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Acoustical Design of New Danish Radio Concert Hall

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PACS: 43.55 Fw Auditorium and enclosure design

ABSTRACT

A new 1800-seat concert hall at the Danish Radio complex in Copenhagen opened in January 2009. The new hall primarily serves classical music forms such as orchestra, chamber ensemble, solo recital, etc. The seating layout of the hall is based upon the vineyard style. During all design phases, the room shape was studied with computer simulations and near the completion of design a detrimental echo check was performed using a 1:10 scale model. Presented here is the acoustical design of the new hall, as well as acoustical data measured after completion.

1. INTRODUCTION

Danish Radio (Danish Broadcasting Corporation) decided to build a new concert hall when the Danish Radio's headquarters and all other facilities moved to a new campus. The concert hall was built as a part of their new home. The new hall has audience seating for approximately 1,800 persons and has been designed as a concert hall for classical music. The Danish National Radio Symphony Orchestra sits on the stage of the new hall as the resident orchestra.

The competition for the design team (architect-acoustician) for the new concert hall was conducted by the client, Danish Radio, from the end of 2001 to the beginning of 2002. The team of the French architectural firm Ateliers Jean Nouvel with Nagata Acoustics as the acoustical consultant was chosen.

Design was took place from April 2002 through July 2003. Construction began after the completion of design, and the completion of construction was expected in the summer of 2007. The concert hall finally opened in January 2009.

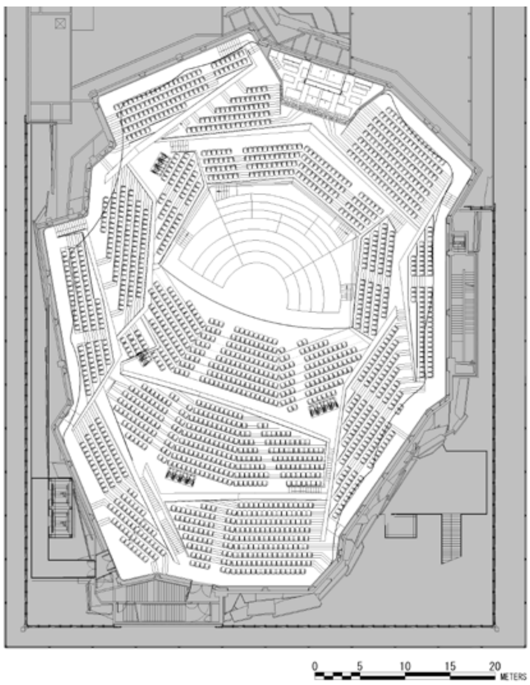


Figure-1 Plan

2. ROOM ACOUSTICAL DESIGN

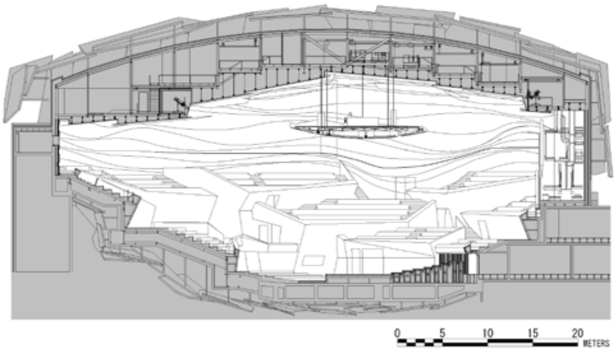
2.1 Room Shape

The competition program specified a vineyard-style layout for the fundamental room shape, audience seating layout and stage configuration. This shape was naturally incorporated into the design.

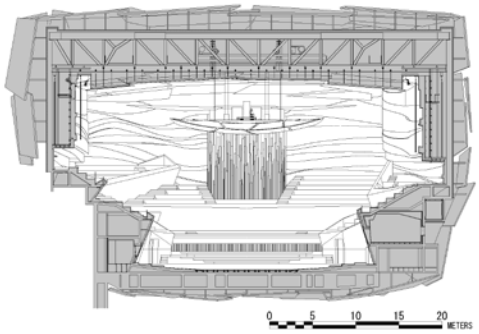
Plan and section are shown in Figure-1 and Figure-2, respectively.

