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BLENDING ARCHITECTURAL AND ACOUSTICAL FACTORS IN DESIGNING A ROUND EVENT HALL

A. Takatsu

Showa Sekkei Co. 1-2-1-800 *Benten, Minato-ku, Osaka* 552-0007*, Japan*

AND

H. Sakai and Y. Ando

Graduate School of Science and Technology, Kobe University, Kobe 657-8501*, Japan.*
E-mail: a-takatu@showa-sekkei.co.jp

A design process consisting of temporal and spatial factors aspects is proposed that blends architectural design with acoustic design. Using this design process, a multi-purpose event hall, which is a part of a complex architecture, was designed. Acoustic measurements were conducted to obtain temporal and spatial factors in the sound field after construction had been completed, the results of which were favourable. One goal of this project was to solve acoustic problems caused by the round shape of the event hall, where the architectural design had already been determined by the theme and concept of the complex. The process is considered to be successful, since the acoustic problems were solved without unduly affecting the architecture of the hall in this worst-case scenario. In addition, new knowledge of methods for solving acoustic problems caused by the round architecture was gained during the design work.

1. INTRODUCTION

Both architectural design and acoustic design deal with temporal factors and spatial factors, because humans use both sides of the brain to perceive sound—the right hemisphere for spatial awareness and left hemisphere for temporal understanding [1, 2]. Architects have been perhaps more concerned with spatial criteria from the visual standpoint, whereas acousticians have been more concerned with the temporal criteria, which is represented by subsequent reverberation time (T_{sub}). Thus, architectural design and acoustic design place importance on different criteria and there has been little or no discussion on how to harmonize the two, until now.

The aim of this study is to develop a process for designing halls and theatres (Figure 1), in which the temporal and spatial factors of architecture are blended with the temporal and spatial factors of acoustics. To this end, a multi-purpose event hall in a complex designed using this process was measured for acoustic factors after its construction, with favourable results.

One goal of this project was to solve the acoustic problems caused by the round shape of the event hall, where the architectural design had been previously determined by the theme and concept of the complex. The acoustic problems were solved without unduly affecting the architecture of the hall. In addition, new knowledge of methods for solving acoustic problems, related to the round shape of the architecture was gained during the design work, through this process of blending architectural and acoustic factors.

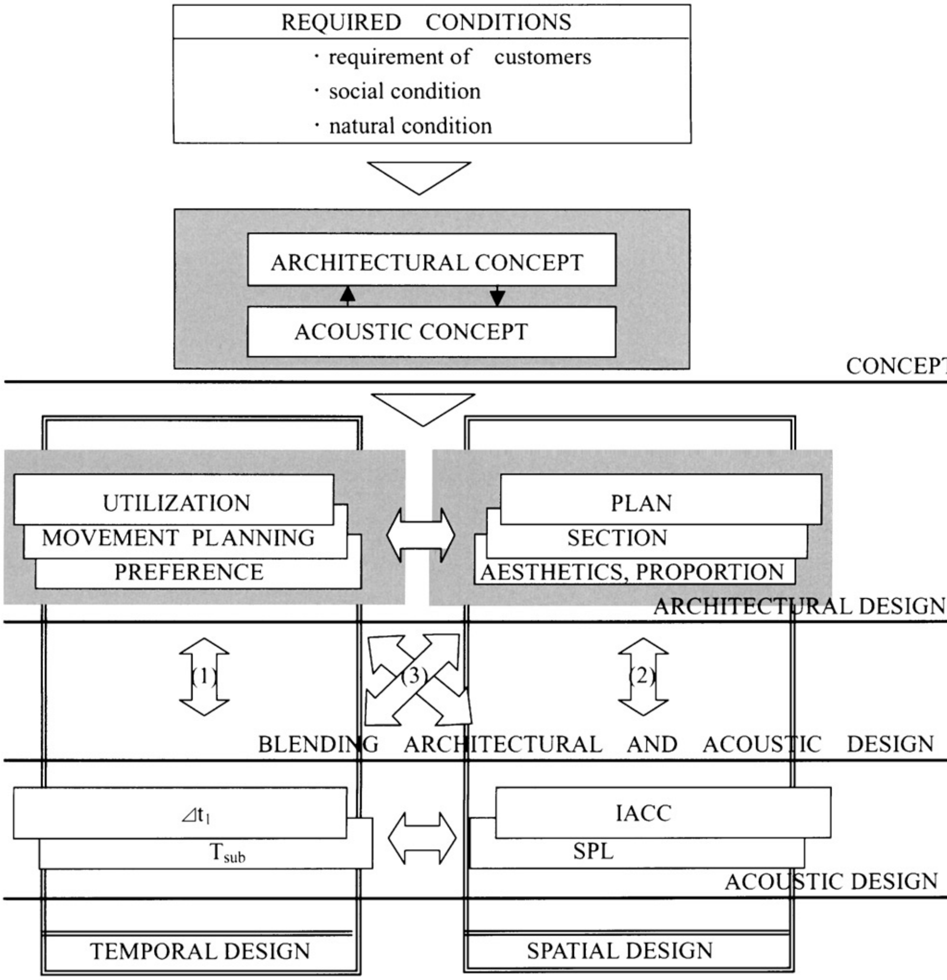

Figure 1. Design-process blending temporal and spatial factors of the architectural design with temporal and spatial factors of the acoustical design.

2. CONCEPT OF A ROUND MULTI-PURPOSE EVENT HALL, ORBIS HALL OF KOBE FASHION PLAZA

2.1. ARCHITECTURAL CONCEPT OF KOBE FASHION PLAZA

The theme of the Kobe Fashion Plaza's architecture is "*Fashion*." However, fashion changes over time. The overall design of the building thus expresses the passage of time from the past to the present and into the future. The effect is created with a lower level that has the appearance of weathered ancient ruins, on top of which a modern building has been constructed. A large staircase, spanning the entire structure, emphasizes the cyclic nature of the fashion world. Just as the mini-skirt periodically reappears in fashion, the spiral staircase is an image of repetition. The idea of fashion being influenced by the movement of people is expressed with the cross-section cutting through this gentle repetitive passage. This concept is symbolized in an architectural form as a UFO-like spacecraft, flying beyond time and space, which has run into the middle of spiraling time, represented by the building itself. Again, the infinitely repeating flow of fashion is expressed by the arrangement of the building's plan—the round atrium structure and the "UFO" overlap—to form the symbol for infinity ∞ (Figure 2) [3].

2.2. CONCEPT OF THE ARCHITECTURAL DESIGN FOR ORBIS HALL

It is intended that the most prominent part of Kobe Fashion Plaza, shaped as a UFO, performs the most important function and serves as the venue for a variety of events and as a source of various media and information services to the community. Therefore, it was not designed to be a genuine purely acoustical hall. This hall was designed so that the "UFO" would be a multi-purpose event hall within the whole concept of the architecture, "Kobe Fashion Plaza."

With this purpose in mind, the most important theme is that Orbis Hall has a circular floor plan so that patrons, who can see the exterior appearance of the "UFO", would feel themselves to be in the "UFO" (Figures 3–5) [3].

2.3. CONCEPT OF THE ACOUSTICAL DESIGN FOR ORBIS HALL

From ancient times to the present, the circular form has fascinated many architects; however, it has many acoustic problems, such as sound focusing, echo-disturbances, and the whispering gallery effect.

