PROCEEDINGS of the
24th International Congress on Acoustics

October 24 to 28, 2022 in Gyeongju, Korea

ABS-0664

Acoustical design of the Nishiwaki Community Hall “Orinas” – Study of the absorption characteristics of its interior perforated blocks

Kimiko NAKAGAWA[1]; Hideo MIYAZAKI[2]; Masahiro TOYODA[3]

[1] Spatial Audio Group, Yamaha Corporation, Japan

[2] Spatial Audio Group, Yamaha Corporation, Japan

[3] Department of Architecture, Faculty of Environmental and Urban Engineering, Kansai University, Japan

ABSTRACT

The Nishiwaki Community Hall “Orinas” opened in May 2021. The main space in this facility is the multipurpose hall with 602 seats. One of the acoustic features of this hall is the use of perforated blocks as the interior material for the side walls. In the design stage, we were concerned about possible acoustic phenomena caused by the line grid arrangement of uniformly sized and equidistant holes. Therefore, in the construction stage, the sound absorption coefficients of the perforated blocks were measured under various conditions while changing the depth of the air space behind the perforated blocks to the walls in the reverberation chamber. The measured results indicated that (1) with no or very small air space, there are large peaks of absorption coefficient at certain frequencies, and (2) with 150–400 mm air space, the frequencies and degrees of the peaks of absorption coefficient depend on the depth of air space. Finally, different air spaces in the range of 150–300 mm were selected by tilting the walls behind the perforated blocks. Acoustic measurements after construction showed no significant acoustic phenomena. In addition, to reveal the mechanism of the sound absorption, we conducted computer simulation based on the finite element method. The results of the simulation are also introduced in this paper.

Keywords: Acoustical design, Absorption, Wave acoustic analysis

1. INTRODUCTION

The Nishiwaki Community Hall “Orinas” is a new community space in the central city area that opened in May 2021 along with the new City Hall building. This facility was designed for replacing the old civic center, which had problems such as deterioration and lack of the earthquake-resistant performance. The facility includes a multipurpose hall, "Orinas Hall," which has 602 movable seats, 10 studios for various purposes such as music, dance, exercise, and cooking, a lounge, a coffee shop, and a rooftop terrace that can be used freely by anyone. The functions of this facility are not only to related to the arts and cultural activities, but also to health and welfare, and to tourism.

Table 1 gives the outline of the facility. This paper introduces the acoustical design of Orinas Hall which is the main space of this facility. One of the acoustic features of this hall is use of perforated blocks as interior material for the side walls. In the design stage, we were concerned about possible acoustic phenomena caused by the uniformly sized and equidistant holes forming a line grid. Therefore, in the construction stage, the acoustical properties of the blocks were measured to determine the optimum installation configuration. Upon completion of construction, we performed reflected sound measurement on site and confirmed that proper acoustic conditions were realized. In addition, to reveal the mechanism of the acoustic absorption, we conducted the computer simulation based on the finite element method. The results of the simulation are also introduced in this paper.

---

[1] kimiko.nakagawa@music.yamaha.com
[2] hideo.miyazaki@music.yamaha.com
[3] toyoda@kansai-u.ac.jp

Table 1 – Outline of the facility

Name	The Nishiwaki Community Hall “Orinas”
Location	128-1 Shimotoda, Nishiwaki, Hyogo, Japan
Rooms	Multipurpose hall, studios (10), lounge, coffee shop, terrace, etc.
Client	Nishiwaki City
Design	Showa Sekkei Inc.
Acoustical Design	Yamaha Spatial Audio Group
Constructor	Dai Nippon Construction
Structure	Steel structure (partially, RC and SRC)
Construction period	September 2019 – March 2021

2. DESIGN CONCEPT

The hall was requested by the client, Nishiwaki City, to fulfill various civic activities, not only activities that were held at the old civic center, such as music concerts, plays, and lectures, but also calligraphy exhibitions, art exhibitions, and so on. Therefore, movable seats were installed to accommodate various audiences and stage configurations according to performance styles, which include two main formats: a stage viewing format with a stepped floor and seats, and a flat floor format without seats. In addition, the configuration of the various equipment has been simplified with consideration of a use case by a small number of residents. Thus, the hall can be used for multiple purposes and it is designed to be easy to use by residents.

A plan and section of the hall and specifications are shown in Figure 1. A summary of the acoustical design concepts is shown in Figure 2.

