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The Acoustical Design of the New Yamaha Hall

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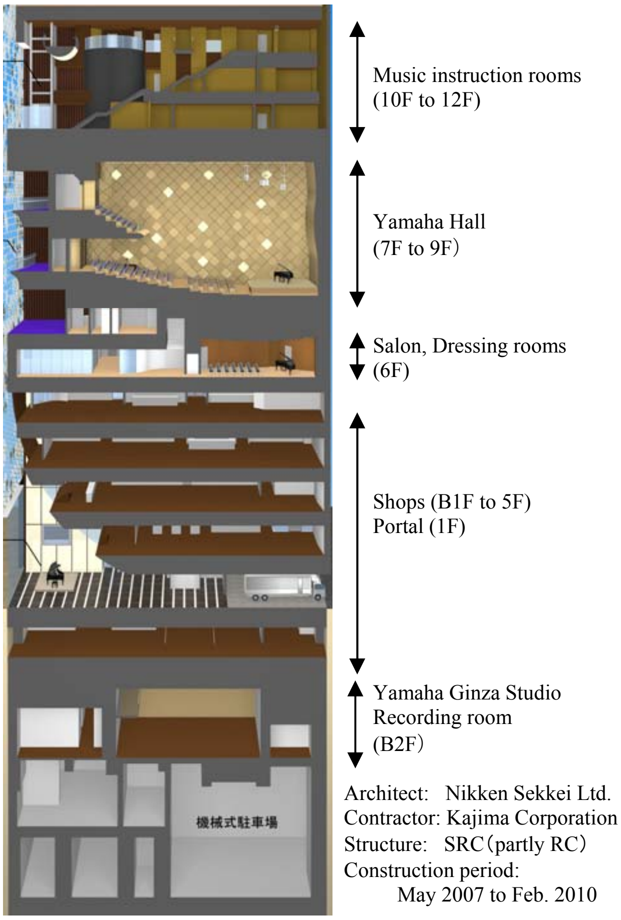
ABSTRACT

The Yamaha Ginza Building, which opened about 60 years ago, was renewed as a commercial complex that has four types of facilities: shops, music instruction rooms, hall facilities, and an information center. The new Yamaha Hall, located on the seventh to ninth floors, has been designed under the concept of a concert hall that has attractive and unique acoustics that are optimal for acoustical instruments and can never be experienced in other spaces. To control the ASW of a small room, where strong reflections from side walls often cause ambiguous sound images, scale model experiments and subjective tests using an auralization system based on a computer simulation have been used to study the pattern of the side walls. In addition, Yamaha's original wood enhancement technologies, which have been gained through the development of materials for musical instruments and utilized for violins, acoustic guitars, etc., have been implemented in the stage floor to achieve the mature, warm sound of the hall.

1. INTRODUCTION

The previous Yamaha Building and Yamaha Hall, which were designed by the famous architect Antonin Raymond, opened in 1951 and had been known as one of the popular venues in Ginza, Tokyo's fabulous fashion and cultural district, for more than half a century. Due to the age of the facilities and thanks to the 1998 easing of the architectural regulation about building height in the Ginza area, these structures were reborn as the new Yamaha Ginza Building on Feb. 26, 2010.

The new building has twelve floors above ground and three floors below ground. The building has four types of facilities: shops, music instruction rooms, hall facilities, and an information center named Portal. The hall facilities include the Yamaha Hall (333 seats), which is designed to hold performances of classical music, and the Yamaha Ginza Studio (96 seats), which is designed for multiple purposes, such as holding performances of light music and presentations of new products. In this paper, the studies of the acoustics of the Yamaha Hall during both the design and construction stages are summarized with a focus on the ASW (Apparent Source Width) control and the stage floor.



Architect: Nikken Sekkei Ltd.
Contractor: Kajima Corporation
Structure: SRC（partly RC）
Construction period:
May 2007 to Feb. 2010

Figure 1. Facilities of the New Yamaha Ginza Building

2. SUMMARY OF THE ACOUSTICAL DESIGN OF THE YAMAHA HALL

The interior of the Yamaha Hall is shown in Photo 1 and a floor plan of the first and second tiers is shown in Figure 1. To realize the concept of a small concert hall that provides a unique and attractive sound, the design of the hall's shape and interior was studied with a focus on the following aspects: (1) richness of acoustical resonance (reverberance), (2) clear and vibrant sound (clearness), (3) ease of performance (support for players on the stage), and (4) resonance variety. Regarding (1), the ceiling was set as high as the limitations imposed by the size of the building would allow. Moreover, the side walls spread toward the ceiling, which creates a rich reverberance falling from above despite the relatively small volume per seat (7.6 m^3). Regarding (3), the walls surrounding the stage are well-designed and reflectors are suspended over the stage to compensate for poor early reflections from the high ceiling. Regarding (4), reverberance can be controlled by opening doors that are connected to the highly absorptive area above the ceiling. In addition, by using the AFC system (Active Field Control system) [1], the reverberation time can be extended up to approximately 3 seconds by electro-acoustic means. This makes it possible to achieve the concept of falling resonance that is the goal outlined in (1). Regarding (2), the sightlines of the audience and the shape of the stage reflectors have been designed to provide the audience with a clear sound even with pianissimo music in a rich reverberant space. Meanwhile, lateral reflections, which are usually considered an important factor for spaciousness, tend to become too strong in a small, narrow room and consequently cause ambiguous sound images. As such, while focusing on ASW as an index related to the sound image, scale model experiments together with subjective tests using an auralization system based on computer simulations have been used to study the optimum pattern of the side walls that control ASW.