The acoustic design for this hall must eliminate acoustic problems that occur due to the hall's circular plan without interfering with the hall's concept and architectural intent. In

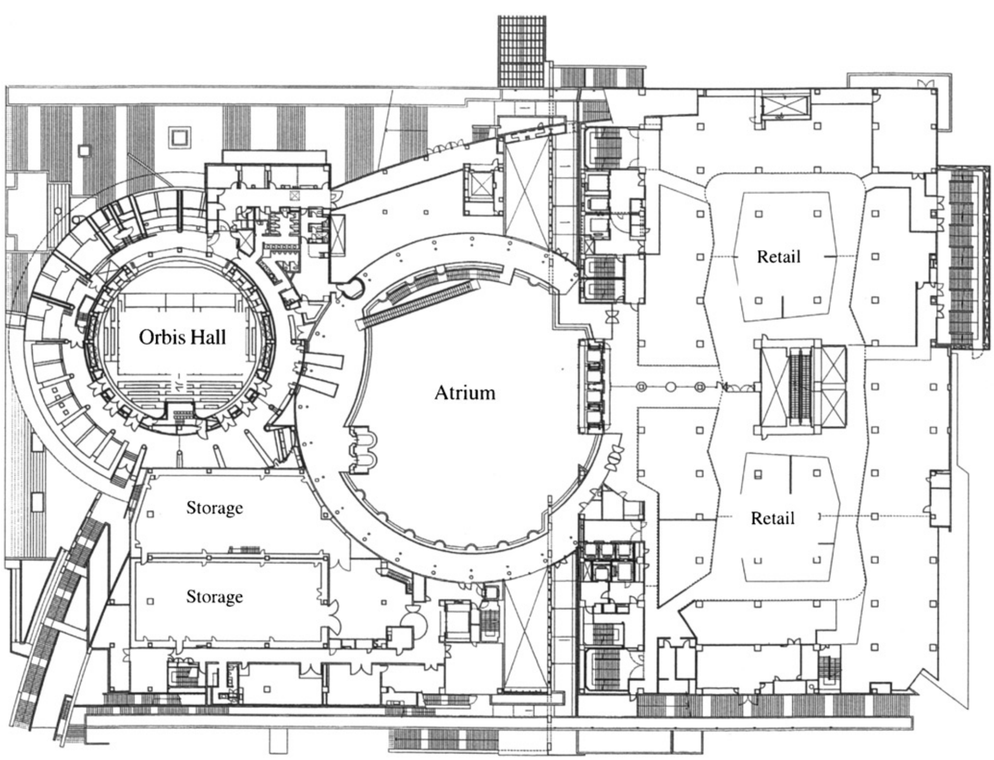

Figure 2. Plan of fifth floor of Kobe Fashion Plaza.

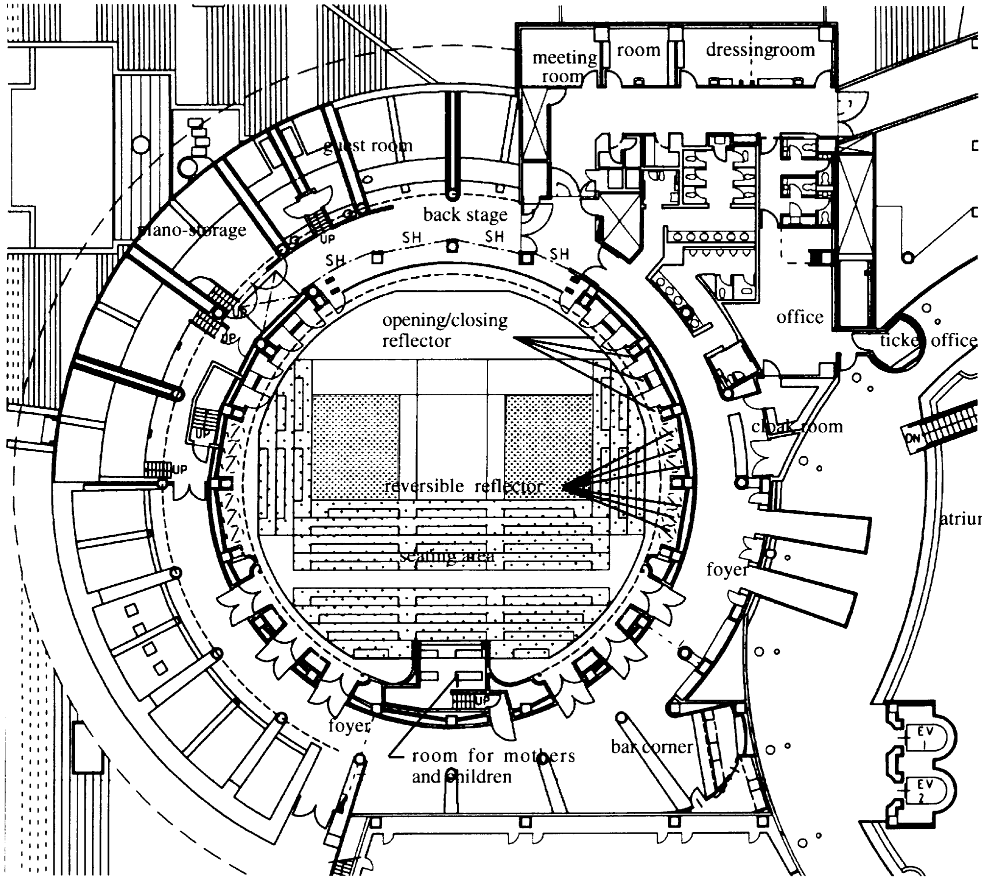

Figure 3. Plan of Orbis Hall with various acoustic equipments.

this case, both the temporal and the spatial factors must be addressed, because people perceive sound through the use of both sides of the brain—the right hemisphere for spatial awareness and the left hemisphere for temporal understanding [2].

3. BLENDING ARCHITECTURAL AND ACOUSTICAL DESIGNS

3.1. BLENDING TEMPORAL FACTORS IN THE ARCHITECTURAL AND ACOUSTICAL DESIGNS

3.1.1. *Temporal factors in architectural design*

It was anticipated that Orbis Hall could be used for any of the following purposes:

- concerts (chamber music, chorus, etc.),
- lectures, meetings,
- fashion shows,
- cinema,
- performances (such as small dramatic performances),
- exhibitions, parties.

In accordance with these uses, the hall has a moving-floor system. Orbis Hall's floor plan is described in Table 1 and illustrated in Figure 6. All seats in the hall are movable.