Among the various uses, design for acoustical instruments was considered to be most important. In order to achieve sufficient air volume to create a rich resonance for classical music performances, a general ceiling interior was not installed and a large volume above the ceiling was secured, resulting in air volume of 13.1 m^3 per seat. In addition, for sufficient loudness and clarity of sound, reflectors above the front audience area were installed to provide early reflections continuously from the stage ceiling reflectors. Other reflectors under the catwalks exposed above the audience area were also installed to provide the early reflections from above.

These exposed catwalks can be utilized for various performances by hanging various equipment. Sufficient reverberation time range is achieved due to large absorption inside the stage fly. For these reasons, this configuration can be used for multiple purposes.

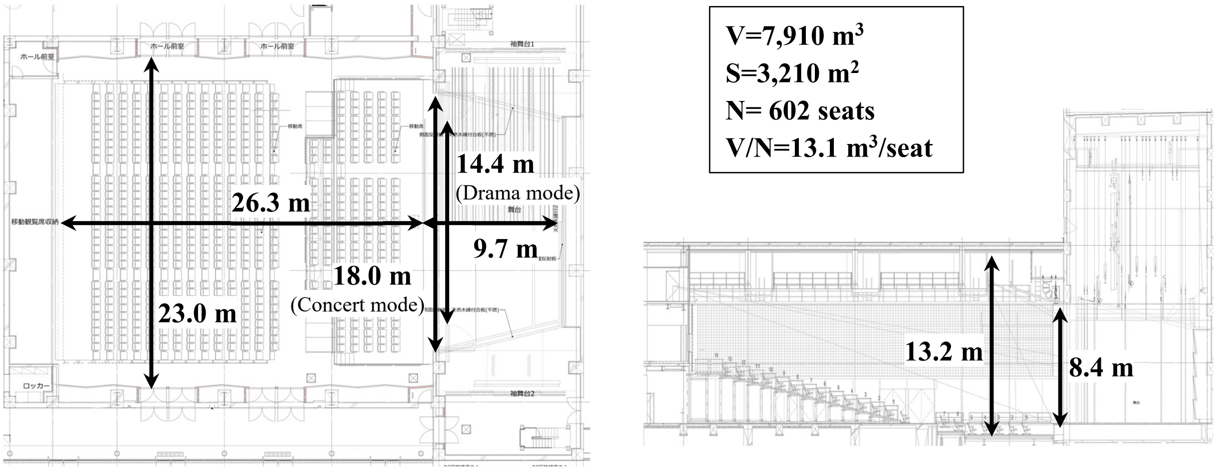
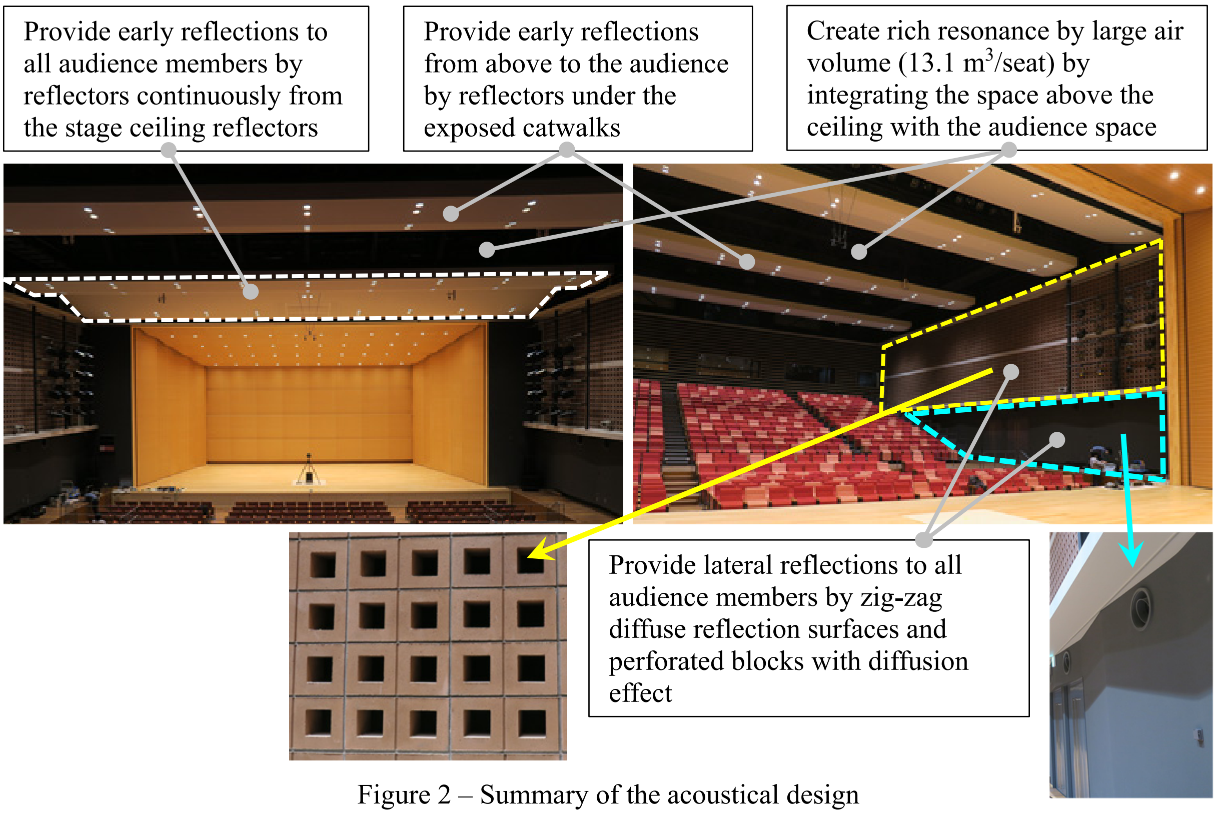