Photo 1. Interior of the Yamaha Hall

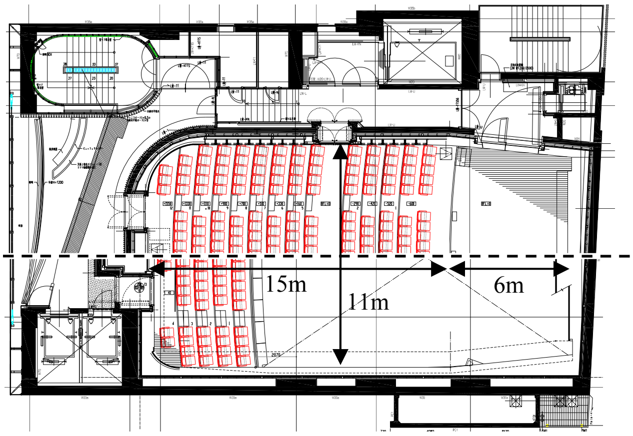
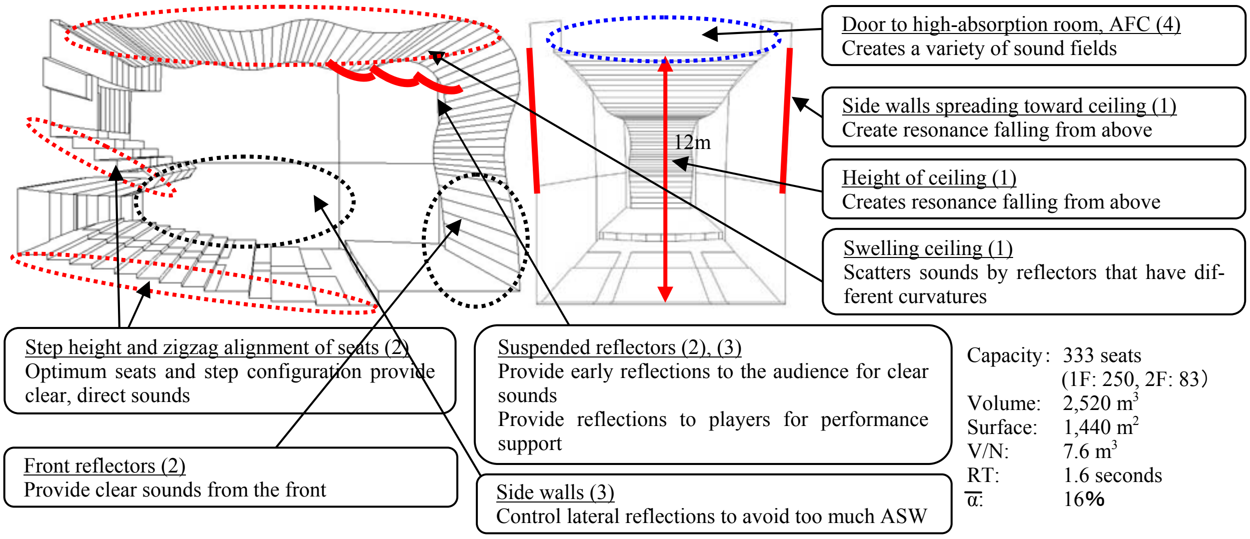


Figure 2. Floor Plan of the First (Above) and Second Tiers (Below)



Door to high-absorption room, AFC (4)
Creates a variety of sound fields

Side walls spreading toward ceiling (1)
Create resonance falling from above

Height of ceiling (1)
Creates resonance falling from above

Swelling ceiling (1)
Scatters sounds by reflectors that have different curvatures

Step height and zigzag alignment of seats (2)
Optimum seats and step configuration provide clear, direct sounds

Suspended reflectors (2), (3)
Provide early reflections to the audience for clear sounds
Provide reflections to players for performance support

Front reflectors (2)
Provide clear sounds from the front

Side walls (3)
Control lateral reflections to avoid too much ASW

Capacity:	333 seats (1F: 250, 2F: 83)
Volume:	2,520 m^3
Surface:	1,440 m^2
V/N:	7.6 m^3
RT:	1.6 seconds
$\overline{\alpha}$:	16%

Figure 3. Summary of Design Concept

3. STUDY OF SIDE WALL PATTERNS THROUGH THE USE OF SCALE MODE EXPERIMENTS

3.1 Summary

The interior design is based on two concepts. On one hand, the acoustical design viewpoint of lateral reflection control. On the other hand, the architectural (visual) design viewpoint of harmony with the building's external design of a grid made of obliquely-crossed lines, which express the movement and vibrations of sound and rhythm. Consequently a balance between the acoustical and architectural designs was considered by tilting diamond-shaped panels surrounded with obliquely-crossed grids in order to control the direction and diffusivity of the reflections. As a result of discussions with design teams, the length of each square panel side was set at 800 mm, the maximum panel-tilt-anglewas set at 15 degrees, and the panel-tilt-direction was set at front-down or rear-up. A 1/5 scale model of the panels was made and a variety of side wall patterns were configured by stacking panels in a frame whose sides were each 1.2 m (6 m in the actual configuration). To figure out the reflection diffusivity of the side walls, the polar patterns of reflections were measured in an anechoic room (Figure 4).

