

Design problems of concert hall acoustics

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1. INTRODUCTION

During past 20 years, a variety of room acoustical parameters have been proposed, and a number of new halls have been built incorporating these new design principles. Nevertheless, the question of what constitutes the optimum acoustical condition for classical music continues to be the object of discussion and theorizing, and some of the new halls have characteristics that negate previously held room acoustical design principles. Historically the first generation of acoustical design work focused on reverberation theory, the second generation gave priority to early reflections, the third generation of thought inclined to emphasizing lateral reflections, and we are now on the verge of a new generation of acoustical design.

In the past, almost all of the halls constructed in Japan were designed for multipurpose use, but a new trend to specific purpose concert or dramatic performance hall construction has become evident in the past few years. Among large-size halls, Symphony Hall (Osaka), Kumamoto Prefectural Theatre (Kumamoto) and Suntory Hall (Tokyo) are specific purpose concert halls, and other halls of large, medium and small size are in various phases of construction in Tokyo and other Japanese cities.

Within the field of architectural acoustics, concert hall acoustics is the most attractive and interesting area of research and study, and is also the area of acoustical design in which the goal are the most encompassing and demanding. However, since there is still a large gap between the level of the objective quality that current technology can control and subjectively perceived quality standards, I have here presented the main questions facing acoustical design of concert halls today, in the hope of providing some direction for future study.

2. NC-15 AS A STANDARD OF QUIETNESS

Quietness is crucial to concert hall acoustics, and one of the significant factors affecting quietness is air-conditioning noise. In the past, NC-20 was considered as the acceptable noise level for concert halls, but NC-20 does not insure a satisfactory level of quietness for classical music performances.

In Japan, since 1950, the level of quietness of air-conditioning noise has been upgraded in stages from NC-30 and NC-25 to NC-20, and now to NC-15. In Europe, however, levels of NR-10~NR-15 have been achieved in concert halls since the 1960s, and a noise level of NC-15 should therefore be considered the minimum standard for noise control of the air-conditioning equipment in new concert halls.

As a method of reducing fan and wind noise, the implementation of glass wool ducts has gained favor in recent years. In addition data on the insertion loss of the sound pressure level and total pressure loss are in the process of being compiled by the manufacturers. Figure 1 shows the experimental facilities for development of sound absorbing ducts at a company specializing in the manufacture of air duct silencers.

Air-conditioning noise levels in concert halls constructed recently in Japan are shown in Fig. 2.

3. DEVELOPMENT OF SOUND INSULATION STRUCTURES OF HIGH TRANSMISSION LOSS

Space limitation in Japan makes it inevitable that auditorium buildings be built with halls adjacent to each other and to rehearsal or music practice rooms. With the increasingly large demand placed on scheduling of halls for classical music, the sound insulation between these rooms has likewise become

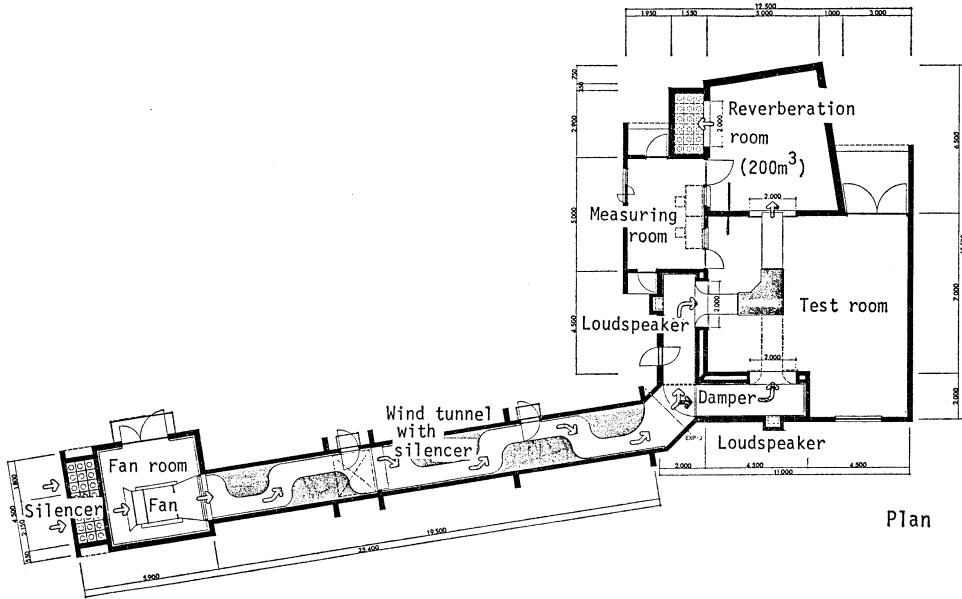


Fig. 1 Experimental facilities of sound absorbing ducts at R company.

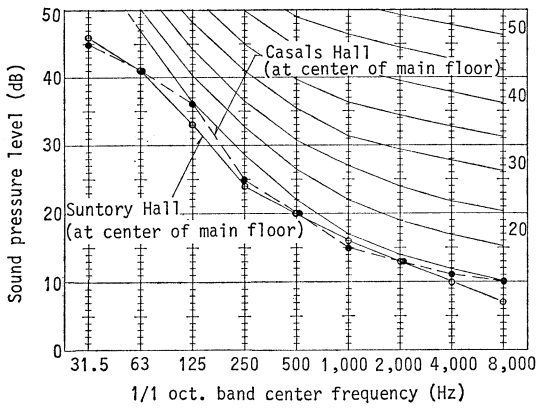


Fig. 2 Air-conditioning noise in Suntory Hall and Casals Hall.

increasingly important.