2.1.1 Ceiling Height

The ceiling of the auditorium reaches a height of approximately 23.5 meters at the highest point, in order to keep enough room air volume to achieve a relatively long reverberation time. The final room air volume is approximately 28,000 cubic meters, resulting in 15.6 cubic meters per seat.



Longitudinal Section



Transverse Section

Figure-2 Section

2.1.2 Small Walls among Audience

The audience seating area was divided into small blocks at different floor levels, creating small walls through the audience area which can provide early reflections to each audience block. They also tilt inward to more effectively provide sound reflections to the audience. The layout of the small walls is shown in Figure-3.

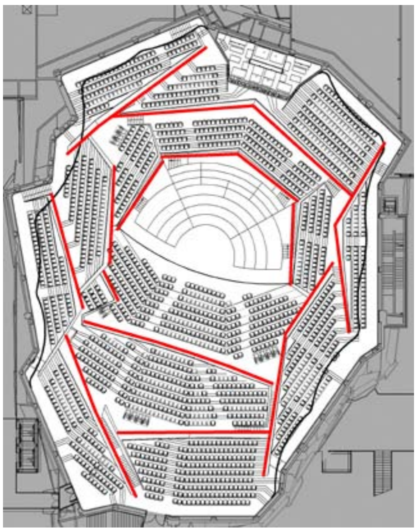


Figure-3 Layout of small walls

2.1.3 Stage Dimensions and Orchestra Risers

The stage was designed to accommodate a full orchestra and chorus with the dimensions of 22 meters wide (at the front) and 15 meters deep (at the center). Powered orchestra risers were planned. The risers are not only for wind instruments and percussion but also for string instruments. The design of the orchestra risers for Walt Disney Concert Hall for the Los Angeles Philharmonic (opened in 2003) was proposed as a base for discussions for the DR stage. Representatives from the DR orchestra were included in the discussion of the riser layout. Mock-ups of the risers were built, and the orchestra rehearsed on it to verify actual shapes and sizes for the design. The latest plan for the risers is shown in Figure-4.

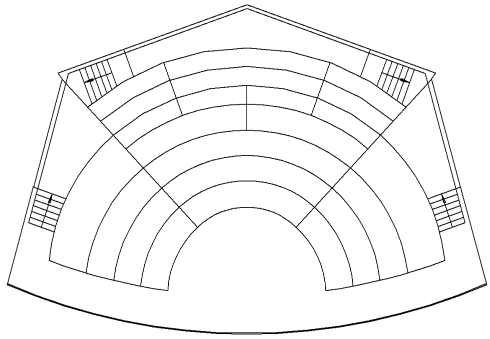


Figure-4 Latest plan for the risers

2.1.4 Suspended Ensemble Reflector

An ensemble reflector was designed to be suspended above the stage area, to provide necessary reflections to the musicians on the stage and the audience around the stage area. The reflector is suspended from the ceiling, and the height is adjustable for acoustical tuning and maintenance. The ensemble reflector was divided into several pieces, but the minimum dimension of each piece was designed to be at least 3-4 meters. The reflector design is shown in Figure-5.

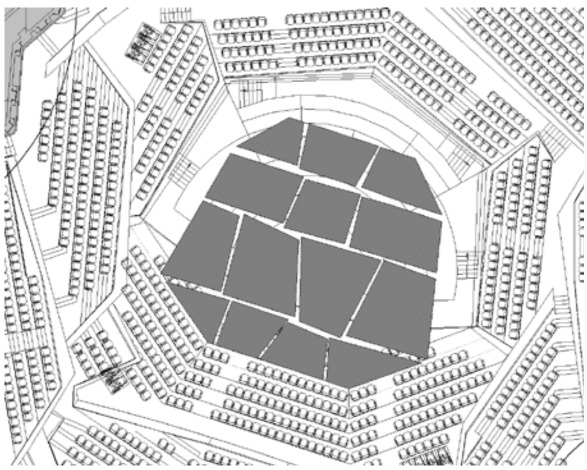


Figure-5 Reflector design

2.1.5 Computer Modeling

Ray-tracing computer simulations were conducted to analyze the distribution of early reflections for different time periods (0-30ms, 30ms-60ms, 60ms-90ms, etc.).

Figure-6 shows the distribution of the early reflections in the Hall.