3.2 Conditions of the Scale Model Experiments

The impulse responses were measured using a TSP (Time Stretched Pulse) signal as a sound source and speakers that can provide playback of up to 50 kHz (10 kHz in the actual configuration). After convolving the impulse responses with the inverse filters of the speakers, the reflections were cut off and their energy was calculated. While changing the incident angle (elevation sα: 0 to 30 degrees, azimuth sβ: 30 to 90 degrees) corresponding to the angle from the stage to the side walls, a hemispherical polar pattern of each incident angle was measured at each 15 degrees of elevation (rα: 30 to 90 degrees) and azimuth (rβ: 0 to 345 degrees) (Figure 5). Three side wall patterns were selected to examine the basic characteristics: all panels set as front-down [DW], all panels set as rear-up [UP], and alternately-displaced mound shapes [MT] (Figure 4).

3.3 Experiment Results

The experiment results are shown in Figure 6. In the DW pattern, geometric reflections that correspond to the sound incident angle against panel direction (ex. rβ=135 degrees at sα=45 degrees) are strong. In the UP pattern, geometric reflections like the DW pattern and reflections at 30 to 90 degrees of rβ can be seen. This indicates that some energy is reflected from the small surface at the edge of the panels that are facing the sound source. In the MT pattern, scattering reflections can be seen.

The basic policy of the side wall pattern was decided based on these results and the design concept shown in Figure 3. In the lower area along seats [A], the UP pattern is mainly used to avoid first order reflections to the audience. In the middle area, above A, [B], the DN pattern is mainly used to create the second and third order reflections to the audience and then to make reflections moderate by lengthening the distance of the sound propagation path. Each tilting angle was adjusted depending on the panel's height from the floor. In the upper area, above B, [C], the MT pattern is mainly used to create a resonant sound. In the rear area [D], the UP pattern is mainly used to support spaciousness by creating reflections behind the audience. For the side reflectors on the stage [E], the MT pattern is mainly used to get sufficient diffusive reflections considering the support required for both solo and ensemble performances. Discussions with architects led to the final overall pattern shown in Figure 6. In addition, random wood slats were placed on the flat panels in the low area to prevent glaring sounds by scattering high frequency sounds.