Figure 1 – Plan and section of the hall



Provide early reflections to all audience members by reflectors continuously from the stage ceiling reflectors

Provide early reflections from above to the audience by reflectors under the exposed catwalks

Create rich resonance by large air volume (13.1 m^3/seat) by integrating the space above the ceiling with the audience space

Provide lateral reflections to all audience members by zig-zag diffuse reflection surfaces and perforated blocks with diffusion effect

Figure 2 – Summary of the acoustical design

Securing the spatial effect required for classical music performance was also an important requirement. To ensure lateral reflections for all audience members, the lower part of the side walls have zig-zag diffuse reflection surfaces and acoustical eaves. Further, the upper part of the side walls was expected to have a diffusion effect in the design stage. On the other hand, the architectural designer had as the design concept the creation of a hall imbued with calmness and warmth and a special place where audiences can feel a sense of elation. To achieve both the diffusion effect and the design concept, it was decided to install stacking perforated blocks, which is a characteristic design (the part shown in yellow in Figure 2). Out of concern about acoustic phenomena arising from the uniformly sized and equidistant holes forming a line grid, we conducted detailed studies in the construction stage. The findings are introduced in detail in the next chapter.

3. STUDY OF THE ACOUSTIC CHARACTERISTICS OF PERFORATED BLOCKS

3.1 Summary

The details of a “perforated block” (hereafter, block) are shown in Figure 3. By stacking these blocks, 100 mm square holes are configured in vertical and horizontal lines at equidistant intervals, the perforation ratio of the surface is about 25%. Due to the weight and perforated shape of the block itself, it was expected to be effective as a diffusing element. On the other hand, we were concerned that it would become a Helmholtz resonator that absorbs specific frequencies like a perforated panel. Thus, in the design stage, the blocks were placed close to the walls.

However, as we had never used such shape elements, there was the risk of unexpected acoustic characteristics. Therefore, to clarify the acoustic characteristics, we made a mockup and studied its acoustic characteristics in the construction stage.

3.2 Acoustical Study in the Construction Stage

In the construction stage, we made a side wall mockup of 10 m^2 by arranging 126 blocks on gypsum boards, and we measured the sound absorption coefficients in a reverberation chamber. Measurement was done in three patterns, (1) Design specification: “with no air space” between blocks and boards, (2) Considering construction accuracy: “with 10 mm air space”, and (3) Large air space: “with 300 mm air space”. The experiment photo is shown in Figure 4, the measurement results are shown in Figure 5. Only in patterns (1) and (2), large peaks of sound absorption coefficient (about 0.6) were

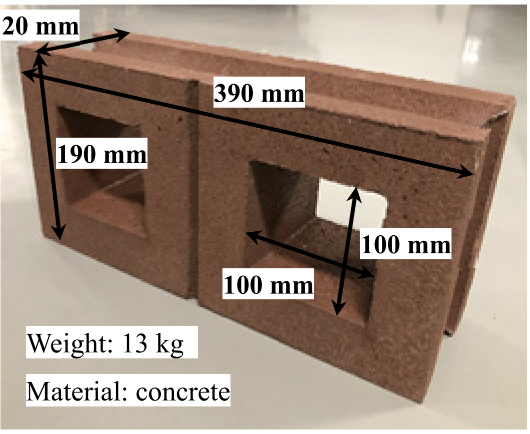


Figure 3 – Detail of "perforated block"