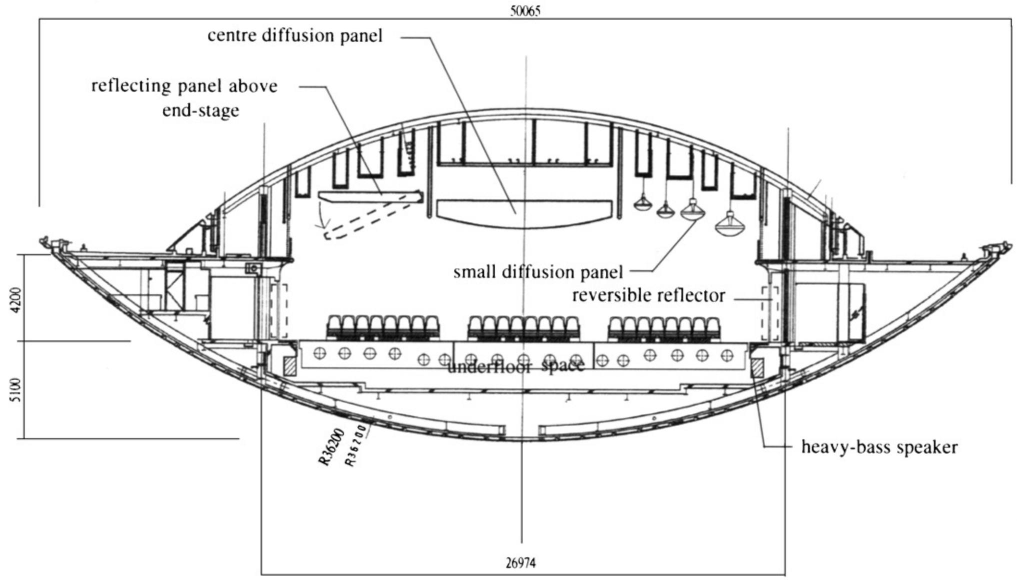

Figure 4. Cross-section of Orbis Hall with various acoustic equipments. Volume of the under-floor space is 990 m^3. Material of the floor and wall in the under-floor space is exposed concrete.

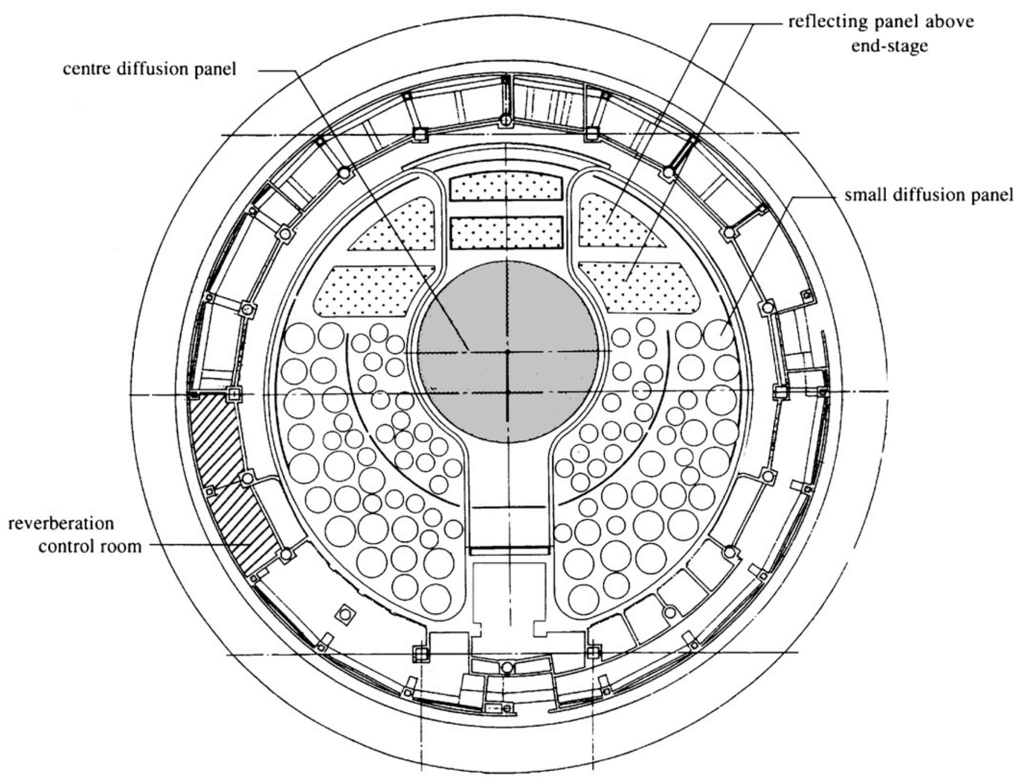

Figure 5. Ceiling plan of Orbis Hall with various acoustic equipments.

TABLE 1

Five hall types

1. End-stage type 1	This type has a broad stage for concerts, chorus, drama, etc. 402 seats
2. End-stage type 2	This type has a narrow stage for speeches, cinema, etc. 426 seats
3. Fore-stage type	For fashion show, etc. 364 seats
4. Centre-stage type	For drama, etc. 400 seats
5. Flat-floor type	All seats are stored in a space under the main floor. There are no steps For parties and exhibitions

Two types of seating can be provided; one type can be lowered into the under-floor space, the other type has casters on the legs and can be moved into the under-stage space. The combination of these two types of seats gives the hall five different floor patterns.

3.1.2. *Temporal factors of acoustic design*

A suitable T_{sub}, which is one of temporal factors of acoustic design, is shown in Table 2 for each kind of event space. The unmodified T_{sub} of the hall is suitable for speech, and was made as short as possible in order to eliminate any negative influences from the circular plan and dome. The target value of at 500 Hz was 0·7 s. To accommodate not only speech but also other acoustic events, an additional subsequent reverberation system for controlling $T_{sub,}$ was designed, which consisted of a reverberation control room and an electro-acoustic system. In this hybrid-reverberation-control system, hyper-directive microphones are placed near the stage, the audio signals of which are sent to the reverberation-control-room located outside the hall. From there, the audio signal is passed through loudspeakers in the ceiling and under the floor of the hall such that only the reverberation component is radiated (Figure 7).

3.2. BLENDING SPATIAL FACTORS FROM BOTH THE ARCHITECTURAL AND THE ACOUSTICAL DESIGNS

Various architectural equipment and devices were fabricated in order to decrease the International Cross-correlation Coefficient (IACC) and get a uniform SPL, which are the spatial factors in acoustics. They are as follows. Opening/closing reflectors were installed at either side of the stage in such a way that the sound from the lateral stage wall would be reflected to the audience, to decrease IACC. For the same purpose, reversible reflectors are also placed on each side of the hall. One side of each reflector is absorptive; the other is reflective, in order that they can be positioned appropriately for either acoustic or electrical sound. Reflectors were also placed above the stage so as to be at right angle with respect to the seats in the hall. These reflectors can be positioned as the occasion demands, towards a cross-section of the stage, so that reflected sound propagates in a certain direction towards the audience (Figures 3–5) [3].

3.3. BLENDING TEMPORAL AND SPATIAL FACTORS FROM BOTH THE ARCHITECTURAL AND THE ACOUSTICAL DESIGNS

3.3.1. *Using the under-floor space to eliminate the SPL dip*

Studies show that when there is a decrease in IACC for all kinds of events, there is a definite increase in preference. It is desirable that SPL be uniform in a hall for all