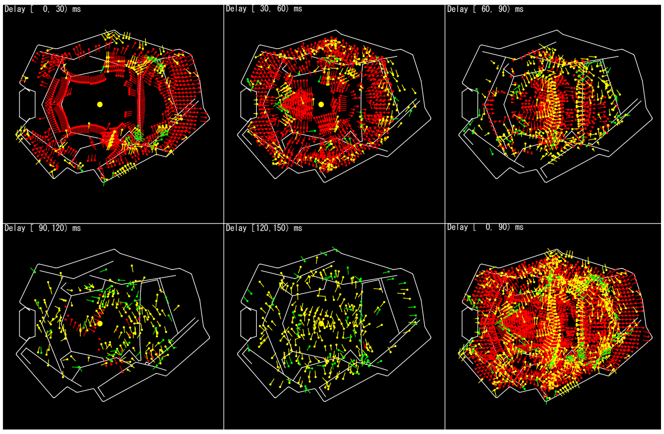


Figure-6 Distribution of early reflections in the Hall

2.2 Interior Material

Acoustically important interior materials in the concert hall are shown in Figure-7.

2.2.1 Ceiling

The interior ceiling was designed as the heaviest and most rigid area in the hall, in order to effectively reflect sound energy from low to high frequencies to the audience area. Multiple layers of gypsum board, totaling more than 100 kilogram per square meter, were specified.

2.2.2 Main Perimeter Walls

The main perimeter walls around the audience area were also designed with multiple layers of gypsum board, but this time with approximately 30-50 kilogram per square meter. Irregularities on the surface were designed to scatter sound.

2.2.3 Audience Area Floor

The audience floor was designed to be acoustically reflective, using wood. The wooden parquet was attached directly to multiple layered gypsum boards with no void space between them.

2.2.4 Stage Floor

The stage floor was designed with approximately 50 mm thick soft wood. The floor is supported by a structure of sleepers and beams, with an air space of more than 500 mm deep under the floor.

2.2.5 Suspended Ensemble Reflector

Rigid and heavy materials, such as concrete, multiple layers of dry boards, etc., were requested for the ensemble reflector. Multiple layers of dry boards were chosen.

2.2.6 Variable Acoustic System

A variable acoustics system was studied to change the reverberation time and provide significantly damped acoustics for non-classical programs, such as pop music. It was imperative that the system have no negative impact on the original, natural room acoustics for classical music.

As the result of those studies, a simple system of retractable curtain was introduced around the main perimeter wall area. See photos on the last page.