In facilities where a hall is adjacent to a rehearsal or a practice room, it is common to use sound insulation structures with floating panels on one wall side, which achieves the sound insulation of up to 65~70 dB. In the past, this level of sound insulation was considered acceptable, even though there was some leakage of choral singing. Obviously, performances using electro-acoustic amplification

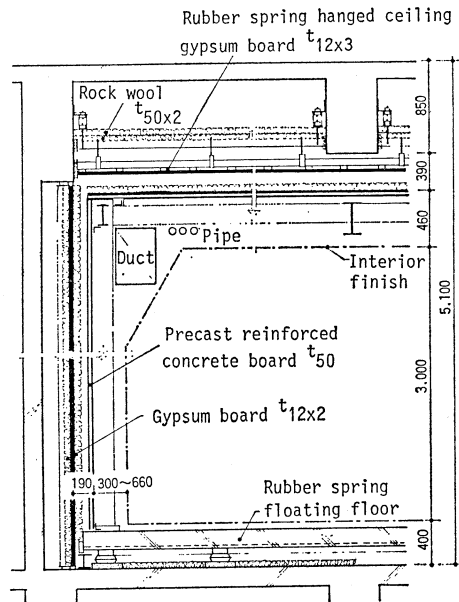


Fig. 3 Sound insulation structures of the music practice room at Niigata Music Culture Center.

creates serious problems for classical concert halls. From listening experiences, I am of the opinion that concert hall must achieve sound insulation of at

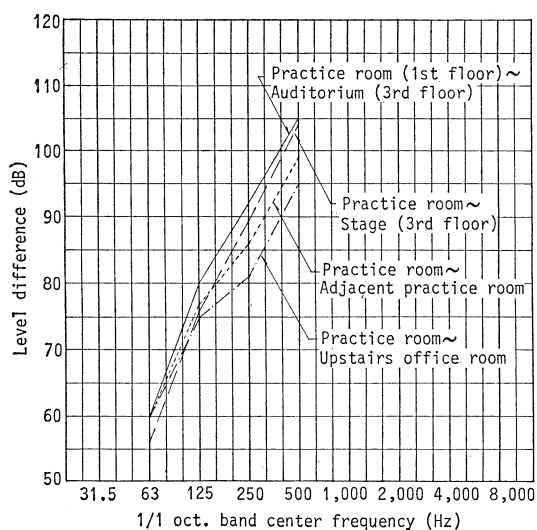


Fig. 4 Measured insulation between the music practice room and adjacent rooms at Niigata Music Culture Center.

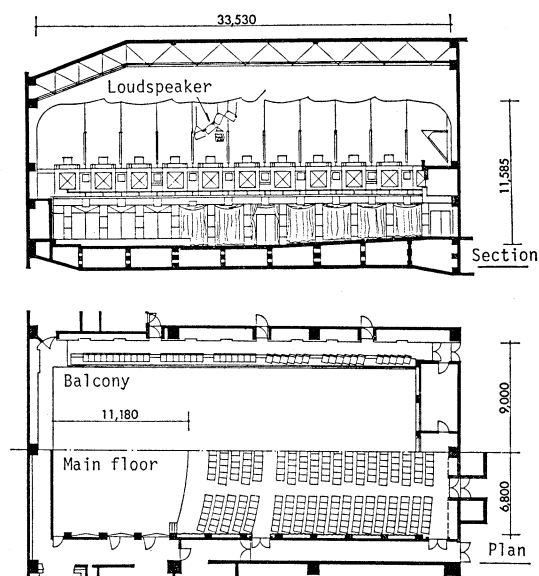


Fig. 5 Casals Hall (Tokyo).

least 80 dB to adjacent rooms.

In the repair work of Niigata Music Culture Center, sound insulation structures which insulate brass band music and rock music sound were designed and introduced to two music practice rooms.¹⁾ Figure 3 shows the structures and Fig. 4 the measured sound insulation between the practice room and adjacent rooms. As shown, sound insulation of more than 90 dB at 500 Hz is achieved between adjacent rooms.

4. DISCUSSION OF ROOM SHAPE: SHOE BOX, VINEYARD AND PANEL HALLS

It is unlikely that anyone would nay-say the laudatory comments made about the brilliantly rich sound of the Vienna Musikvereinssaal. With all of the advanced technology available to today's acousticians, performers and concert-goers often ask why it is impossible to recreate the identical sound quality of the Misikvereinssaal.

Shoebox-shaped halls continue to be built in Europe and the United States, and in Japan as well. But almost none of these recently built halls have not equalled the high reputation of the Vienna Musikvereinssaal. In Japan, popular opinion has given the Vienna Musikvereinssaal a legendary standing on a pedestal of excellence apart from all

other halls. However, it should be noted that most of Japan's shoebox-shaped halls have stepped or inclined floors, which absorb more direct sound than do flat floors and bring significantly influence the room acoustical characteristics. Casals Hall in Fig. 5 is presently virtually the only concert hall that can be called a shoebox-shape in this strict sense of the term.

The question may also be raised, however, as to whether the Vienna Musikvereinssaal epitomizes the perfect hall for classical music performances in the present day. In the early planning stage of Suntory Hall (Tokyo, 1986), it was indeed this very question was the major focus of thought and discussion. When the advisory role of Maestro von Krajan, and the specific nature of the client—Suntory Ltd.—influenced the decision of the hall's configuration towards the innovative vineyard, or "Berlin," shape, many Japanese musicians and others associated with musical activities in Japan expressed their sympathy at the plight of the acousticians assigned to the project! Ten out of ten people in Japan automatically assumed that the Musikvereinssaal shape was to be preferred.

The first time I heard the Berlin Philharmonic Orchestra in Neuphilharmonie, in 1963, the acoustics might not have been as brilliant as in the Musikvereinssaal, but the sound had softness,

clarity, and a refreshing impression. Thereafter, the only other examples of vineyard-shaped halls that I experienced first hand were the Sydney Opera House Concert Hall and the Christchurch Town Hall, both of which I visited in 1980. Recently, I have had the opportunity to visit the newly renovated Gewandhaus Hall in Leipzig. These halls that have implemented the vineyard configuration can be said to tend to have acoustics that differ from the sound of older halls of traditional shape.