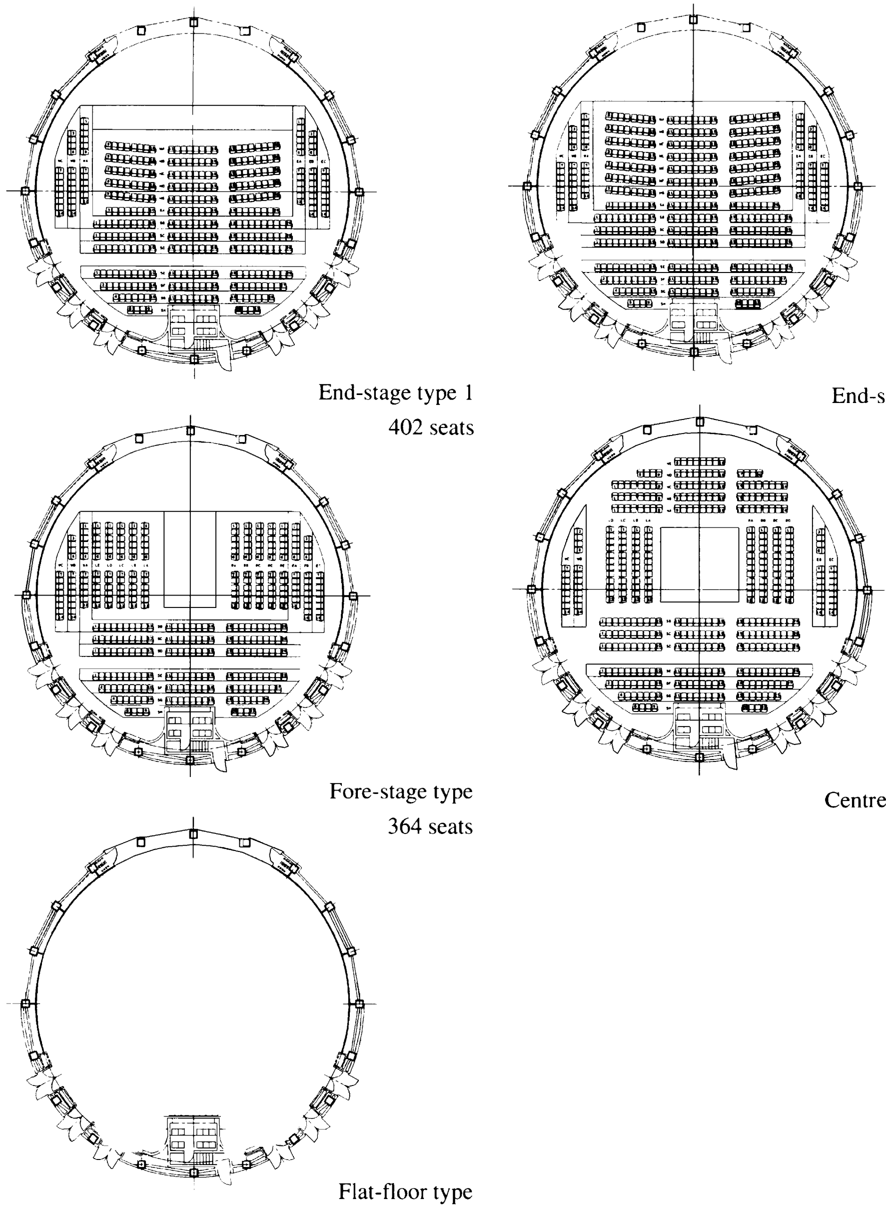

Figure 6. Five stage and seating patterns in Orbis Hall.

kinds of events. However, it is widely reported that there is a dip in SPL at low frequencies in the seating area in front of the stage. The cause is considered to be sound waves reflecting off the floor of the seating-area near the stage, interfering with the direct sound wave.

The current acoustic design of concert halls only considers the above-floor space. Since the acoustic field below the ears of the audience is equally important as the one above the ears, the under-floor space has also been taken into consideration in designing the sound field at each seat. Therefore, to eliminate the SPL dip at

TABLE 2

T_{sub} values for each event type

Event	T_{sub} (s)
Concert of acoustic sound (slow tempo)	2·0
Concert of acoustic sound (quick tempo)	1·5
Speech, dramatic performance	0·7
Fashion show, cinema (with electric sound system)	0·7
Exhibition, party	0·7

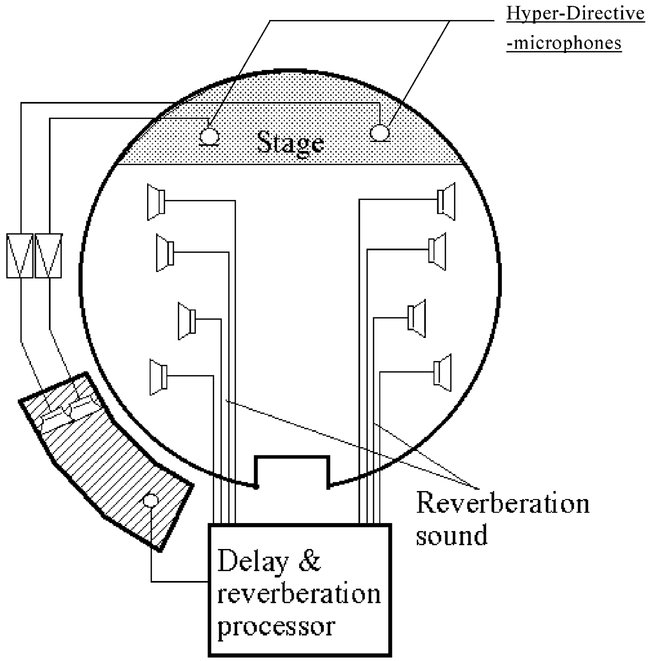

Figure 7. Block diagram of the hybrid-reverberation-control system.

low frequencies, this hall was designed in such a way that the sound path, which is considered one of temporal factors controlled by the architectural design, can be changed using the under-floor space.

In the area in front of the stage, where the chairs with casters are located, 5-mm-diameter holes have been drilled through to the under-floor space in a 15×15 mm grid in order to fuse the above-floor space with the under-floor space. The seating areas on the sides and in the back of the hall have movable chairs that can be lowered into the floor for convenient storage. In these areas, holes of a 25% ratio have been drilled into the steel plates of the chair, to the extent that strength permits. This allows sound waves to pass through to the under-floor space, which eliminates the low-frequency SPL dip. In addition, five heavy bass loudspeakers have been placed in the under-floor space. They create the sensation that the bass sound rises from the floor (Figures 3 and 4) [3].

3.3.2. *Eliminating sound focusing*

"UFO"-shaped sound diffusion panels were installed as a counter-measure against sound focusing caused by the domed ceiling. The large diffusion panel above the centre area of the hall is cut from a sphere 26 m in diameter. The diameter of this panel is 9 m. Many smaller sound diffusion panels, shaped like "UFOs", with diameters of 0·9, 1·275 and 1·500 m, were installed. The largest panel is placed near the walls, the smallest ones near the centre, and the medium-sized ones between the largest and the smallest. In addition to their sound reflection and diffusion functions, this group of diffusion panels, including the large centre one, act as lighting fixtures. They are aesthetically pleasing to the audience who, upon entering the "UFO", finds itself surrounded by light radiating from the "UFOs" in the ceiling. The large centre diffusion panel is located just above the centre stage; the centre stage is located away from the centre of the ceiling dome. Production equipment and lighting fixtures can be hung from slits on the panel (Figure 5) [3].

3.3.3. *Eliminating the "Whispering gallery effect"*

A room for mothers with little children was installed directly facing the stage. This helps prevent echo-disturbances caused by the whispering gallery effect. The room was designed about 4·20 m by 3·00 m (Figure 3) [3].

4. ACOUSTICAL MEASUREMENTS AFTER CONSTRUCTION

4.1. ACOUSTICAL MEASUREMENT WITHOUT THE HYBRID REVERBERATION CONTROL SYSTEM

4.1.1. *Measurement set-up*

An omni-directional-dodecahedron loudspeaker S was placed at a height of 1.5 m above the floor of stage and nine receiving points were carefully selected. The maximum length sequence (MLS) signal from the loudspeaker was received by two half-inch condenser microphones, which were placed next to the ears of a seated person. The acoustical data received by the microphones were transferred to a personal computer through a real-time audio and sound-analyzer. The angle of the reflecting panels on the side walls was set appropriately [4].