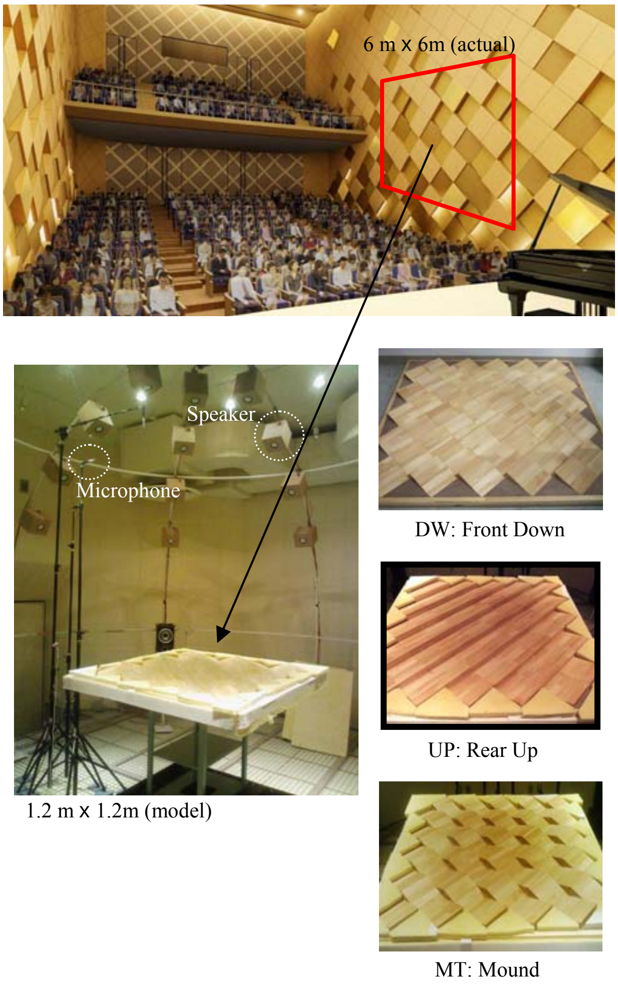


Figure 4. Scale Model Experiment

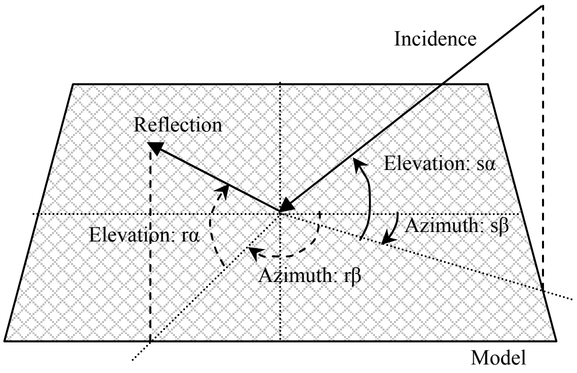


Figure 5. Angles of Incidence and Reflection

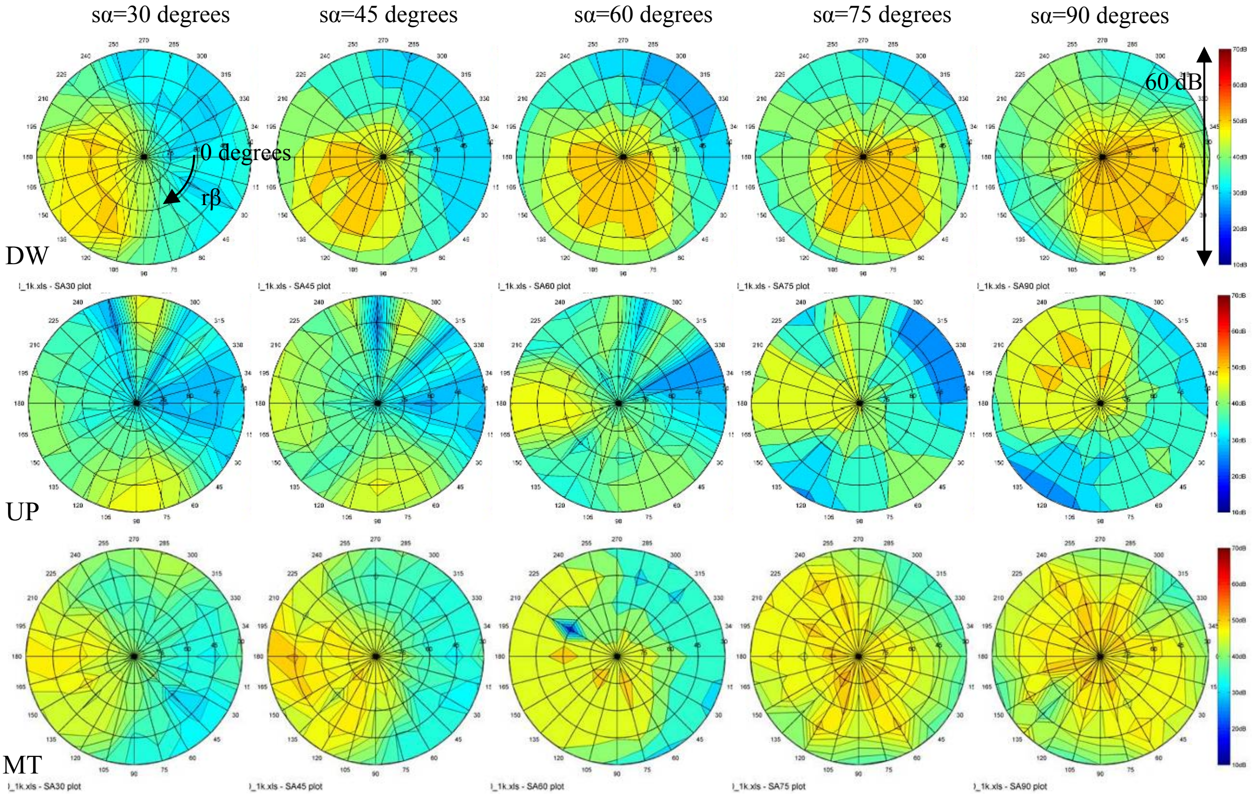
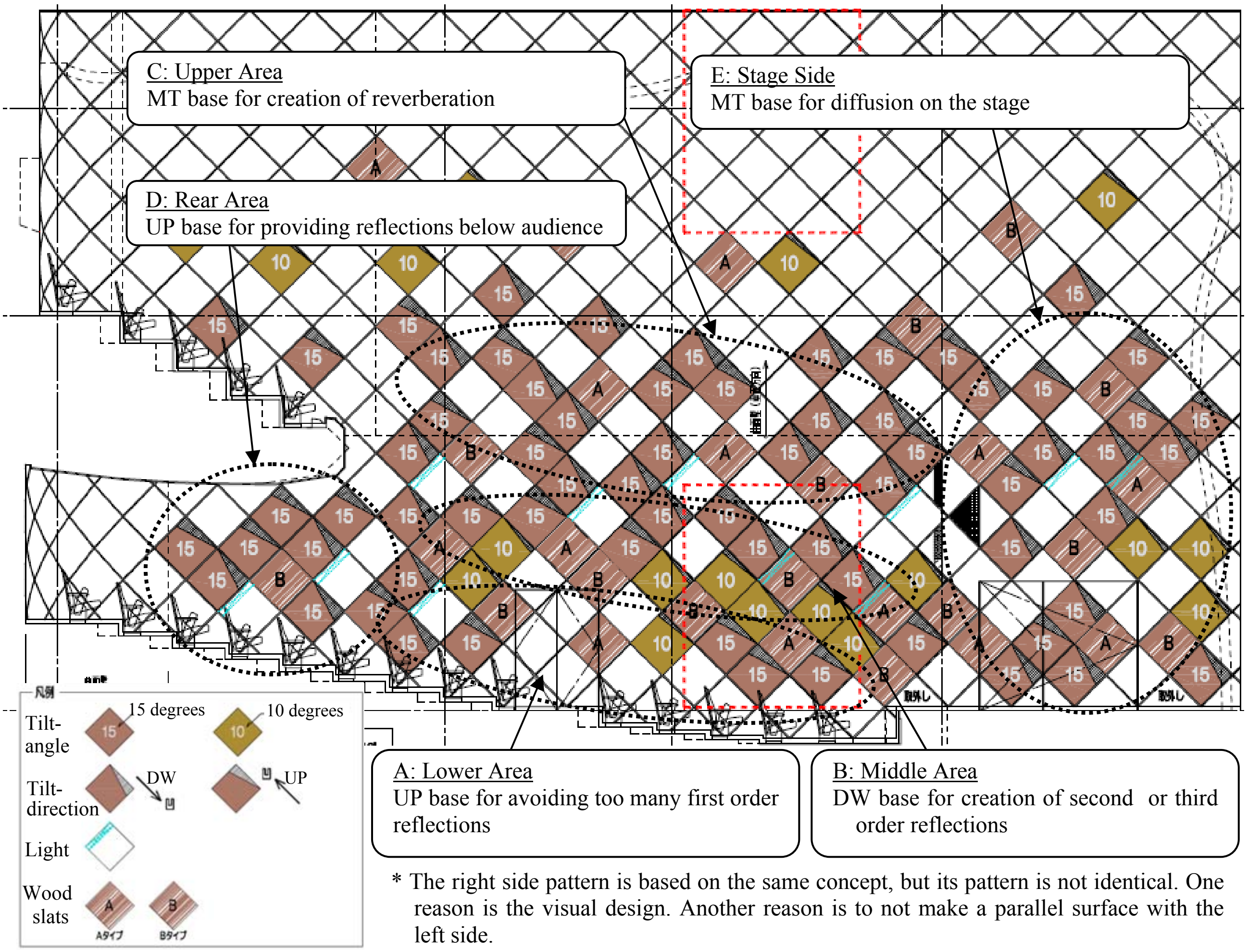