Despite the numerous preconceptions that might well have given a yellow light to adoption of the vineyard configuration, it was decided that Suntory Hall should be designed using this innovative shape. Later, in 1984, I had the lucky opportunity to listen to two large orchestral concerts in close succession: first, Stravinsky's "Le Sacre du Printemps," at the Musikvereinsaal, then, the next evening, a concert of Bruckner's Symphony No. 7 in Berlin. While these two concerts were played by different orchestras, it was still a most enlightening experience to listen to them in the two halls one day after the next. My interest was especially strong, since one of the expressed major objectives of Suntory Hall was to provide an appropriate venue for orchestral music of large formations.

Simply stated, the answer that I drew from listening to these two concerts was: (1) the sound volume of the Vienna Philharmonic's Musikvereinsaal is too loud for Stravinsky, so that the sound seemed cramped within the hall's space; and (2) by comparison, in Berlin, the Bruckner's work fit the available space well, with comfortable impressions of loudness. Certainly, this was only a sample of two concerts: nevertheless, the sound of the Berlin hall enabled the audience to listen comfortably to relatively loud performances in a way not possible at the Musikvereinsaal.

At the ICA Symposium in Edinburgh, in 1974, Dr. Ted Schultz pointed out that of six halls rated A+, in Beranek's "Music, Acoustics and Architecture," only two were of the shoebox shape, and of the 19 halls rated A, 14 were shoebox shaped, so that it cannot be said that the rectangular shape is a necessary condition for optimum concert hall acoustics.²⁾

The vineyard configuration started in Berlin and adopted for Suntory Hall, shown in Fig. 6, can be fairly said to be an epoch-making innovation in the design concept of concert halls of large size. How-

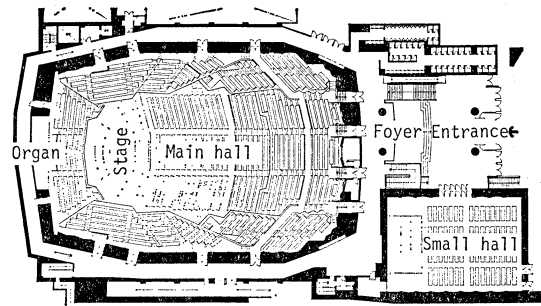


Fig. 6 Suntory Hall (Tokyo).

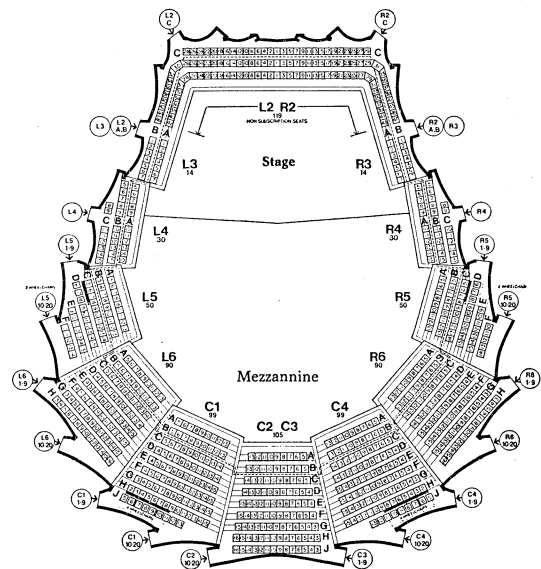


Fig. 7 Roy Thomson Hall (Toronto).

ever, to the extent that lateral reflections continue to be emphasized in vineyard configurations, the fundamental acoustical concept remains constant with that of shoebox-shaped halls. On the other hand, there are examples of halls in which lateral reflections have been ignored from the outset and which have gained some measure of recognition. A primary example of this last kind of hall is Schultz's "panel hall" configuration.

The Roy Thomson Hall in Toronto, is an example of Schultz's panel hall concept. As shown in Fig. 7, this hall has an almost circular shape in plan with balconies. Though all the side walls are constructed as diffusing panels, long path echos are heard on the stage. Early reflections are obtained exclusively by reflector panels hung from the ceiling.

M. NAGATA: DESIGN PROBLEMS OF CONCERT HALL ACOUSTICS

Since the shape of the Toronto Hall is at variance with virtually all of the principles and intuitive thinking of accepted acoustical design, I was curious about the conditions and situation that led Dr. Schultz to agree to design a hall of this shape, and I asked him about this directly. Dr. Schultz, however, expressed surprise at my question, replying that it was he who had proposed the hall's shape from the outset, and that the architect had been selected with the prerequisite that this shape be adapted. For Dr. Schultz, creating lateral reflections was irrelevant. Rather, his primary concern was the number, height and inclination of the suspended ceiling reflectors. It was only after my meeting with Dr. Schultz that I read his paper on

Table 1 Total area of the stage reflectors in concert halls.