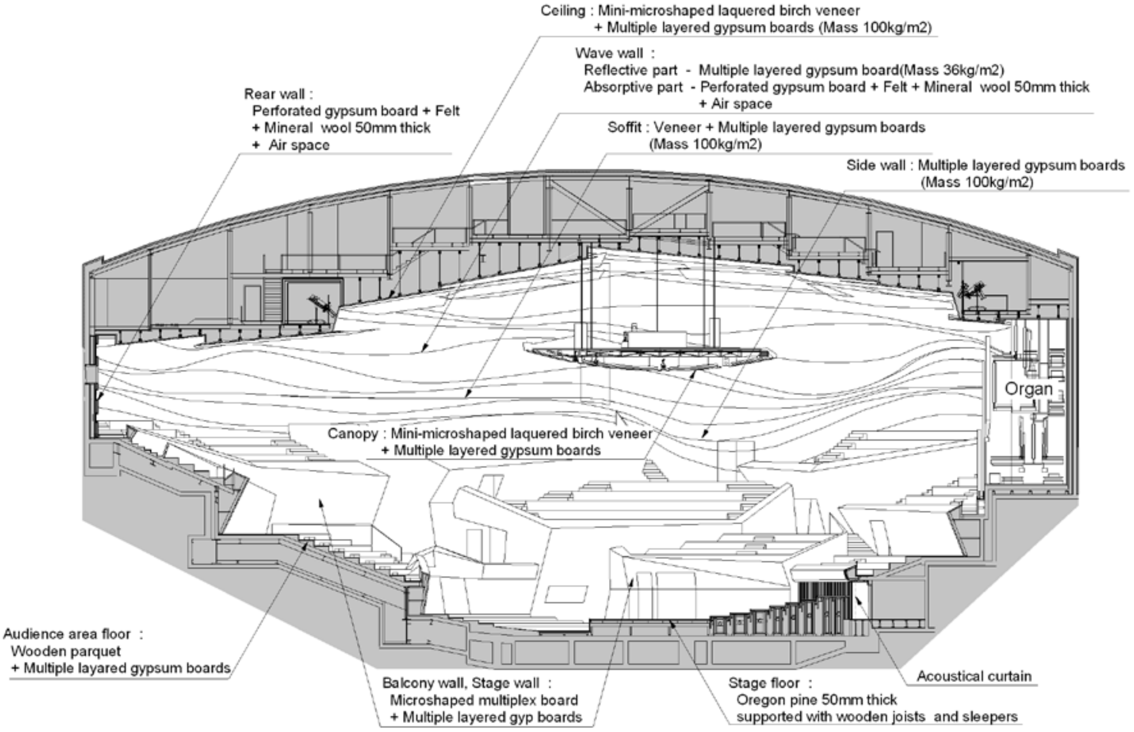


Figure-7 Acoustically important interior materials in the concert hall

3. 1:10 ACOUSTIC MODEL TEST

The main purpose of the test was to detect any detrimental echoes in the hall. An important merit of this large scale model is that the detection of detrimental echoes can be done with an audition of the actual sound in the model. This is the only reliable method of detecting detrimental echoes.

Photo-1 Inside model

3.1.1 Test Conditions

The structure and interior materials of the model were chosen so that the acoustical properties of the model could have the best similarity to the actual size hall. The layout of materials in the model is shown in Figure-8 and Photo-1.

The space was filled with nitrogen gas, replacing oxygen, to mitigate the excessive attenuation of sound in ultra-sonic frequencies.

3.1.2 Test Equipment

The measuring equipment used in the test and their block diagram are shown in Figure-9.

(1) Sound Source

Two sound sources, each with different directivity characteristics, were prepared. A leaf tweeter (Technics EAS-10TH1000) was used as a directional sound source in order to simulate brass instruments, such as trumpet and trombone. A dodecahedron loudspeaker was used as an omni-directional sound source in order to simulate instruments such as strings and percussion. The effective frequency ranges of the sound sources as follows:

a) Leaf tweeter: 2,500Hz-100,000 Hz (250Hz - 10,000Hz in real)

b) Dodecahedron: 500Hz-80,000 Hz (50Hz - 8,000Hz in real)

(2) Microphone

For the detection of echoes, a binaural dummy head (ACO DH-7046) with two embedded capacitor microphones (1/6 inch-caliber), one on each side of the head, was used. A 1/4-inche capacitor microphone (B&K 4315) was used as an omni-directional microphone.

(3) Equipment for Data Analysis

A personal computer and its peripheral equipment were used for the measurement of impulse responses, signal processing, and analysis.