4.1.2. *Result of the measurements and discussion*

The results of the measured acoustic factors and of the calculated factors, which are SPL, Δt_1, T_{sub} and IACC, are shown in Figures 8–11.

Generally, the values of IACC in the front seating area are large because of the strong direct sound with relatively weak initial reflections from the side of walls. Thus, the calculated IACC values were larger than 0·5 in front of the stage. However, the measured IACC values were much improved even in the front seating area (Figure 11). This result may be due to the small diffusers on the ceiling, which were not considered in the simulation. The reflectors above the stage were also thought to decrease the IACC value for performers on stage.

In this measurement, the hybrid reverberation-control system was not used. If it is properly calibrated, it is expected that the IACC values and the subjective preference would be much improved [4].

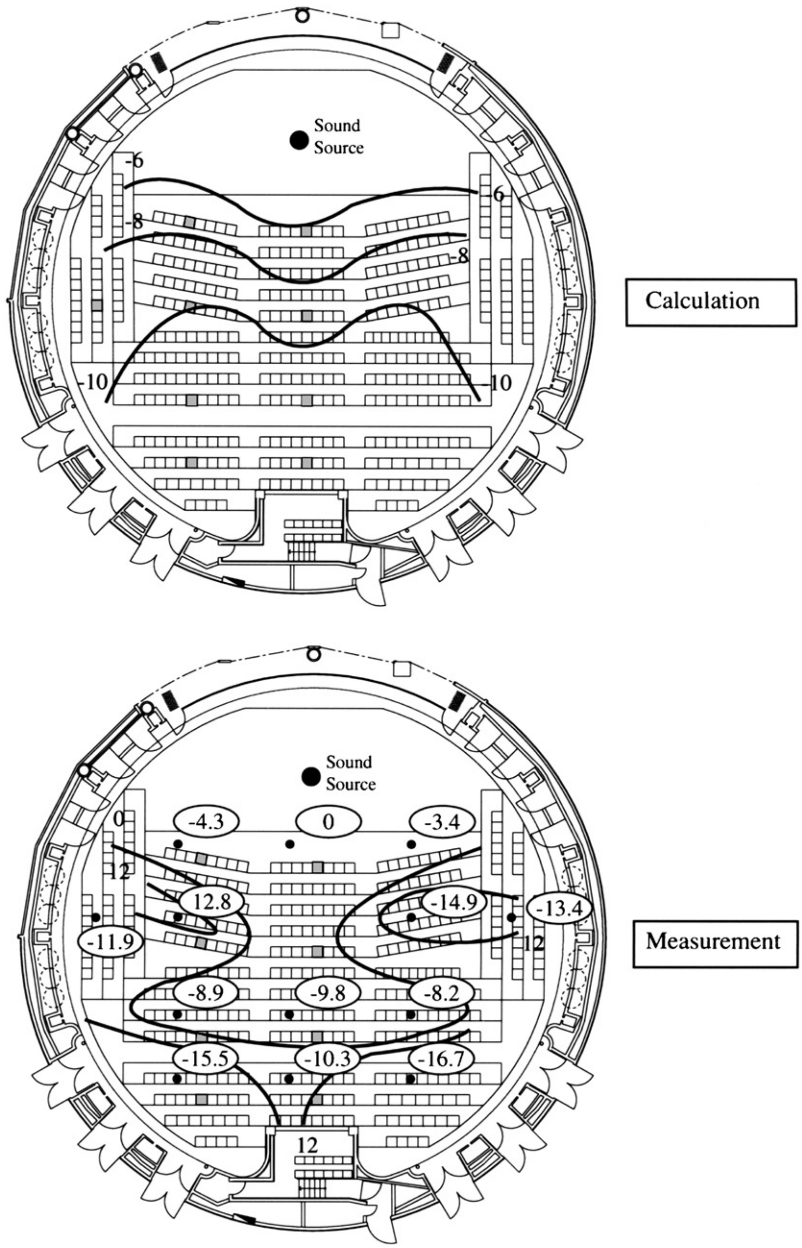

Figure 8. Relative SPL (dB) at 500 Hz. The top figure shows the result of the acoustic simulation. The bottom figure shows the measurement results.

4.2. ACOUSTICAL MEASUREMENTS WITH HYBRID-REVERBERATION-CONTROL SYSTEM

4.2.1. *Measurement set-up*

The measurement set-up in the hall was the same as for the architectural acoustic measurement (section 4.1). For acoustical measurement in the reverberation-control-

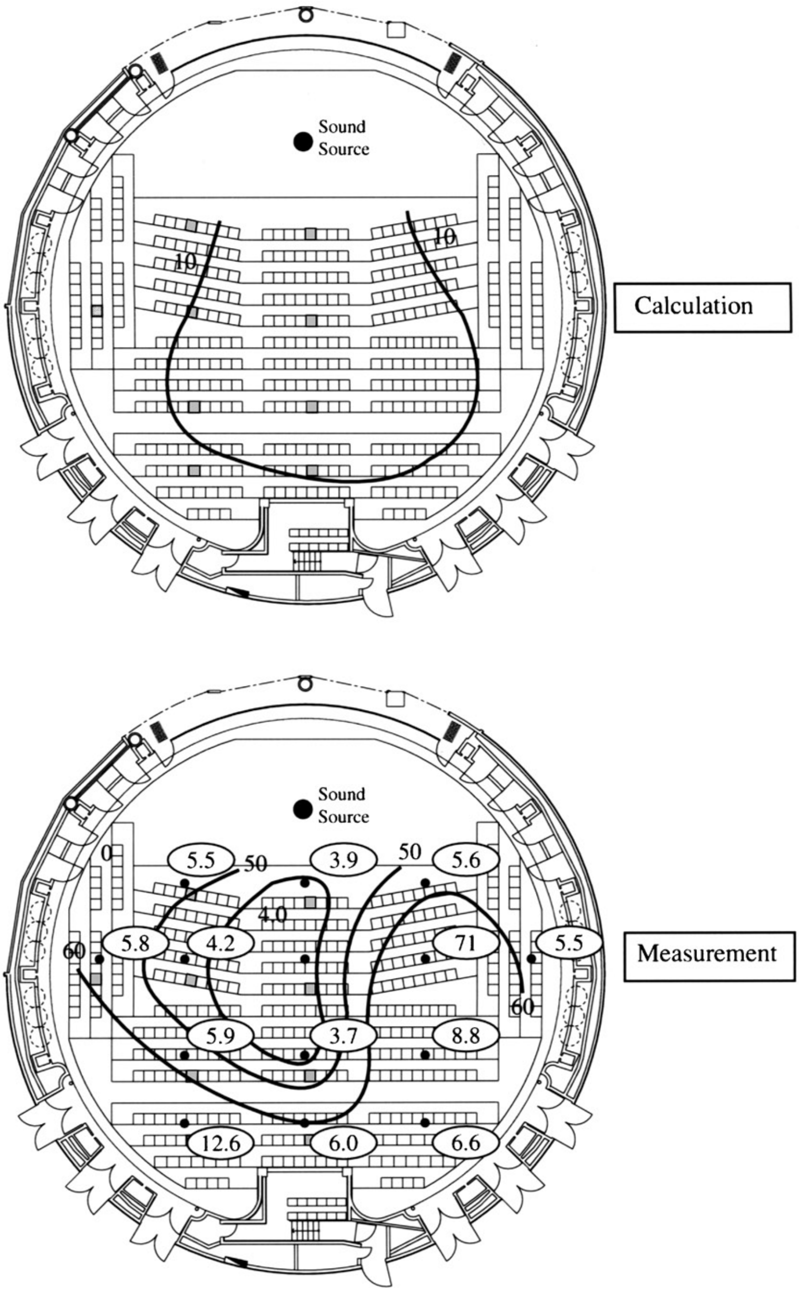

Figure 9. Δt_1 (ms) at 500 Hz. The top figure shows the result for the acoustic simulation. The bottom figure shows the measurement results.

room, sound from a loudspeaker in the corner of the room was generated, received without the hybrid-reverberation-control system and recorded by tape-recorder. The recorded data, in the frequency range from 63 Hz to 8 kHz, was analyzed in 1/3 octave bands.