Hall	Stage area (m ²)	Reflectors area (m ²)	Reflectors area as percent of stage area (%)
Louise M. Davies Symphony Hall	212	102	48
Roy Thomson Hall	208	98	47
Victorian Arts Centre Concert Hall	181	91	50
Joseph Meyerhoff Symphony Hall	179	62	35
Suntory Hall	250	40	16

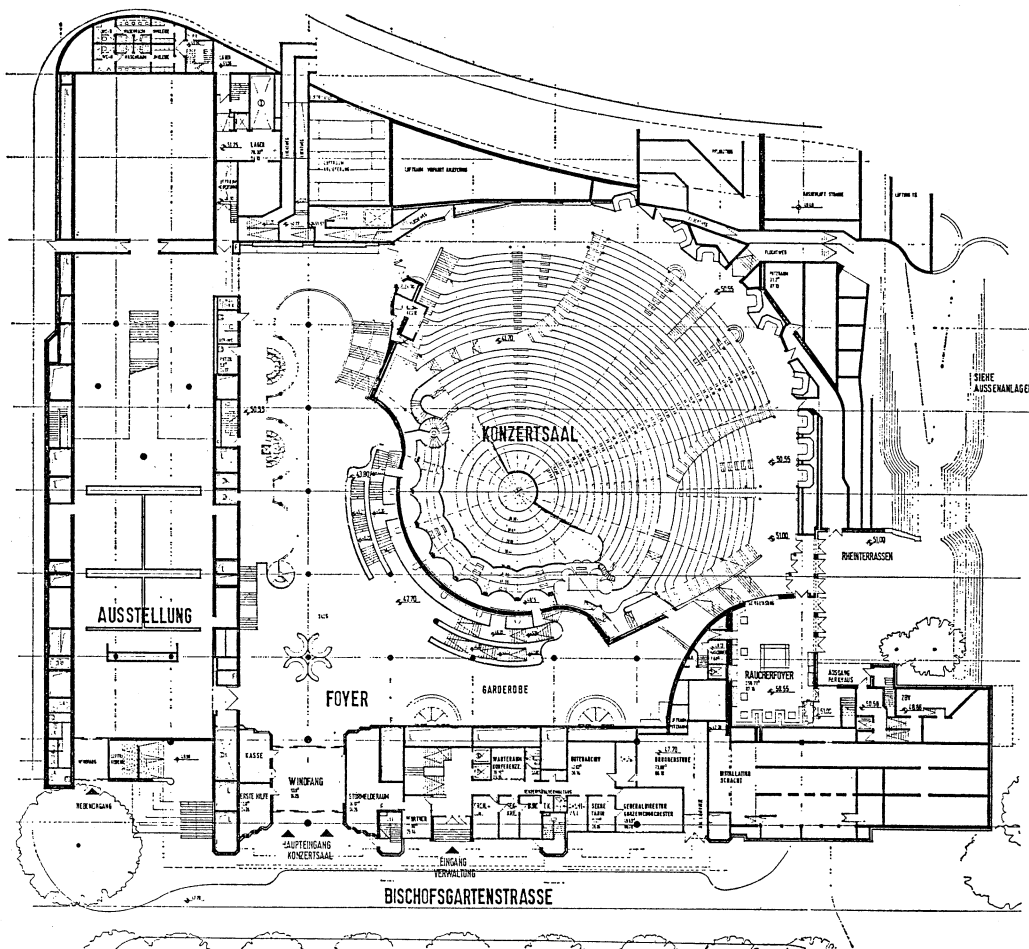


Fig. 8 The Cologner Cultural Center.

this hall.³⁾ The total area of the stage reflectors relative to the stage area of the concert hall is shown in Table 1.

In 1986, the Cologne Cultural Center Hall opened and has received high praise for the quality of its acoustics. This hall is also of circular plan as shown in Fig. 8, and has an organ at one side. Thus, the design of new concert halls show a divergence from the traditional shoebox shape to vineyard configuration and panel hall types, and even to cylindrical configurations without reflectors, ignoring the heated controversy over lateral reflections that continues in the academic field. I look forward to the birth of yet new concepts of spatial configurations in the halls of the future.

5. CONSIDERING THE IMPORTANCE OF LOUDNESS

At the symposium on "Acoustics and Theatre Planning for the Performing Arts" in Vancouver, in the summer of 1986, there was considerable interest in loudness as an acoustical parameter, and the majority of papers relied on the parameter known as strength "G."

In Japan, where most large halls are still of the multi-use kind, one's first impression of the acoustics is often the insufficiency of loudness. It was my understanding that this was a characteristic peculiar in Japan, and not to be found in Europe or North America. With the increase in large, multipurpose halls in those two continents, however, the parameters that describe the characteristics of the loudness have become more important world wide.

When radiating power of a sound source is a constant, the sound energy density in a room is directly proportional to the reverberation time, and inversely proportional to the total volume of the room. In relation to the average sound pressure level of the Vienna Musikvereinsaal, Dr. J. Meyer calculated the relative sound pressure level in various auditoria in Europe and the U. S.⁴⁾ This same method has been employed to explain the relative loudness of major halls in Japan as shown in Fig. 9.⁵⁾ While the subjective loudness of a hall is affected not only by reverberation time and room volume, but by many other factors as well, the results shown in Fig. 9 seem to be a valid way of describing some of the distinguishing characteristics of each of the halls, in keeping with our expectations based on actual listening.

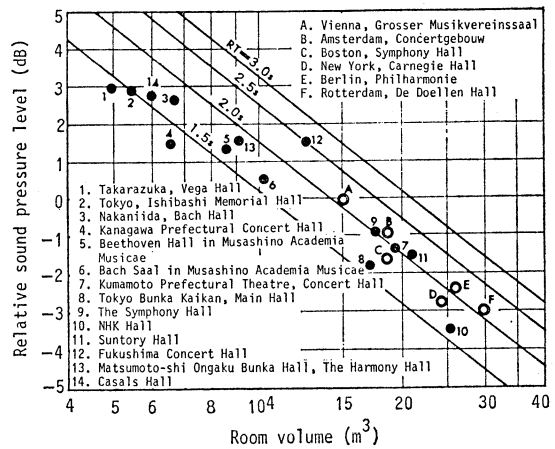


Fig. 9 Relative listening SPL in halls in relation to room volume and reverberation time.

With respect to Fig. 9, a further question is how to evaluate the relative SPLs shown; that is, is the loudness of the Musikvereinsaal the optimum value of loudness of a concert hall? In my opinion, answering this question affirmatively is shortcut reasoning and not the correct answer. Nevertheless, with regard to classical music, I am of the opinion that it should be possible to formulate ideal loudness conditions for specific works of music, instrumentations, and formations.