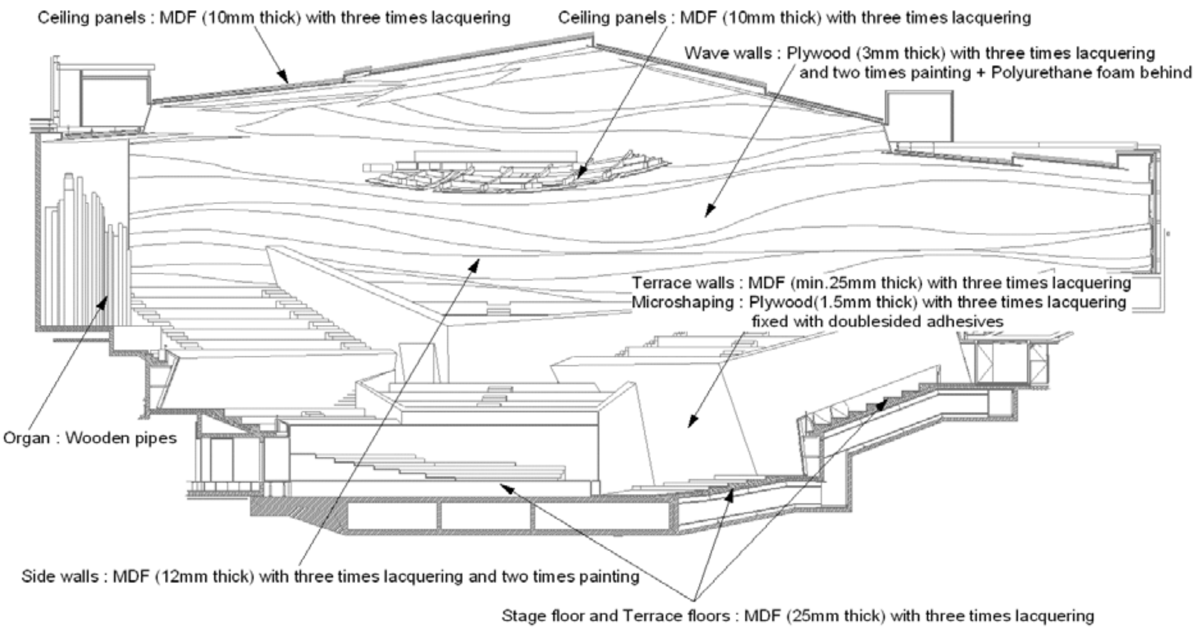


Figure-8 Materials of model

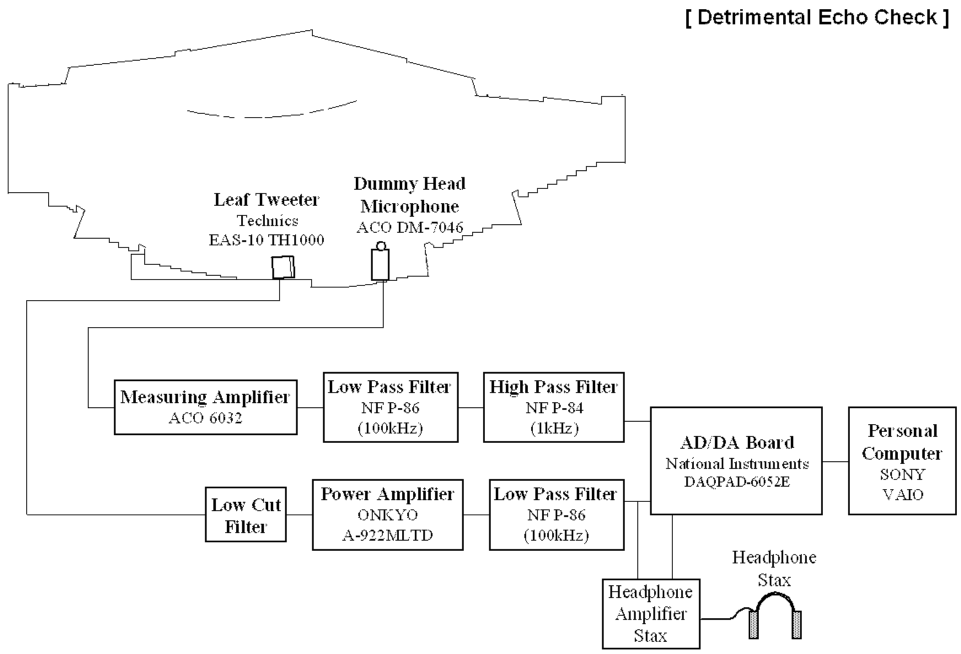


Figure-9 Measuring instruments and block diagram

Computer	SONY VAIO PCG-SRX7E/P
D/A, A/D Board	National Instrument DAQPAD-6052E
D/A Channel	1 channel
Sampling Rate	300kHz（Measurement in the model） 30kHz (Listening)
A/D Channel	2 channel
Sampling Rate	300kHz（Measurement in the model）
Sound Source	Maximum-length Sequence
Averaging	16 cycles
Analysis	Filtering, Reverberation Time, REC Curve

3.1.3 Measuring Method and Result

Impulse responses from the sound sources were measured at various measuring points with the stereophonic dummy head system. Positions of the sound source and the microphone are shown in Figure-10. A Maximum Length Sequence signal was used as the sound source signal. Averaging over 16 cycles was performed in order to improve S/N (signal and noise ratio).

The echo check was conducted with the directional sound source being set first pointing upwards approx. 6 degrees, then pointing upward approx. 15 degrees. Finally, the omnidirectional sound source was used for the echo check.

When a detrimental echo was found, the sound path of the echo was investigated and various measures were investigated to eliminate the echo. For example, sound-absorbing material was used or the angle of the surface was changed. Then, the echo was re-checked until the elimination of the problem was confirmed.