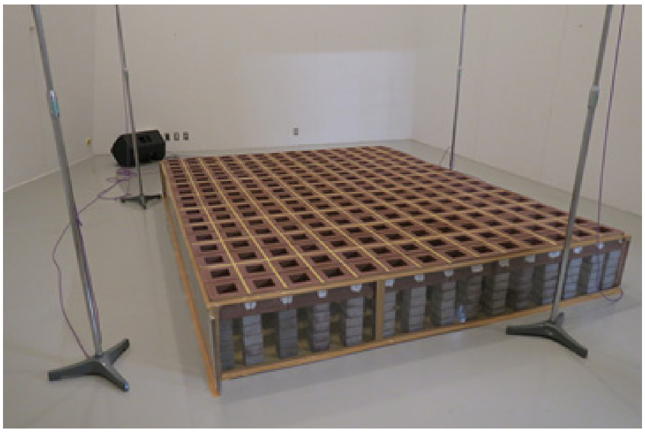


Figure 4 – Experiment photo (pattern (3))

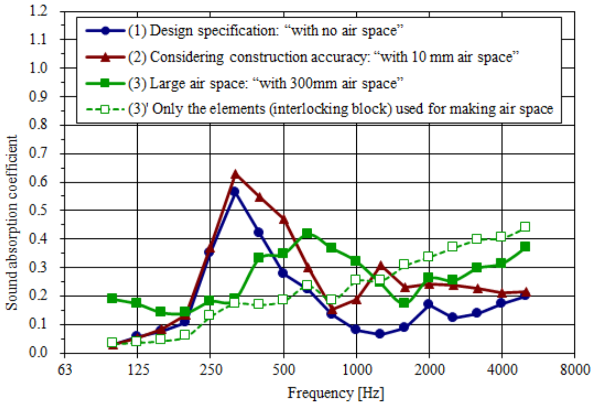


Figure 5 – Measurement results: patterns (1) – (3)

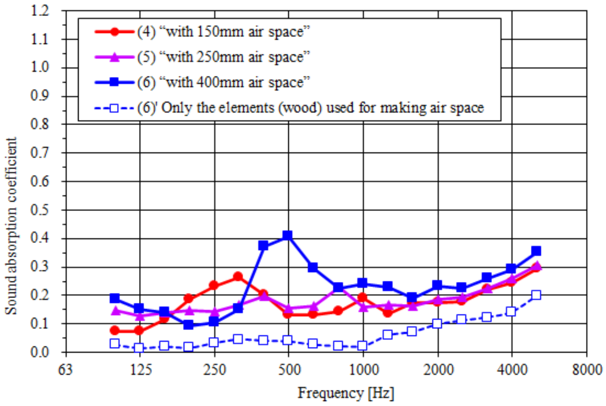


Figure 6 – Measurement results: pattern (4) – (6)

seen around 315 Hz. These results indicate that the specification of boards closely behind the blocks entails the risk of absorption at a certain frequency. In addition, the result of pattern (3) suggested that the peak of the absorption may become smaller and the peak frequency may shift by large air space. There is a possibility that the sound absorption coefficient of the high frequencies above 1 kHz is affected by the absorption itself of the elements (interlocking blocks) used for making air space.

Based on these results, in order to study the effect of the depth of air space, we performed measurements in three additional patterns, (4) "with 150 mm air space", (5) "with 250 mm air space", and (6) "with 400 mm air space". The elements used for making air space were changed to wood with low absorption. The measurement results are shown in Figure 6. In patterns (4) and (5), no large peaks of absorption were seen, and sound absorption coefficients ranged from 0.1 to 0.3 at all frequencies. In pattern (6), a peak of sound absorption coefficient (about 0.4) was seen around 500 Hz, and the peak was smaller than the peaks in patterns (1) and (2). At above 1 kHz, there is a possibility that the sound absorption coefficient of the block seems to be slightly larger due to the effect of the absorption itself of the elements (wood) used for making air space.

The results of this series of experiments indicated that with no or very small air space, there are large peaks of absorption coefficient at certain frequencies, and with 150–400 mm air space, the frequencies and degrees of the peaks of sound absorption coefficient depend on the depth of air space. Therefore, we decided to change the depth of the air space in order to eliminate the bias of sound absorption coefficient by frequency. Finally, different air spaces in the range of 150–300 mm were selected by tilting the walls behind the perforated blocks (Figure 7). In addition, after reviewing the sound absorption coefficient, the reverberation time calculation was performed again. Based on the calculation results, we adjusted reverberation by removing the GW on the rear wall and not installing acoustic curtains around the catwalks area.