It is also safe to conclude that the larger the relative SPL of a hall is, as shown in Fig. 9, the better adapted it is for music of small instrument formations and performances of instruments producing small sound volume, such as the harpsicord and original instruments. Likewise, halls with large minus relative SPLs are appropriate for large orchestra formations, and works written to be played forte. While it is obviously unsatisfactory when the sound is not loud enough in a large hall, it is equally unbearable when the sound exceeds a certain level in a small or medium-sized hall. I have experienced the latter situation at an actual performance in the new Casals Hall, a 500-seat small hall.

Figure 10 shows my suggestions for the ranges of relative sound pressure level, SPL, for comfortable listening of various kinds of classical music performances.⁵⁾ These ranges are, however, based purely on my own subjective findings.

one of the most important aspects of work during the planning stage of a hall and additional measurements of the absorption characteristics of the finishing materials and seats may even be made during the construction stage. In the final stage of an acoustical design project, we always measure the reverberation characteristics of the new halls so that we have accumulated a large number of the data on reverberation times in differing architectural conditions. The measured reverberation times of some Japanese concert halls are listed in Table 2.

The reverberation time is, of course, a simple measure of the liveness of a hall, but its frequency characteristics will show the distinctive tonal quality of the reverberant sound. In a concert hall design, therefore, the reverberation characteristics seem to be very important. We are further convinced of this is through actual listening experience in several halls.

With regard to the optimum reverberation time for concert halls, the recommended times in relation both to types of halls and room volume, proposed by Beranek; Kundsén and Haris; Bagenal and Wood,⁷⁾ continue to be our standard reference. However, there are other divergent opinions as well, one example of which is shown in Fig. 11.⁸⁾ Whenever I use these data as references, I am always concerned about the situations in which the data was developed: that is, in what types of halls were which works of music heard that led the acousticians involved to come to the conclusions presented? Further, how many of the halls included in their investigation actually had reverberation times exceeding 2 seconds? While it may be fair to assume that the results in Fig. 10 and similar data, are presented as overall, general conclusions, one would at least like to know the names and number of halls measured and the titles of the works of music on which the data are based.

One of the major difficulties I have in relying on the reverberation time parameter concerns how it is affected by the kind of music performed. The proposal by BBN in Fig. 12 provides some response to this question by showing the preferred reverberation times for different types of music, such as solo piano, chambermusic, orchestral works, opera, organ music and oratorio.⁹⁾ Many pianists in Japan claim to prefer relatively short reverberation time, but it is also true that a number of famous pianists choose halls with long reverberation times for their recordings of solo music.

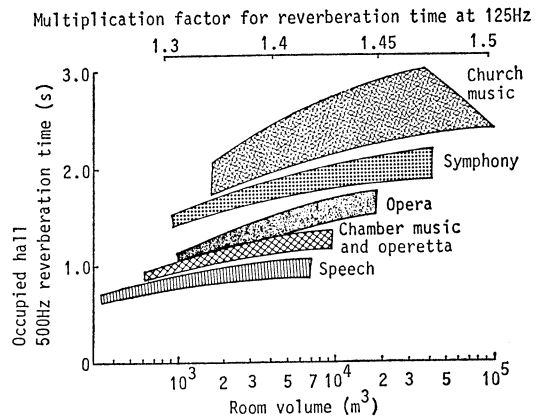


Fig. 11 Optimum reverberation time another recommendation.

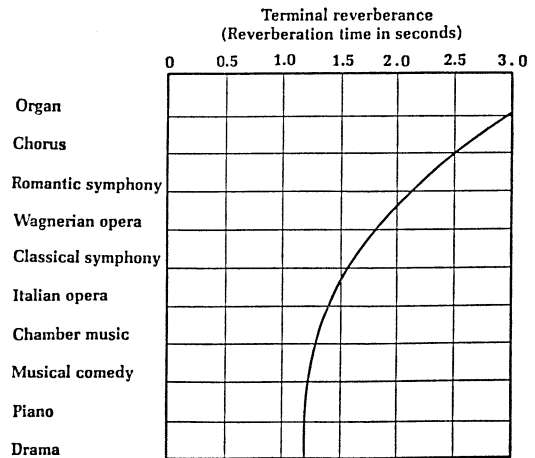


Fig. 12 Optimum reverberation time in relation to types of music (BBN).

While reverberation time is much talked about in Japan, the reverberation frequency characteristics do not receive much attention. Classical music extends across a wide range of frequencies, and, not only can we intuitively suggest that the frequency characteristics of the reverberation will affect the tonal quality of reverberant sound and then, orchestra balance too, but I can corroborate this from my actual listening experience. The patterns of reverberation frequency characteristics for a sampling of Japanese halls are shown in Fig. 13. Among the halls sampled, some have characteristics that were successfully achieved through the acoustical

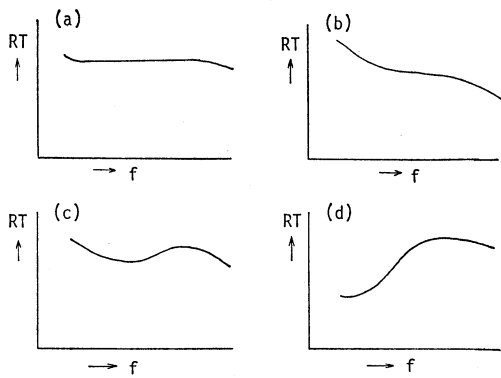
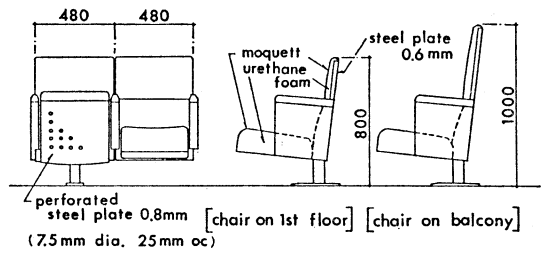
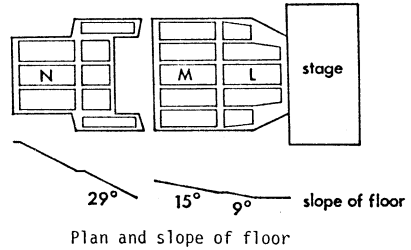


Fig. 13 Pattern of reverberation frequency characteristics.