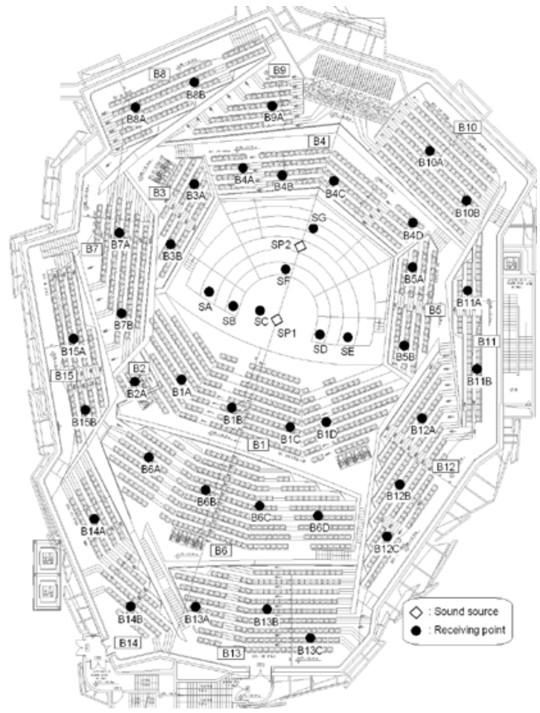
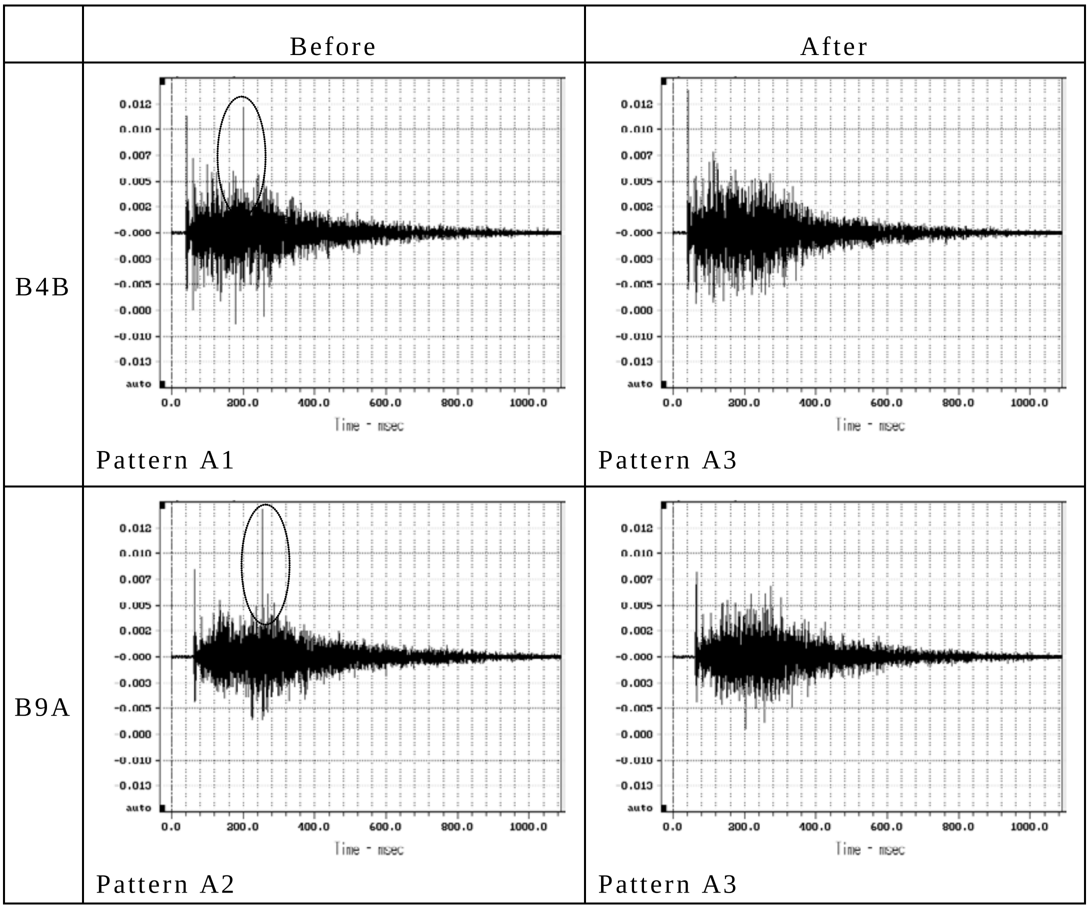


Figure-10 Sound Source and Receiving Point

Figure-11 shows some examples of echo problems we observed. The responses shown were measured at B4B and B9A, both before and after the treatment with absorptive material or changing the angle of balcony 13, respectively, to delete the detrimental echoes.