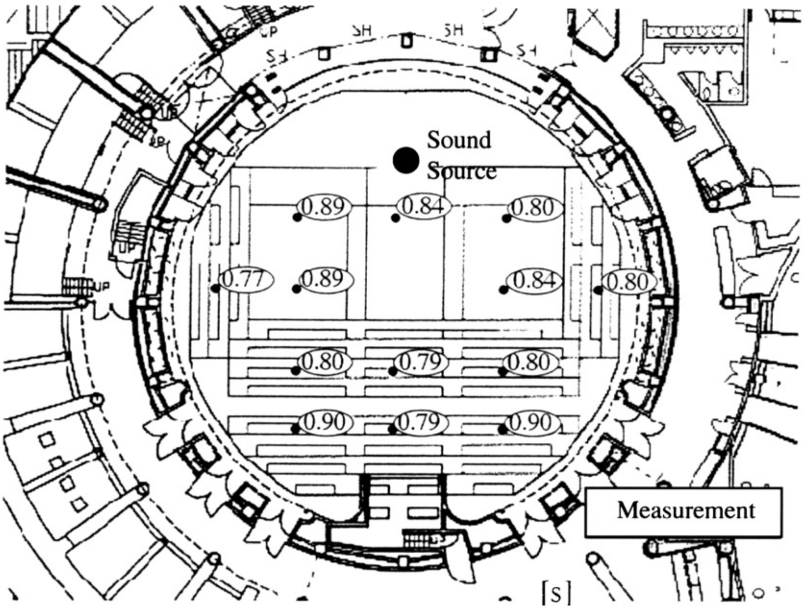

Figure 10. T_{sub} (s) at 500 Hz. Its calculated value was 0·7 s, when the hall was vacant.

4.2.2. *Measurement results and discussion*

The T_{sub} measurement results for Orbis Hall are shown in Figure 12. The results for the measured reverberation time in the reverberation-control-room are shown in Figure 13. The T_{sub} at 500 Hz with the hybrid reverberation control system was 1·9 s for a design target of 2·0. Similarly, at 500 Hz, the T_{sub} was 1·5 s for a design target of 1·5 and 0·9 s for a design target of 1·0 s. These results show that the reverberation-control-system worked as planned.

4.3. ACOUSTICAL MEASUREMENT FOR ASSESSING THE EFFECT OF THE PERFORATED FLOOR

4.3.1. *Set-up and measurement conditions*

An omni-directional-dodecahedron loudspeaker S was set up as shown in Figure 14. The centre of the loudspeaker was 1·5 m above the stage floor. Two half-inch condenser microphones were placed at the ears of a person standing on the floor. The receiving points were at 6·0, 8·0 and 10·0 m from loudspeaker for both the perforated floor and the normal floor. The MLS signal was radiated from the loudspeaker as the source signal.

To compare the results of the perforated floor and normal floor measurements, the conditions of the hall were constant in the experiment. The pattern of the hall was the flat type, the floor had no stairs and all seats were stored under the floor.

4.3.2. *Results and discussion*

The measured impulse responses at each receiving point (left ear) on the perforated floor are shown in Figure 15(a) and those on the normal floor in Figure 15(b). These impulse

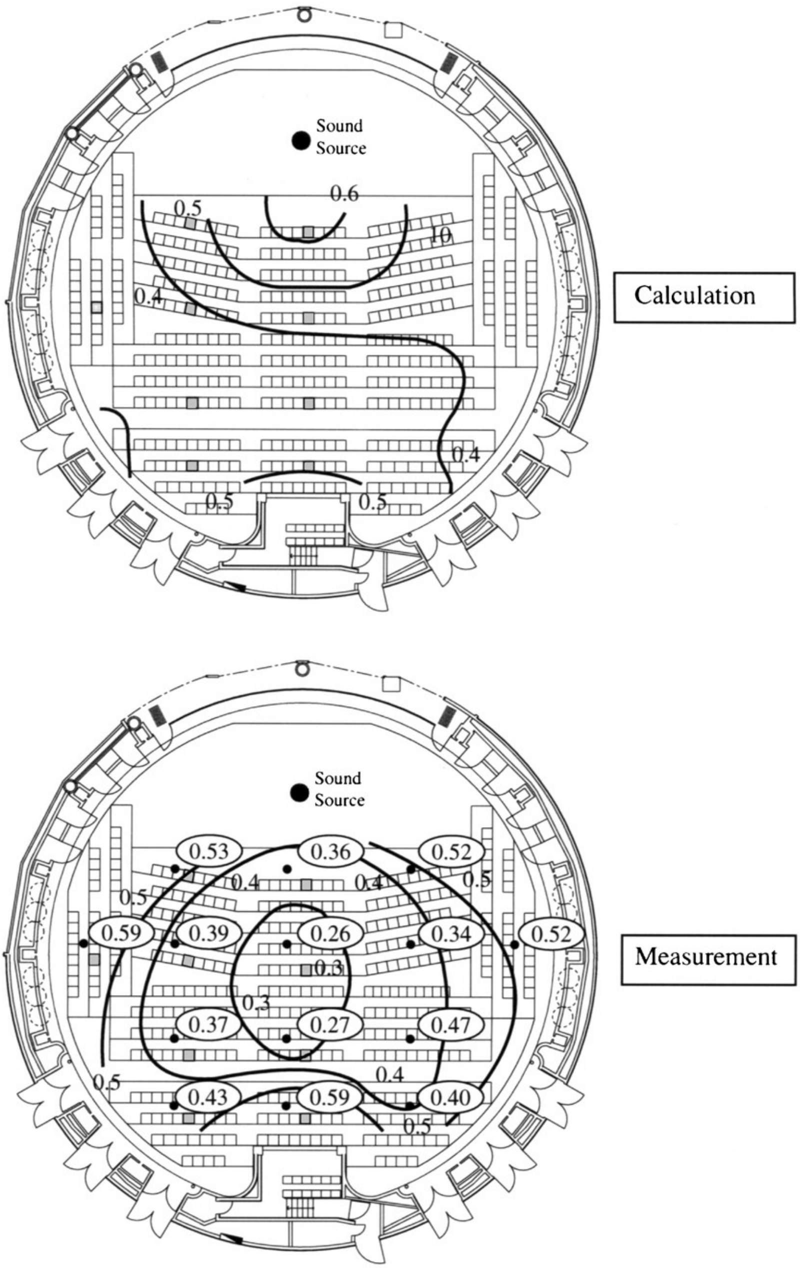

Figure 11. IACC at 500 Hz. The top figure shows the result of the acoustic simulation. The bottom figure shows the measurement results.