Geometries and materials of chair

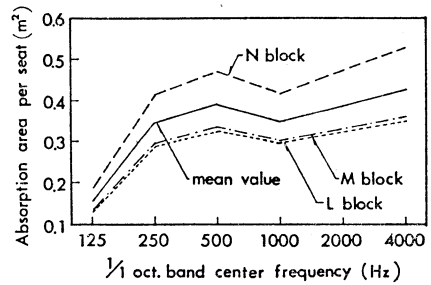


Plan and slope of floor

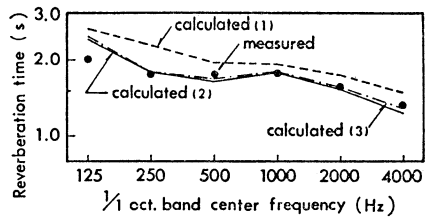
design, while others have characteristics that differ from those that were intended or desired.

In my opinion, Fig. 13 reveals that each of these halls has a subjectively perceivable, distinct reverberation sensation, and, undoubtedly the desired characteristics will differ depending on the type of music and size of the ensemble. Nevertheless, I think it is safe to say that facilities planned for organ music, religious music and orchestral performances should avoid frequency pattern (d), and facilities for piano, vocal music and chamber music should avoid pattern (b). It should be noted that most of the recently built large concert halls have either flat reverberation frequency characteristics or a slightly longer reverberation time in the lower frequency range; and certainly, deficiency of reverberation time of the lower frequency range is something that should be avoided in the acoustics of large halls.

In the design work of the reverberation time, there still remains uncertainty of the estimation of the sound absorption coefficients of some finishing materials and audience seats. As the absorption characteristics of the seats govern the total absorption in a concert hall, in the past 10 years studies have been carried out to improve the accuracy of this estimate. The method of estimation of the absorption power of the auditorium seats in relation to their size, construction materials and even to their location in a hall was developed in 1984 and is now being used in actual design work. Figure 14 is a chart of the estimated sound absorption of auditorium seats in relation to their location in a hall.¹⁰⁾



Absorption area per seat in a block



	chair	absorption area used in calculation wall, ceiling and floor
(1) ---	recommended to use so far	obtained from reverberant absorption coefficients of the respective materials and their area
(2) ———	obtained by the presented method	ditto
(3) - - -	ditto	obtained from the reverberation time of the hall before installation of chairs

Calculated and measured reverberation time

Fig. 14 Estimation chart of seat absorption.

Another problem in this field is the control of the lower frequency absorption of reflecting and diffusing panels used on the walls and ceiling. Some

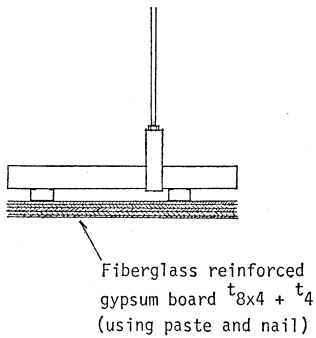


Fig. 15 Ceiling construction to suppress the panel vibration (Casals Hall).

types of panel construction to avoid the panel vibration have been developed and used in several concert halls since 1972. Figure 15 shows one such panel construction, used in Casals Hall.

Suppression of panel vibration is not yet satisfactory and still requires further study.

7. ON VARYING THE REVERBERATION OF CONCERT HALLS

In my opinion, it may be desirable to vary the reverberation time of a concert hall in the following situations:

- (1) for rehearsals;
- (2) when a hall is used for auditions without an audience; and
- (3) for organ recitals.

In the case of (1), variable sound absorbers are necessary. I have heard that the Boston Symphony hangs curtains over its hall's empty seating in order to decrease the reverberation time during rehearsals,

but there are also many musicians who prefer that a hall be left as is, since their ears are trained to the difference between empty and full conditions. For (2), the problem is not serious enough to warrant use of variable sound absorbers, and can be dealt with sufficiently by placing free-standing, sound absorbing panels on stage. The case of (3) is, however, an important problem and one that is not easily solved. Organists and other persons concerned with organ music stress their desire for a reverberation time in excess of 3 seconds, such as is found in many western cathedrals, but this is an unrealistic aim in concert hall spaces unless electro-acoustic devices are used to lengthen the reverberation time.

As shown in Table 3, the electro-acoustic devices for lengthening reverberation time can be divided into two categories¹¹⁾; active systems with reverberators and passive systems utilizing acoustic feedback. In Japan, at the present time, five systems are available, including two that add early reflections in addition to lengthening the reverberation time. However, as the additional energy increases, the tone is distorted by coloration, therefore, the range of additional reverberation that may be added is limited.

The incorporation and use of electro-acoustic devices to control and vary hall acoustics is certain to continue to increase in the acoustical design of new facilities, but as the essential *raison d'être* of concert halls is the appreciation of untampered live performances, caution should be exercised in the installation and use of electro-acoustic devices in concert halls. Many people involved in classical music continue to have an automatic prejudice against any use of

Table 3 Electro-acoustic systems adding reverberation and reflection energy.