Figure 6. Polar Pattern of Reflections from Side walls (sβ = 0 degrees, 1 kHz in real application)



* The right side pattern is based on the same concept, but its pattern is not identical. One reason is the visual design. Another reason is to not make a parallel surface with the left side.

Figure 7. Side Wall Pattern (Left side)

4. STUDY OF SIDE WALL PATTERNS THROUGH THE USE OF ACOUSTICAL SIMULATIONS

4.1 Summary

Using geometrical simulations, comparative studies with other rooms were done on the final pattern that was determined through the scale model experiments. The ASW was focused on as an index for evaluating sound images.The following formulae proposed by Morimoto et al. [2] were used to calculate the ASW.

$$ASW = -39.6 \times DICC + 1.55 \times BSPL - 31.9$$
$$BSPL = 6\log_2(2^{Ll/2} + 2^{Lr/2})$$

Ll : SPL at Left Ear, Lr : SPL at Right Ear

Fomula 1. Definition of ASW and BSPL

Since these fomulae were derived from subjective experiments, it is not certain that they can be utilized for real fields, but here it was assumed that comparative studies based on these fomulae were possible. The sound fields that were compared are shown in Figure 8 and Table 1. The sound fields were produced by the Yamaha Hall with different side wall patterns: the final pattern, all flat (no tilt), all DW, and all UP and two other halls that are approximately the same size as the Yamaha Hall (halls X and Y). In hall X and hall Y, the members of the design team actually listened to and evaluated performances, and then adjusted the target image of the sound field based on the results. Since the ASW of hall Y was a bit bigger than the assumed target because of less diffusion of the side walls and the ASW of hall X was a bit smaller because of the hall's wider width, a value in the middle of the two halls' ASW values was set as the target.

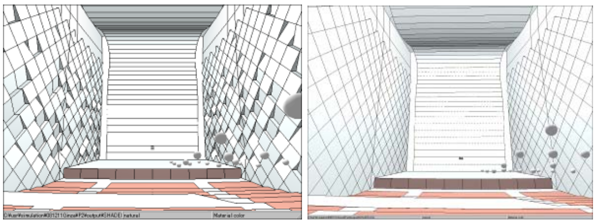
The first 30 seconds of Fantaisie by Chopin was used as the sound source. Using the CATT-Acoustic™, the impulse responses at both ears were calculated, and then major acoustical indexes and ASW derived from fomula 1 were calculated after convolving the sound source with the impulse responses. The average values for each sound field were calculated from the 27 measument points on the first tier.

4.2 Simulation Results

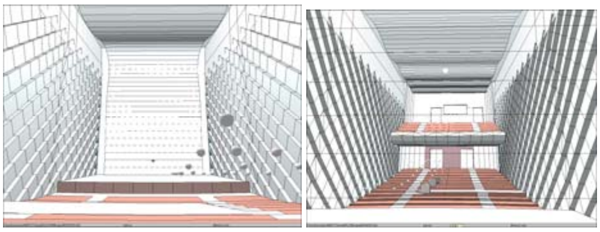
The ASW, LE5 (Lateral Efficiency), 1-ICC (ICC: Interaural Cross Correlation), and G (Strength) results are shown in Figure 9 to Figure 12. The ASW of (a), the final pattern, is 86.6 degrees and is between the ASW of (e), hall X (84.1 degrees), and (f), hall Y (89.2 degrees). This result corresponded to the assumed target. The G, 1-ICC, and LE5 results are similar to the ASW result. The other ASW values are (in descending order) (b) all FL (87.5 degrees), (c) all DW (86.9 degrees), and (d) all UP (83.1 degrees). The G results have the same order. On the other hand, the largest LE5 value was produced by (c) at 34.2%, followed by (b) at 29.0%, and (d) at 21.9%. This result indicates that ASW derived from Formula 1 includes some factors which cannot be expressed only by LE5.