Pattern	Condition		
A1	*Stage Riser:	With	
	*Canopy height:	Stage FL+15m	
	*Absorptive area:	Upper part of rear wall (only behind B13 block)	
A2	*Stage Riser:	With	(same as A1)
	*Canopy height:	Stage FL+15m	(same as A1)
	*Absorptive area:	Upper part of rear wall (only behind B13 block)	(same as A1)
	*Terrace wall:	Incline terrace wall B13 more (+20mm thick)	
A3	*Stage Riser:	With	(same as A1)
	*Canopy height:	Stage FL+15m	(same as A1)
	*Absorptive area:	Whole rear wall, except below audience head level	
	:	(behind B13 block and right side of B14 block)	
	*Terrace wall	Incline terrace wall B13 more	
		(+30mm thick = 66 degrees)	



*Sound source: SP1 (approx. 15 degrees face-up)

Figure-11 Comparison of impulse response before and after application of measures for elimination of detrimental echo

Some detrimental echoes were found in the following particular conditions:

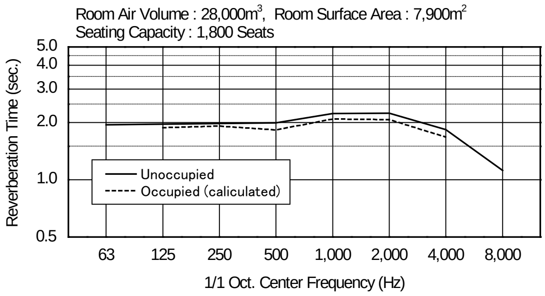
	Sound Source		Measuring Point	Echo from
	Position	Degrees		
a)	SP1	15	On the stage, B3, B4	B13 terrace wall (Rear wall of B6)
b)	SP1	6	B9A	Rear wall of B13 (upper part only)
c)	SP1	15	B9A	Rear wall of B13 and right side of B14 (above head of audience)

a) Changing the angle of the terrace wall of B13 (rear wall of B6) eliminated the echoes. The angle of B13 was set to 66 degrees from the horizontal.

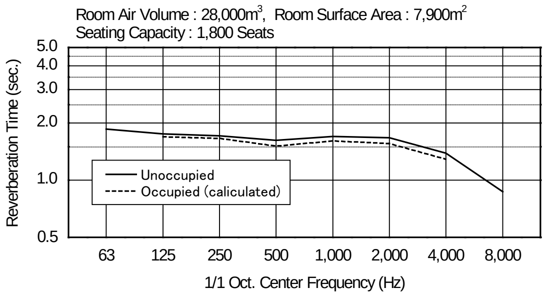
b) Putting absorptive material on the rear wall of B13 (upper part only) eliminated the echoes.

c) Above head level of audience, putting absorptive material on the rear wall of B13 and on the right side of B14 eliminated the echoes.

As a result of the investigation to find the echo paths, the rear wall was treated with absorptive material and the angle of the front wall of balcony 13 was changed.



Variable Acoustics: Reflective



Variable Acoustics: Absorptive

Figure-12 Reverberation time

4. MEASURED ACOUSTIC DATA

4.1 Reverberation Time

The measured reverberation times are shown in Figure-12.

4.2 Room Acoustical Parameters

Other room acoustical parameters: EDT, C80, D50 and G averaged over 36 measuring points distributed in audience area are shown in Table-1.

Table 1. Room acoustical parameters

	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
EDT [sec.]	2.0	2.0	1.9	2.0	2.0	1.6
C80 [dB]	-0.7	0.2	1.4	1.6	1.4	2.4
D50 [%]	28	38	45	47	46	50
G [dB]	7.3	5.8	3.5	3.0	3.9	4.3

Acknowledgments

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