3.3 Measurement of a Reflection Sound on Site

In order to confirm the acoustic characteristics on site, the primary reflection sound from the block wall was measured after the completion of construction. The positions of the sound source and the measurement points are shown in Figure 7. The sound source was placed at a position without ceiling

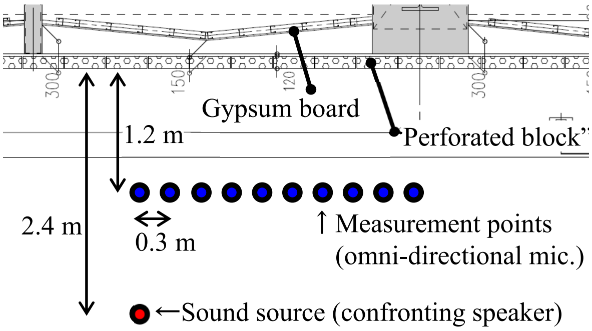


Figure 7 – Positions of the sound source and measurement points

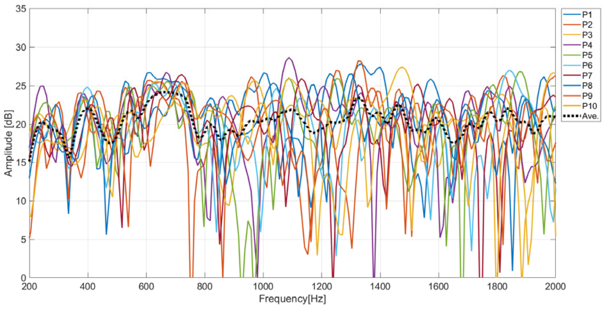


Figure 8 – Frequency characteristics of primary reflection

reflectors to eliminate the influence of reflection from the ceiling, and a total of 10 measurement points were set at intervals of 0.3 m from the front of the sound source. The impulse response was measured at each measurement point, and the primary reflection from the block wall was cut out and analyzed for frequency characteristics in the range from 200 Hz to 2 kHz.

The frequency characteristics of each point and the average of 10 points are shown in Figure 8. Although peaks and dips are seen at each measurement point, each frequency is different, and no particular peaks or dips are seen from the results of average energy.

The results of these measurements indicated that the peculiar characteristics of sound absorption at certain frequencies can be avoided, and the blocks provide proper sound diffusion.

3.4 Verification of Acoustic Characteristics by Wave Acoustic Analysis

The presence of large peaks of sound absorption coefficient around 315 Hz with no or very small air space cannot be explained because the frequency does not match with the air column resonance absorption by the block holes. In the future, in order to avoid the risk of interior materials having such special acoustical characteristics, we thought that it is necessary to elucidate the mechanism of this sound absorption. To this end, we conducted computer simulation based on the finite element method. Commercial analysis software (COMSOL) was used as the simulation software.

First, we made a 3D model of half of the block, with a hole of 100 mm square and 120 mm depth, and calculated the normal incidence absorption coefficient and the random incidence absorption coefficient, with no air space behind the block. An overview of the 3D model 1 is shown in Figure 9, and the results are shown in Figure 10. In both incidence patterns, the peaks of sound absorption coefficient were seen around 600 Hz. The frequency of the peak did not match the experiment results. Since the air column resonance frequency is 709 Hz without considering the end correction, the peaks around 600 Hz seen in these simulations are considered to be due to the air column resonance.

Next, we calculated the same patterns as the experiment, with 10 mm, 150 mm, 250 mm, 300 mm, and 400 mm air space behind the block. The results are shown in Figure 11. The large peak of the sound absorption coefficient was seen around 500 Hz with 10 mm air space, but the peak frequency did not match the experiment results. In addition, it was indicated that the peak of the sound absorption coefficient becomes smaller and the peak frequency shifts to lower frequencies as the depth of the air space becomes larger. These results of simulation indicate that the cause of the peak of absorption around 315 Hz is not a hole of 100 mm square and 120 mm depth.

Then, we observed the shape of the block again and considered the possibility that a Helmholtz resonator is formed by the gaps between the blocks and the hollows on the side of the blocks (Figure 12). We made a 3D model with a gap of 1 mm between the blocks, and calculated the normal incidence absorption coefficient and the random incidence absorption coefficient, with no air space behind the block. Thermoviscous acoustics was used to consider sound absorption by viscous friction of Helmholtz resonance. An overview of the 3D model 2 is shown in Figure 13, and the results are shown in Figure 14. The large peaks of sound absorption coefficient were seen around 350 Hz in the normal incidence pattern, and around 250 Hz in the random incidence pattern. These frequencies are close to the experiment results (around 315 Hz). Therefore, the cause of the large peak of sound absorption observed in the experiment is considered to be the absorption by the Helmholtz resonator formed by the gaps and hollows between the blocks. In the experiment, the gaps between the blocks were covered with masking tape to prevent air from entering and exiting, but it is considered that the effect was insufficient. On the other hand, since the gaps and hollows between the blocks are actually filled with mortar, it is considered that Helmholtz resonance does not occur on site.