responses represent the initial 5 ms after the arrival of the direct sound wave. It is obvious that amplitudes appearing around 1–2 ms after the arrival of the direct sound wave, which are affected by interference between the direct sound and the first reflected sound wave from the floor surface, decrease in the case of the perforated floor. The transfer functions were obtained by the discrete Fourier transform (DFT) method. Figure 16 shows the

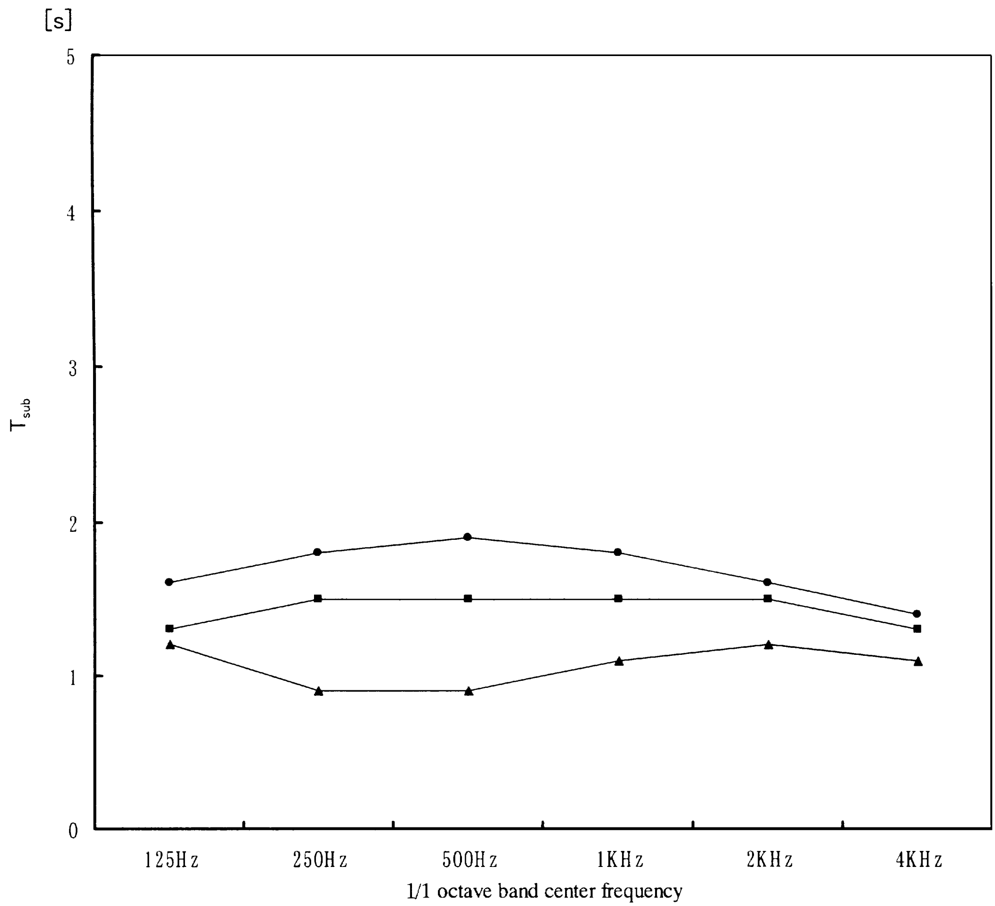

Figure 12. Measured T_{sub} (s) in the hall with the hybrid-reverberation-control system. —●—, target $T_{sub}=2{\cdot}0$ s; —■—, target $T_{sub}=1{\cdot}5$ s; —▲—, target $T_{sub}=1{\cdot}0$ s.

results of relative SPL as a function of frequency up to 1 kHz. As can be seen from this Figure, the SPL-dips around 400 Hz at points 6·0 and 8·0 m from the source on the perforated floor were improved by more than 10 dB compared with the results for the normal floor [5].

5. CONCLUSION

5.1. FUSION OF ARCHITECTURAL AND ACOUSTIC DESIGN METHODOLOGIES

A circular multi-purpose event hall was designed with a process that blended the temporal and spatial factors of architecture with the temporal and spatial factors of acoustics.

After construction of the complex (Kobe Fashion Plaza) housing the event hall (Orbis), acoustical measurements were performed in the hall. The results show that there were none of the acoustical problems associated with circular forms. This provides strong evidence of the effectiveness of the design process, because the acoustical problems could be

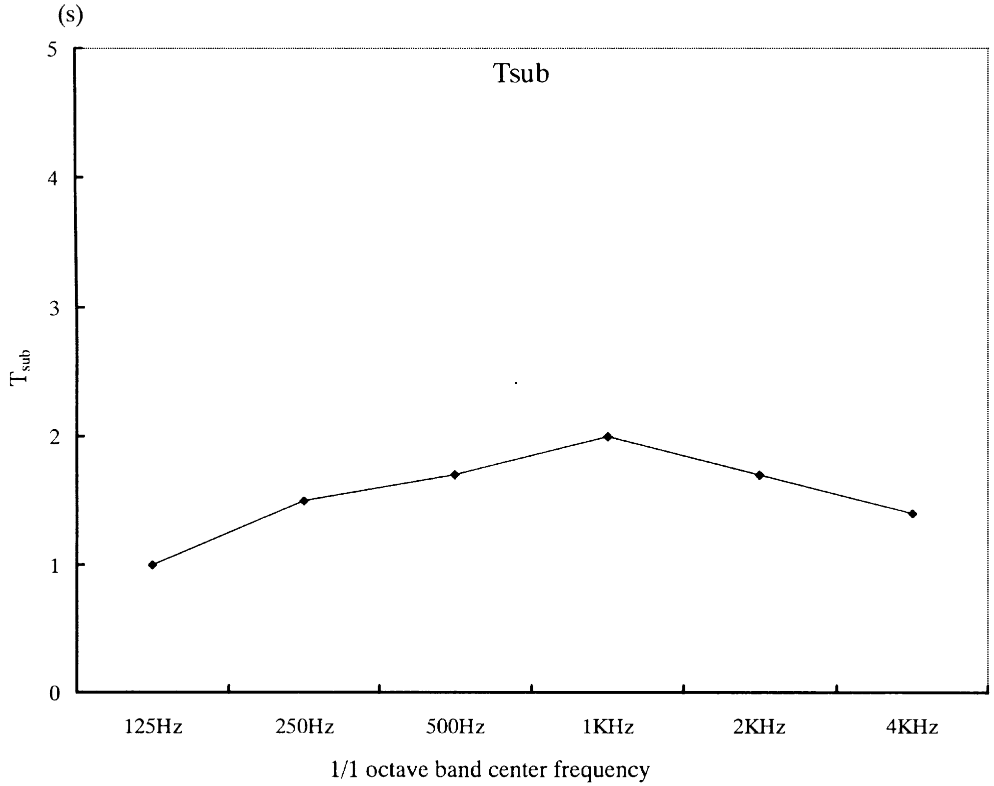

Figure 13. Measured T_{sub} (s) in the reverberation-control-room.

solved without compromising the architectural concept under the worst acoustical conditions.