Table 1. Summary of Sound Fields

	(a) to (d) Yamaha Hall	(e) Hall X	(f) Hall Y
Capacity	333 seats	-	300 seats
Volume	V=2,520 m^3	V=3,595 m^3	V=2,190 m^3
Seats	W=11.0 m D=15.0 m H=12.0 m	W=14.0 m D=22.0 m H=12.0 m	W=11.0 m D=18.0 m H= 8.3 m
Stage	W=11.0 m D= 6.0 m	-	W=11.0 m D= 6.0 m
RT	1.6 sec	1.5 sec	1.6 sec



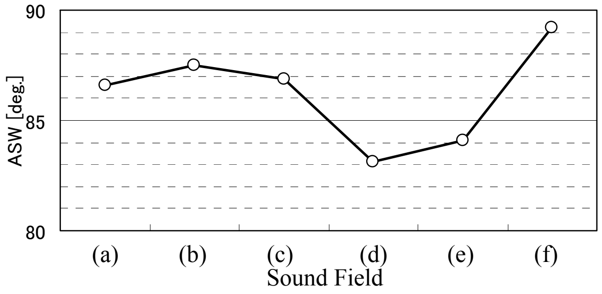
(a) Final pattern (b) All Flat: FL



(c) All DW: DW (d) All UP: UP

(e) Hall X (f) Hall Y

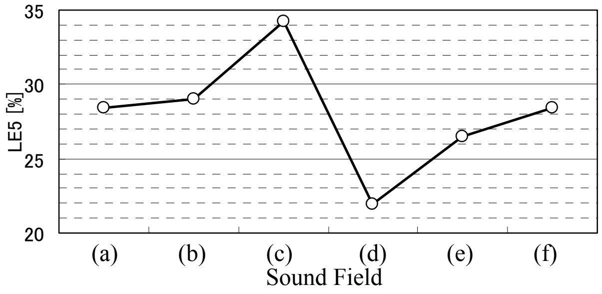
Figure 8. Sound Fields for Comparative Study



ASW	(a) Final	(b) FL	(c) DW	(d) UP	(e) Hall X	(f) Hall Y
Ave.	86.6	87.5	86.9	83.1	84.1	89.2
SD	2.7	2.8	3.3	4.0	4.3	2.5

Ave. : Average Value
SD: Standard Deviation

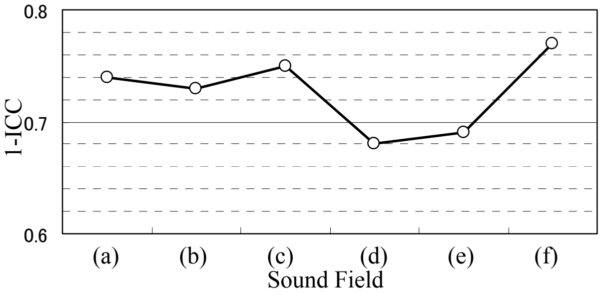
Figure 9. and **Table 2**., Comparison of ASW [degrees]



LE5	(a) Final	(b) FL	(c) DW	(d) UP	(e) Hall X	(f) Hall Y
Ave.	28.4	29.0	34.2	21.9	26.5	28.4
SD	2.9	3.4	2.5	3.5	5.6	2.3

Ave. : Average Value
SD: Standard Deviation

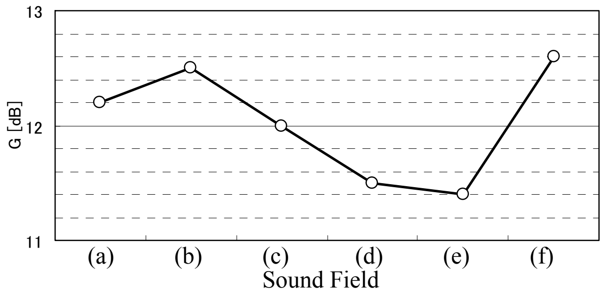
Figure 10. and **Table 3**., Comparison of LE5 [%]



1-ICC	(a) Final	(b) FL	(c) DW	(d) UP	(e) Hall X	(f) Hall Y
Ave.	0.74	0.73	0.75	0.68	0.69	0.77
SD	0.07	0.07	0.08	0.08	0.12	0.07

Ave. : Average Value
SD: Standard Deviation

Figure 11. and **Table 4**., Comparison of ICC



G	(a) Final	(b) FL	(c) DW	(d) UP	(e) Hall X	(f) Hall Y
Ave.	12.2	12.5	12.0	11.5	11.4	12.6
SD	0.9	0.9	1.3	1.2	0.9	0.7

Ave. : Average Value
SD: Standard Deviation

Figure 12. and **Table 5**., Comparison of G [dB]

5. COMPARATIVE STUDY BY LISTENING TEST

5.1 Summary

The simulation results mentioned above were confirmed by actually listening to each sound field and performing comparative listening tests. The measuring point was set at the center of the first tier approximately 12 m away from the sound source. The directional impulse responses were calculated using CATT-Acoustic™, and each sound field was synthesized with the 6-ch auralization system [3] (Figure 13 and Photo 2). The SD method was used to evaluate the ASW of each sound field. Six acoustical designers and one recording engineer were selected as the subjects for the listening test.