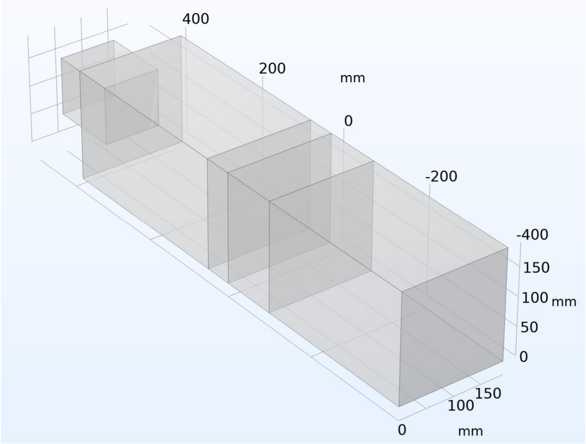


Figure 9 – Overview of the 3D model 1 (Hole of 100 mm square and 120 mm depth)

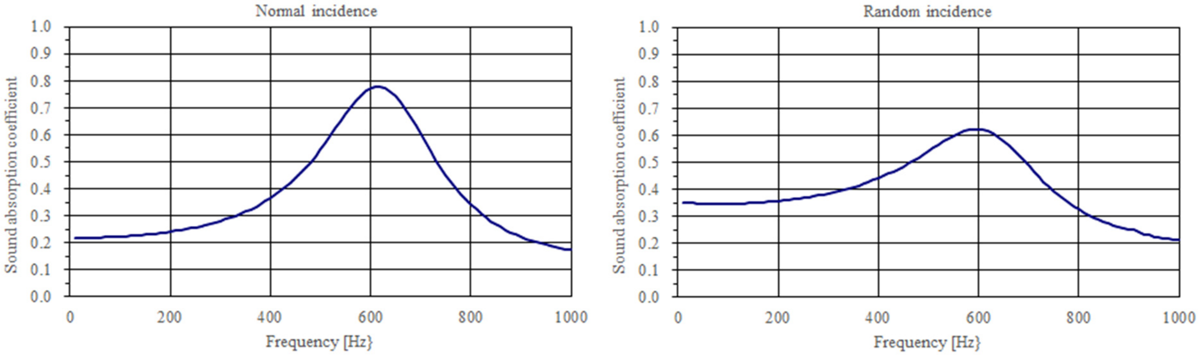


Figure 10 – Simulation results with no air space: 3D model 1

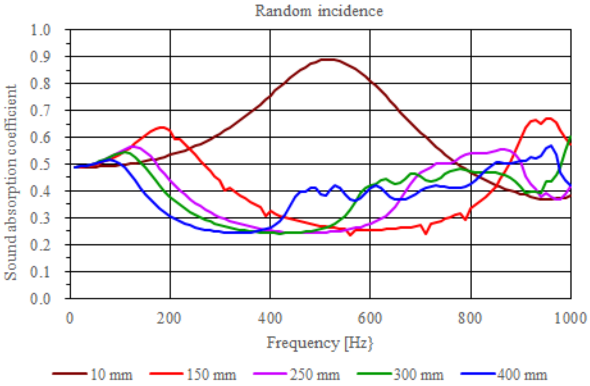


Figure 11 – Simulation results with air space: 3D model 1

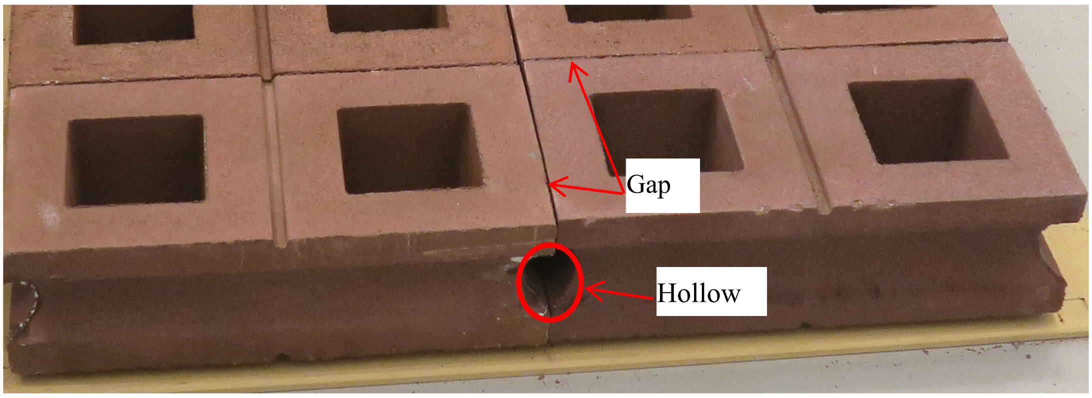


Figure 12 – Gaps and hollows between the blocks in the experiments

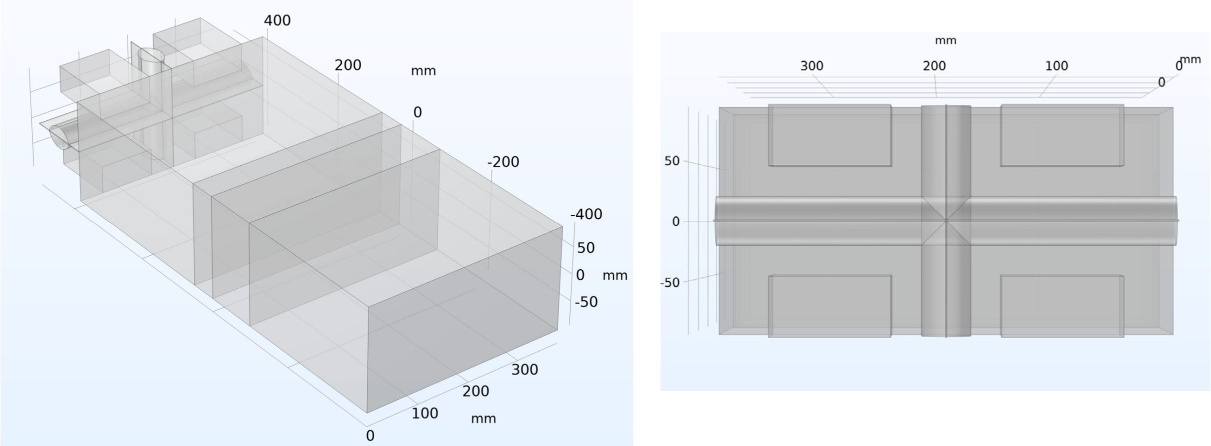


Figure 13 – Overview of the 3D model 2 (Gaps and hollows between the blocks)

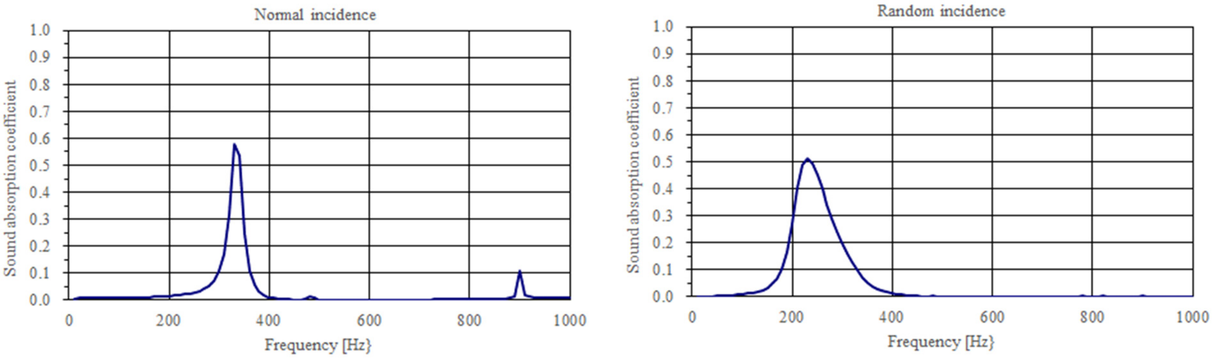


Figure 14 – Simulation results with no air space: 3D model 2

4. MEASUREMENT RESULTS OF THE HALL

The measurement results of the hall are shown in Figures 15, 16, 17.

In the concert mode, the reverberation time was 1.8 seconds (average in the midrange (250–2 kHz), unoccupied, same hereafter), and the average absorption coefficient was 0.20. These results satisfy the design target values, and sufficient reverberation is achieved. The frequency characteristics are flat in the midrange, resulting in a well-balanced acoustic condition. The value of J_{LF} (23%, average in the range of 500–2 kHz) is large, and a sufficient spatial impression is achieved.