5.2. DESIGN METHOD TO ELIMINATE THE ACOUSTICAL PROBLEMS OF CIRCULAR HALLS

The acoustical design of a circular hall was examined by using IACC measurements. The IACC values were much improved by the acoustical treatments. In particular, the effects of small diffusion panels, which were not taken into account in the calculation, seemed to greatly improve the results. The effects of the various equipment and methods of acoustics used to eliminate the acoustical problems of a round hall are described below.

Through the fusion of the temporal factors of both the architectural and the acoustical design, the following conclusions can be made. The efficacy of the hybrid-reverberation-control system, which consisted of architectural-acoustic and electro-acoustical elements, was verified in multi-purpose event hall.

Firstly, the reflector panels at the side of the stage and over the seating area decrease IACC and contribute to a uniform SPL. Secondly, the reflector panels above the stage decrease IACC and contribute to a uniform SPL. Thirdly, the UFO-shaped diffusion panels decrease IACC and make for a unique interior.

The SPL dip at low frequencies near the front of the stage is shallower when using the perforated floor. Therefore, a room (for children and their mothers) measuring

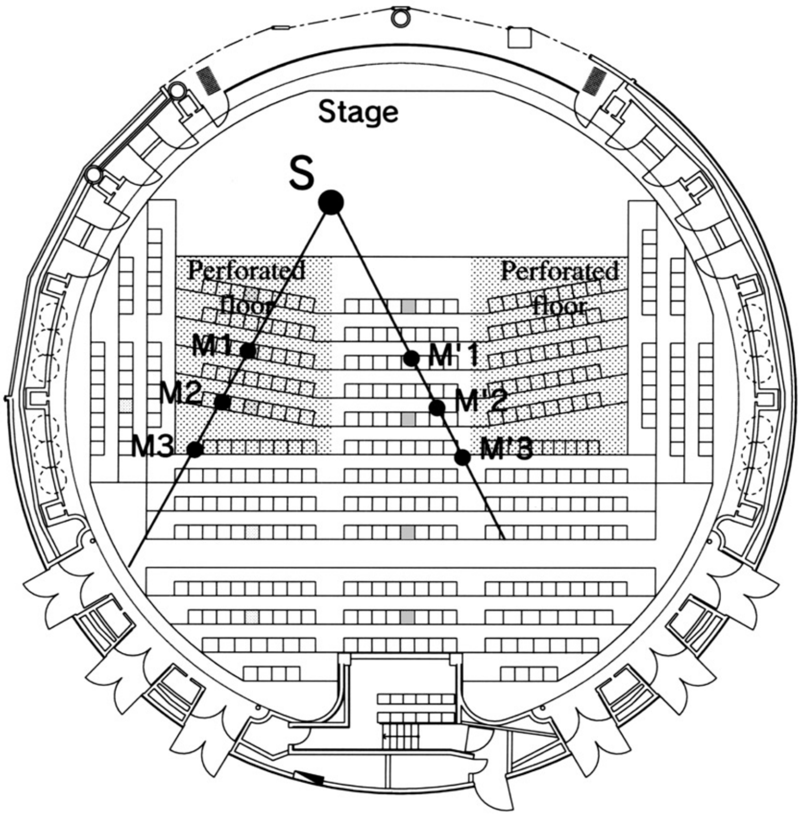

Figure 14. Location of sound source and receiving points for measurement of the effect of the perforated floor.

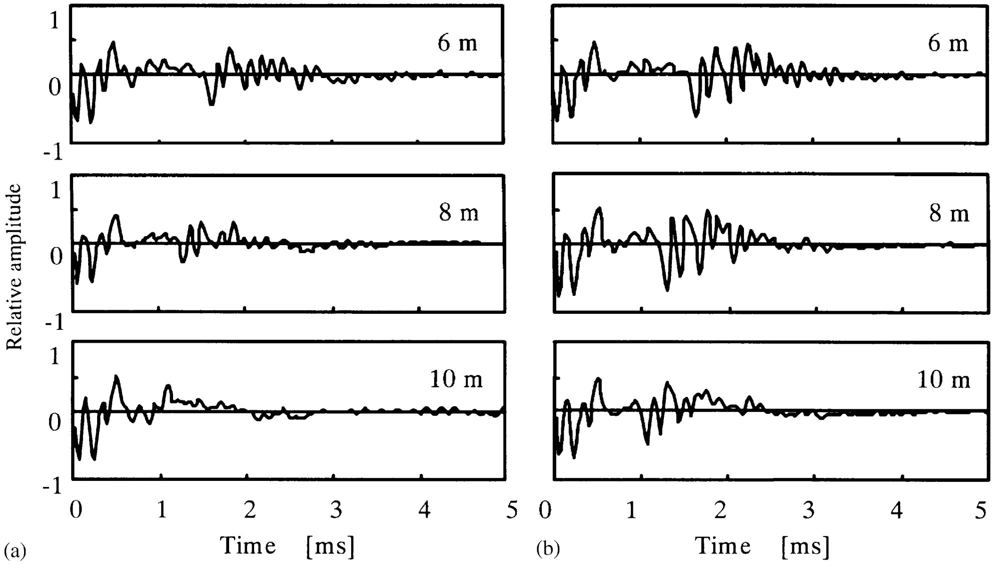

Figure 15. Measurement of echo–time pattern to evaluate the effect of the perforated floor: (a) Relative SPL on the perforated floor and (b) relative SPL on the normal floor.

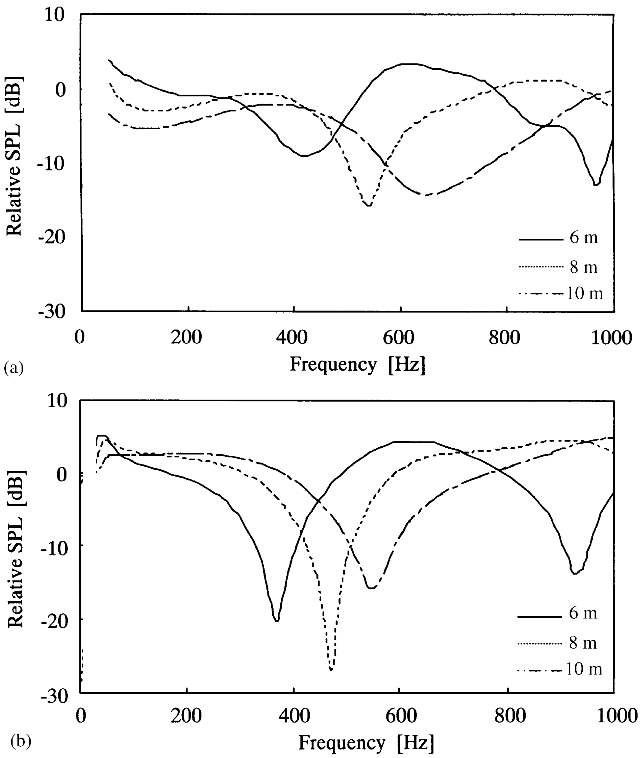

Figure 16. Relative SPL as a function of frequency up to 1 kHz: (a) relative SPL on the perforated floor and (b) relative SPL on the normal floor. ——, 6 m;·······, 8 m; —·—·, 10 m.

3·00 × 4·20 m was installed along the long axis of the hall, to eliminate the echoes of the "whispering gallery effect."

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