Function	System				
	Assisted resonance (AR)	Multi-channel reverberation system (MCR)	Reverberation on demand systems (RODS)	Electronic reflected energy system (ERES)	Assisted acoustics (AA)
Acoustic feedback	○	○			
Reverberator	△		○	○	○
Addition of reflections				○	○
Reinforcement of low frequency sound				○	

electronics in live musical performances, and this will only be overcome, in the future, by approaching the use of electro-acoustics from the aesthetic sensibility of classical music. Grains will not be made in this area by relying on thinking that is geared to sound-reinforcement used for popular music. Recognition of the basic aesthetic goals are therefore the first step in decisions about the installation of electro-acoustic devices in concert halls.

8. ACHIEVING A BALANCE AMONG ROOM ACOUSTICAL PARAMETERS

As previously described, in the past two decades a variety of room acoustical parameters have been defined and presented. However, in order to employ these parameters successfully in room acoustical design, it is essential to know the conditions or levels at which each parameter becomes an impediment as well as its optimum conditions. Achieving the proper balance among the parameters, in relation to the size of a hall and types of performances, is also important. Unfortunately, while research analysis of parameters is progressing, little is being done to better understand how all of the various parameters combine to form a total acoustic environment. For example, we understand that the lateral reflections are important, but what is the effect of strong lateral reflections in a small hall. Actual experience has taught us that not a few musicians dislike such halls. Rather, a considerable number of halls with good reputations among musicians actually have a minus value for lateral reflections.

The work of the late Prof. Reichardt focused on the balance between Clarity, *C*, and Room Response, *RR*, in concert halls.¹²⁾ He found the optimum conditions of these two parameters for symphonic music of the classical and romantic schools. The late V. L. Jordan was the first to actually use these parameters in the acoustical design of a concert hall,¹³⁾ by charting *C-RR* values measured in scale model experiments. We appreciate *C* and *RR* as the first parameters developed to supplement reverberation time in describing the acoustical characteristics of halls and use them as an essential tool for successful acoustical design.

Figure 16 shows the *C* and *RR* of ten Japanese halls in a *C-RR* chart.¹⁴⁾ If we compare the balance between *C* and *RR* of a facility such as Hibiya Kokaido, which only has reflections from the ceiling,

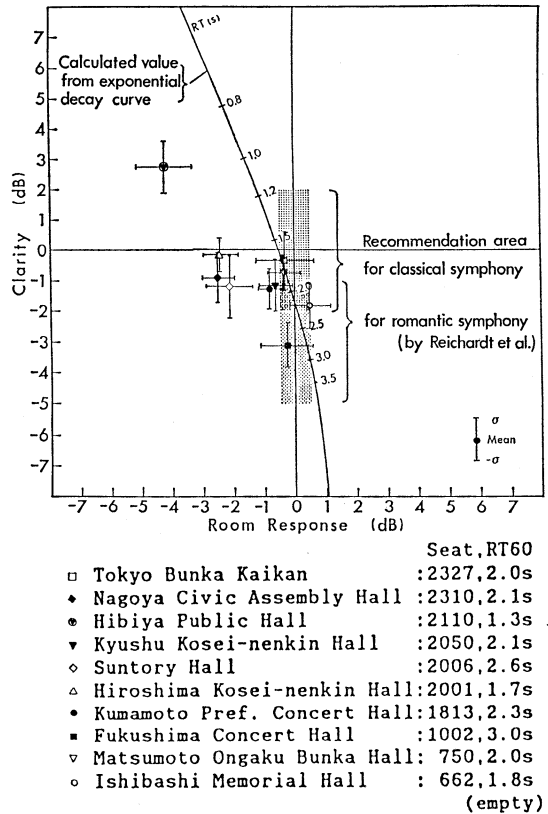


Fig. 16 *C-RR* evaluation of ten Japanese halls.

and concert halls, such as Suntory Hall, the superior balance of the concert halls is obvious, reflecting the distinguishing sound characteristics of the different facilities.

Of course, the perceived impressions of a hall's sound quality, and the difference in impression one may receive in different seats of a hall, can only be partially explained by these two parameters. Likewise, lateral reflections only tell one part of the story. Currently, we focus on all of the following criteria in the evaluation of the acoustics of a concert hall.

- (1) Strength of the direct sound, including the early reflections;
- (2) Reverberation time and its frequency characteristics;
- (3) Density and time distribution of early reflections;
- (4) Balance between ceiling and lateral re-

flections;

(5) Clarity and Room Response and their balance;

(6) Diffusion of reverberant sound; and

(7) Detrimental echos.

In addition, there is the Inversion Index (*I. I.*) proposed by Jordan, the effect of echoes on tone coloration, and other parameters yet to be defined. All of the above are certainly significant criteria, but acousticians have yet to fully understand, utilize and control them.

9. SCALE MODEL EXPERIMENTS AND COMPUTER SIMULATION

Several years ago, computer simulation began to be developed in Japan as a method to replace scale model experiments. In the beginning, this new method was used as an actual tool than as a means of impressing clients with the level of technological sophistication of acoustical consulting. The mere availability of computer simulations is meaningless, unless their use is coordinated with the acoustical design process by:

- (1) defining what questions computer simulations can answer;
- (2) explaining how the data to be evaluated; and
- (3) developing methodology for using the data obtained in the determination of actual acoustical design.

Likewise, coordination of scale model experiments with actual acoustical design is essential to meaningful use of scale models.

Both scale models and computer simulations are tools, not ends in themselves. The type of the hall under construction; the methodology, work flow and the scope of the acoustical design in the architectural design process; and time limitations are the factors that should determine when, or at which stage, computer simulations (or a combined of both) will be effective tools for the acoustician to use. Scale models provide a visual representation of the architectural features of a facility; computer simulations provide a visual representation of the sound characteristics in a hall. We use both optical experiments, with lasers in 1/50 scale models, and computer simulations during the conceptual and schematic design phases of acoustical consulting.¹⁵⁾ Figure 17 shows an example of the study of room shape regarding the distribution of the early reflections by computer simulation.