In the drama mode, the reverberation time was 1.4 seconds, and the average absorption coefficient was 0.24. These results satisfy the design target values, and sufficient reverberation time range is achieved. The value of D_{50} (59%, average in the range of 500–2 kHz) is large enough, and speech intelligibility without using the sound system is achieved sufficiently. The value of STI (0.63) using the sound system is “good”, and it is possible to amplify speech clearly.

After the completion of construction, we confirmed the acoustic of the hall by playing instruments (violin and cello). Both instruments produced a clear and rich resonance, and thus a proper acoustic condition for playing acoustical instruments was realized. In addition, the lateral reflection sound gave a soft impression without glare, which is attributed to the diffusion effect of the perforated blocks.

5. CONCLUSIONS

Through the acoustical design of Orinas Hall, we confirmed the risks of using special interior material in the hall, as well as the importance of conducting a series of acoustic studies from the design stage to the construction stage. The acoustic characteristics of perforated blocks were revealed by experiments using mockups in the construction stage, measurements of the reflection sound on site, and wave acoustic analysis.

Finally, a good acoustic condition was achieved by acoustic adjustment in the construction stage.

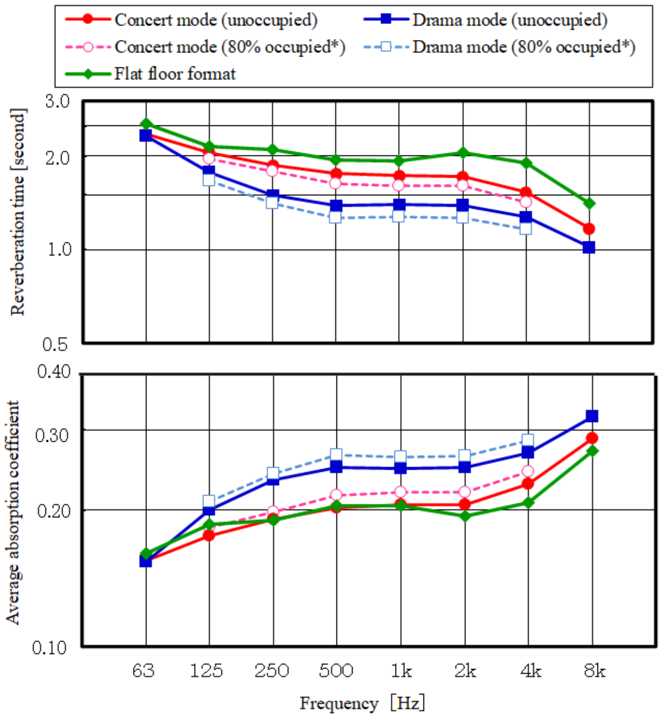


Figure 15 – Reverberation time and average absorption coefficient of the hall

*: Values of 80% occupied are calculated

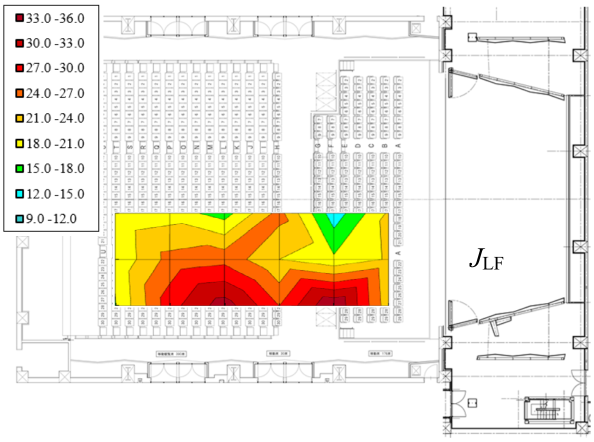


Figure 16 – Distribution of J_{LF} (average in the range of 500–2 kHz)

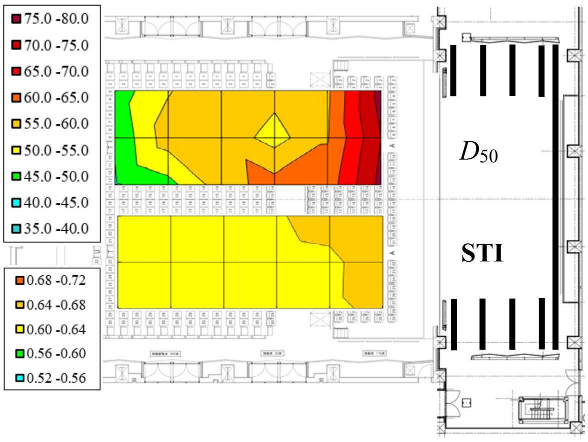


Figure 17 – Distribution of D_{50} (average in the range of 500–2 kHz) and STI

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to all the designers and all the constructors involved in this project.