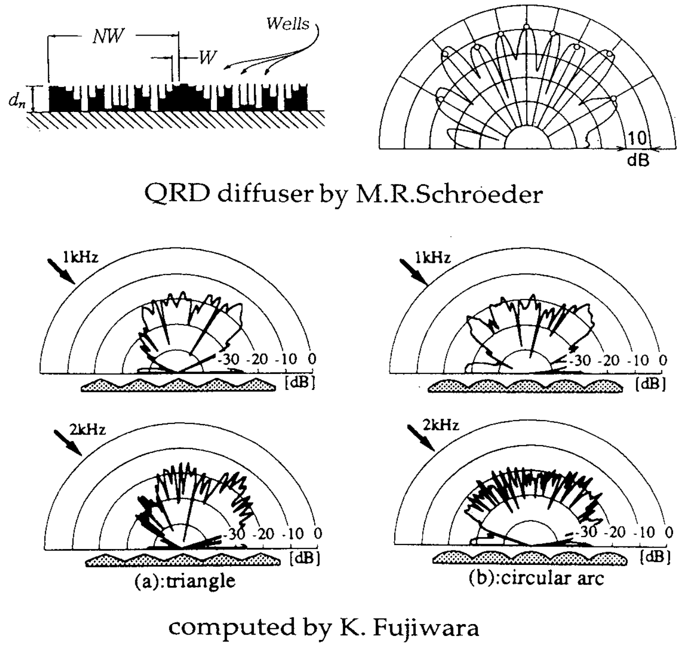


Fig. 12 Directional patterns of reflected sound from diffusers on surface of ceilings or walls inside concert halls.

assumption of perfect diffusion of the sound field at the beginning of this century, we have not yet developed the measure of diffusion. A design method of diffusers was presented by M. R. Schroeder[27] and applied considerably to many halls or studios, but its acoustic features are still under investigation regarding not only diffusion but also absorption. Other design methods for free type diffusers are also under development,[28] as shown in Fig. 12. However, we must still ask "How much diffusion can be obtained ?," "How much diffusion is appropriate ?," and "How to change a timbre with how much diffusion ?." These troublesome problems of concert hall acoustics have yet to be solved.

As one more technical topic, I would like to mention that acoustic researches of materials have decreased. However, sound reflection characteristics of panels or membranes are undergoing study.[29] We are expecting to have information as to what material or what construction produces which tonal quality or timbre. This information may facilitate noticeable skill in designing a concert hall, since we can recognize the difference of the timbre of, for example, sounds reflected from a thin steel plate and a wood panel. Recently, the huge spaces of stadiums or domes are often built up utilizing large surface of membranes. The acoustics of those spaces, of course depend on the characteristics of the membranes, for which data did not exist until recentry.[30] The results of such research are benefiting people who enjoy events in the domes.

3.3 For Handicapped or Aged People

Not only the visually handicapped who rely upon auditory information but also an increasing number of aged people have come to understand the environment surrounding them under different conditions. What kind of consideration is needed? A study to find a better sound environment for the visually handicapped pedestrian[31] will be presented tomorrow afternoon.

Regarding the aged, the effect of hearing loss on speech intelligibility has continued to be researched under sponsorship of the Japan Ministry of Education.[32] And in practice, an example of the improvement of a sound system of a church has been reported.[33] From now on, such considerations as those mentioned above shall be important social issues in the era of a welfare society for the aged.

3.4 $1/f$ Fluctuation of Sound in Personal Environment

It has been nearly twenty years since it was realized that the spectral density of fluctuations in the audio power of many kinds of music or noise varies approximately as $1/f$ (inverse frequency).[34] Not only acoustical phenomena but many natural environmental factors are fluctuating, *e.g.* air temperature, breeze or wind *etc.* We know the fluctuation makes us comfortable and even delighted. So far we could scarcely find research on such fluctuations. But recently, a research on Physiopsychological effects of fluctuating sound on human activities has been presented.[35] It might extend to a general measure to evaluate the environmental acoustics.

Now, let us listen to an example of test signal with famous music 'Vivaldy : Four Seasons' in L. ch. and artificial noise with same fluctuation of $1/f$ in R. ch.

This artificial noise makes us not so disturbed. It might be useful for masking noise.

4. FINAL COMMENT

Both public and personal aspects of "environmental acoustics update" have been reviewed briefly. The environment can be defined as the interface between human beings and everything surrounding them, *i.e.* the human Psycho-physiological factors and surrounding Physical factors. I think it seems to be imperative to promote Psycho-physiological research for developing environmental acoustics.

Thank you for your kind and considerate attention.

ACKNOWLEDGEMENT

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