5.2 Results

Each subject's results are shown in Figure 14. The results of hall X (V), hall Y (VI), and the final pattern (I) are in the same order as the assumed target which is hall X > the final pattern > hall Y. In addition, the ASW values that were calculated by the acoustical simulation (Table 2) exhibit the same trend as the listening test results. Moreover, if we add the results of the listening tests and calculations from FL (II), DW (III), and UP (IV), the values nearly exhibit the same trend. As a result, it can be said that the ASW value derived from Formula 1 is effective as an index used to evaluate ASW in the design stage.

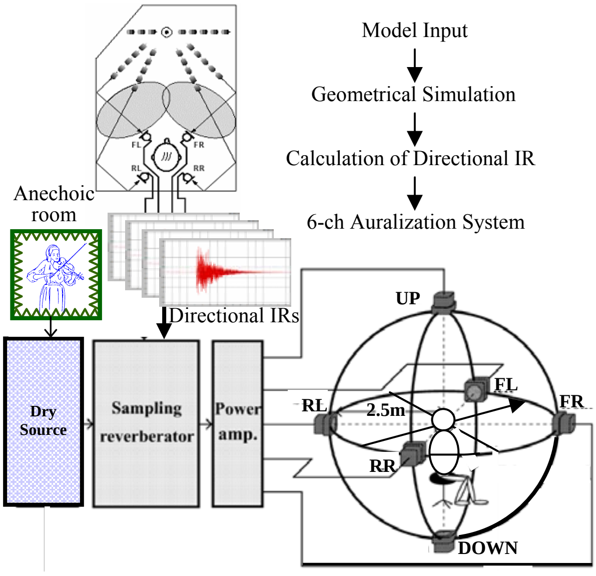


Figure 13. Method for Listening Tests

Photo 2. 6-ch Auralization Room

6. DESIGN CONCEPT OF THE STAGE FLOOR

Besides the hall shape studies mentioned above, a new idea was introduced into the design of the stage floor. A unique technology called A.R.E. (Acoustic Resonance Enhancement) has been developed for designing musical instruments. This technology can change the characteristics of wood to the same characteristics of aging wood by controlling temperature, pressure, and humidity. A.R.E. wood has been used in the implementation of the Yamaha Hall stage floor. The structure of the stage is shown in Figure 15. A.R.E. technology was used to process the top layer of cypress and the next two layers of cedar. In the design phase, sample stages were constructed with wood that had under gone the A.R.E procedure and with wood that had not, in order to examine the acoustical features of the sample stages and to confirm their efficiencies. The vibration responses of the stages when hit by an impulse hammer are shown in Figure 16. The differences can be especially seen at the beginning of the responses. In addition, actual listening tests were performed using instruments such as cellos and pianos.. Both the listeners and players mentioned that the sound of the instruments on the A.R.E. stage was bigger, brighter, and clearer (Photo 3).

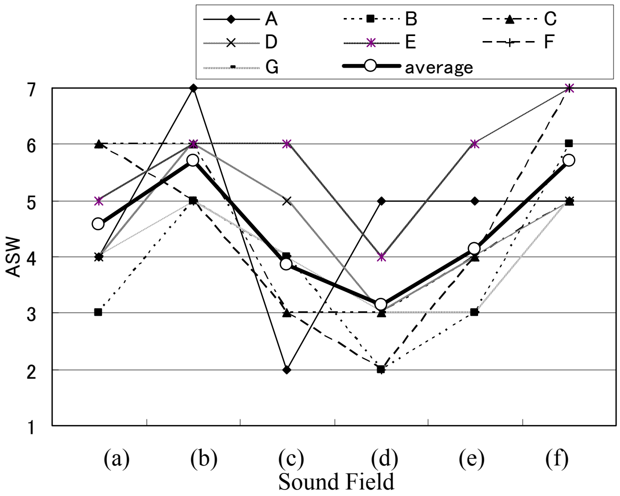


Figure 14. ASW Listening Test Results

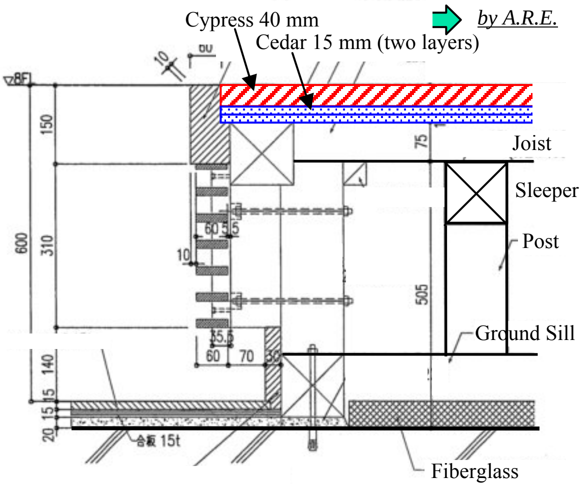


Figure 15. Structure of the Stage Floor

7. MEASUREMENT RESULTS IN A REAL FIELD

The reverberation time, absorption coefficient, and LE5 measurement results in a real field are shown in Figure 17 to Figure 19 and Table 6.