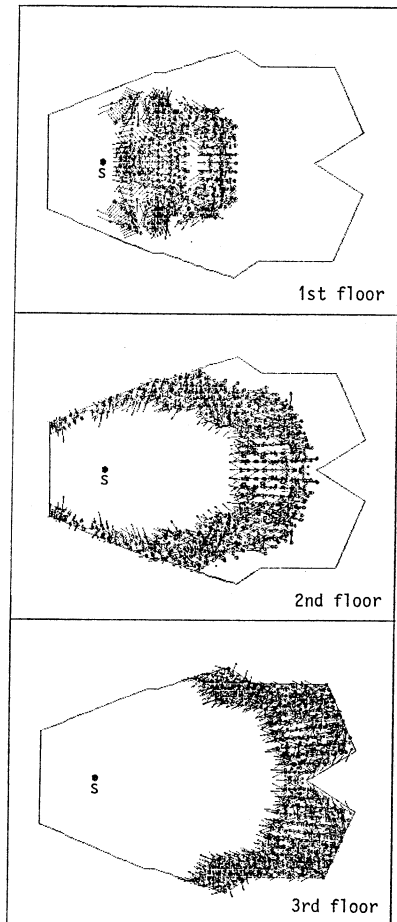


Fig. 17 Study on the distribution of early reflection arriving within 80 ms after the arrival of direct sound by computer simulation.

Scale model experiments are a tool that provides valuable information if used at the appropriate stage of a project. Unfortunately, in Japan, use of 1/10 scale models is virtually impossible due to scheduling and the flow of construction work. The only time available for scale model experiments is the period after construction has begun on the building, but prior to installation of the interior. At this stage, of course, neither the shape of the hall nor the major characteristics of its interior design can be changed; therefore, unless there is some clearly defined and circumscribed reason for testing in a 1/10 scale model, its use at this stage does no more than satisfy the whim of the acoustician. The

use of scale models that enable checking of planned electro-acoustic and lighting installations, as well as other aspects of the interior design, is also worth consideration.

10. ELECTRO-ACOUSTIC SYSTEM

The importance of the electro-acoustic systems in concert halls tends to be overlooked. A public address system—one part of the electro-acoustic system—is used to announce the start of every concert; but how many halls in Japan have P. A. systems that give comfortable and intelligible announcements.

Furthermore, programs such as “Peter and the Wolf” that require narration, and concerts that include interviews of the composers or other conversation on stage, require speech amplification.

Speech amplification in concert halls is difficult for the following reasons:

- (1) Good articulation is difficult to achieve due to the long reverberation characteristics;
- (2) The directional characteristics of loudspeaker systems require large speaker systems which do not match the visual atmosphere of a concert hall; and
- (3) The available stage locations for stage monitor speakers are limited, and it is difficult to determine the optimum level of monitoring speakers without creating acoustic feedback.

In the case of Suntory Hall, a movable main cluster speaker is installed in the ceiling. For P. A. use, the cluster remains flush with the ceiling, and the bottom side and supplementary speakers cover the entire seating area. In the case of narration from the stage, the cluster is lowered as shown in Fig. 18, and all the speakers are used.

In the case of Casals Hall, the speakers are also suspended from the ceiling as shown in Fig. 19, but they cannot be recessed as can the Suntory Hall cluster. These installations represent the most reliable concert hall speaker systems available at this time.

Although the electro-acoustic equipment for concert halls should incorporate a variety of functions—such as the high quality recording of live performances—speech transmission is its basic function. While public address system technology leaves considerable room for improvement, this area has shown little progress in the recent past. There are still problems with insuring articulation and comfortable speech transmission capability in

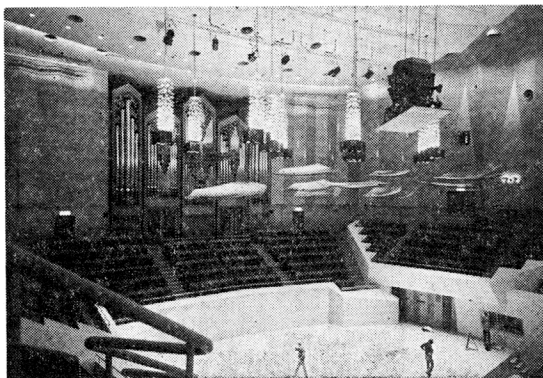


Fig. 18 Main loudspeaker system in Suntory Hall.

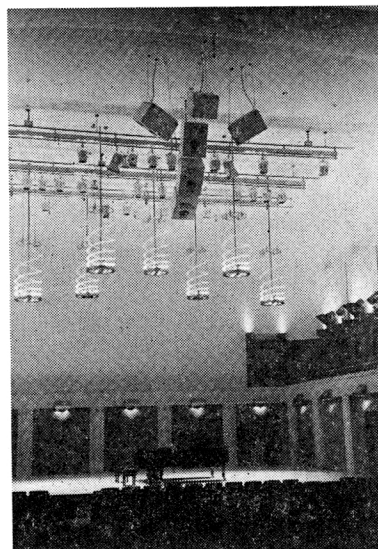


Fig. 19 Main loudspeaker system in Casals Hall.

concert halls. Further, the system should have the versatility to handle the different requirements of short announcements, and interviews and other long speaking events held on stage.

11. CONCLUDING REMARKS

In the above paragraphs, I have summarized the various questions and problems confronting the field of acoustical design today. Another aspect which deserves attention is the acoustical design of halls with pipe organs. Concert organs are not standardized instruments and acousticians have

many unanswered questions, such as the placement of organ in the hall, its effects on the total acoustics of the hall, and what constitutes the best acoustics for organ music. Another new and important factor is the role of stage flooring in the acoustics of performing spaces. Using the information we have from past experience and new data both from the academic field and actual listening in existing halls, I trust that we can move forward to better understanding and solutions to these and other questions.

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