8. CONCLUSIONS

To control lateral reflections in a small hall,this paper has proposed an acoustical design that focuses on ASW . Geometrical simulations and 6-ch auralization systems were utilized to evaluate sound fields. As a result, this paper has indicated the feasibility of this design method. Further work includes a discussion of the correspondence between simulated and actual measured results. Many concerts have been held in the Yamaha Hall. We have received responses from both stage players and audience members. As a next step, in addition to the evaluation of those responses, the design method for small halls will be further developed through on-site measurements and performances.

ACKNOWLEDGEMENT

The authors wish to thank Dr. H. Iida for his advice in thiswork.

WORK.REFERENCES

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2 M. Morimoto and K. Iida, “A practical evaluation method of auditory source width in concert halls” *J. Acoust. Soc. Jpn. (E)*, 16, 2 (1995)

3 Yokoyama et al., “6-ch recording/reproduction system for 3-dimensional auralization of sound fields” *Acoust. Soc. Jpn.*, 23, 97–103 (2002)

Photo 3. Listening Test Using an Automatic Piano

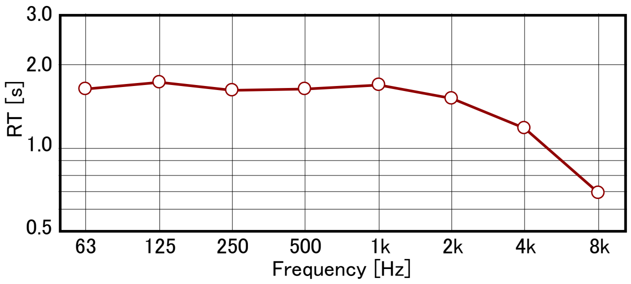

Figure 17. Reverberation Time of Yamaha Hall

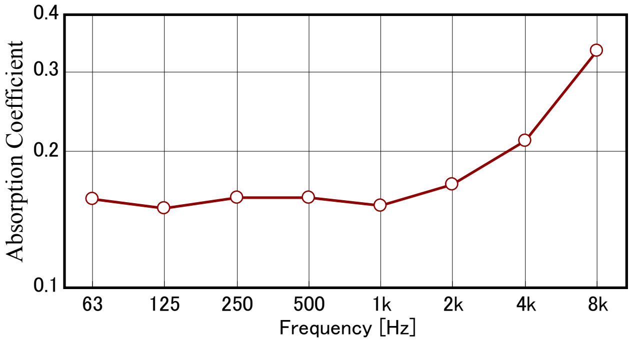

Figure 18. Average Absorption Coefficient of Yamaha Hall

Table 6. RT and Average Absorption Coefficient

Freq.	63	125	250	500	1 k	2 k	4 k	8 k
RT	1.64	1.73	1.63	1.63	1.70	1.52	1.19	0.69
$\bar{\alpha}$	0.16	0.15	0.16	0.16	0.15	0.17	0.21	0.33

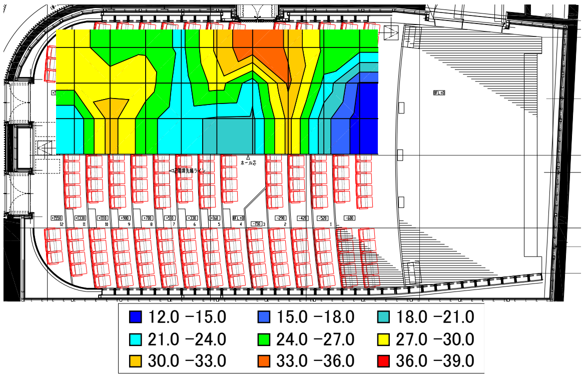

Figure 19. Measured Results of LE5 (Average at 500 to 2 kHz)

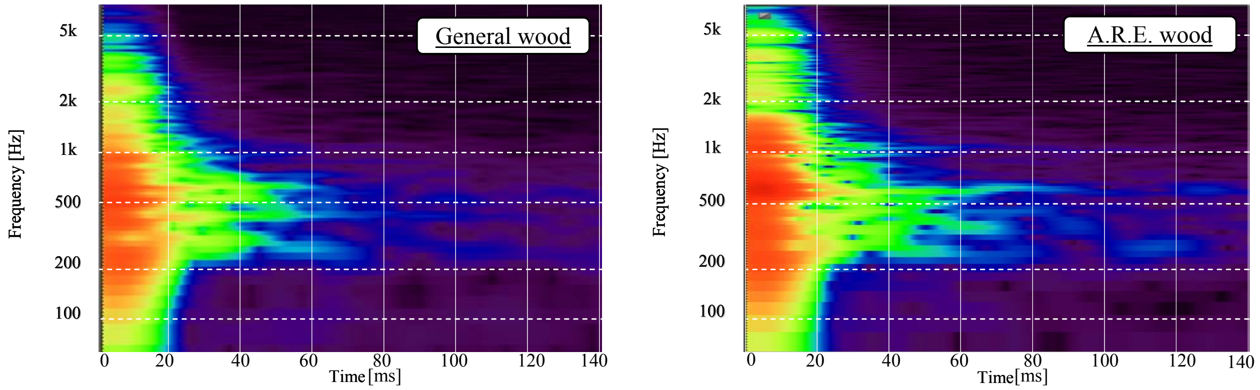

Figure 16. Vibration Responses of Stages When Hit by an Impulse Hammer