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# Effect of sample size on measurement of the absorption by seats

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## ABSTRACT

This study deals with measurements of the sound absorption by seats which are one of the important parameters in the early design stage in auditorium. In this study, the effects of sample size on measurement of the sound absorption by seats are investigated to define an optimum range of sample size for obtaining reliable measurement results. In the measurements, the absorption coefficients of unoccupied seats at a scale of 1/16 are measured in a 1/5 scale-model of the reverberation chamber based on ISO 354. Various seating blocks having 9 different P/A (perimeter/area of the sample) values ranged from 0.4 to 1.37 $m^{-1}$ were measured to extrapolate to the absorption coefficients of the larger seating blocks found in a real hall. The predicted results from reverberation chamber measurements were then compared to the measured values in a 1/16 scale-model of the real hall for the validation of this method. The present results show good agreement between values obtained from the hall measurements and those predicted from reverberation chamber measurements.

## INTRODUCTION

It has been known that sample size influences the measured sound absorption coefficients in a reverberation chamber [1-3]. This is mainly caused by the additional absorption and diffraction effects from the exposed edges of the samples. For this reason, ISO 354 [4] suggests the use of screens around the edges of the sample for measuring the sound absorption. For measuring the seating absorption, a smaller seating block with a few rows of seats is installed in a reverberation chamber. This arrangement tends to overestimate the absorption of the exposed edges of the seating block compared to the larger blocks found in a real hall. To overcome the drawbacks of reverberation chamber measurements, the effects of various-sized samples on measurement of the sound absorption by seats and audience have been investigated in reduced-scale [1, 5] and full-scale [3, 6-9] of reverberation chambers.

Two methods [3, 6-8] for measuring the absorption coefficients of seats have been proposed. The first method was proposed by Kath and Kuhl [7] and they used screens around the seating block to eliminate the sound absorption by the exposed edges of seats. This method was further investigated by Davies et al. [8]. Davies et al. showed that the results obtained using the screens around the seating block were reliable to compare with real hall measurements, but found that the screens could lead to an increase in low-frequency sound absorption. Hegvold [1] and Bradley [3] found that even with screens around the edges, the absorption coefficients of the seating block varied with various-sized samples.

The second method was proposed by Bradley [3, 6]. He proposed to measure the absorption coefficients of various-sized seating blocks having different P/A values and showed that the absorption coefficients of the seating blocks were linearly related to the P/A value.

$$\alpha=\beta\,(P/A)+\alpha_{\infty} \tag{1}$$

where $\alpha$ is the sound absorption coefficient of a finite sample, $\beta$ is the regression constant, $P/A$ is the perimeter/area of the sample, and $\alpha_{\infty}$ is the absorption coefficients of an infinite sample. If $\alpha$ is measured for various-sized samples having different P/A values, a linear regression line is fitted to the data and this is extrapolated to a P/A value of 0 $m^{-1}$ corresponding to a sample of infinite area. This method could be used for seats with the edges either exposed or screened.

One of the advantages for measuring the sound absorption by seats in a scale-model is that the larger blocks of seats typically found in real auditoria can be measured. Barron and Coleman [5] examined the perimeter/area method proposed by Bradley [3, 6] for measuring the absorption coefficients of the seating blocks with P/A values ranged from 0.4 to 2.4 $m^{-1}$ (200 seats in total) using a 1/25 scale-model seating. They found that the P/A method was useful for measuring the seating absorption in a reverberation chamber. They also compared the results obtained from the P/A method with those from the screen method by Davies et al. [8] for measuring $\alpha_{\infty}$ and showed that the screen method appeared to overestimate $\alpha_{\infty}$ at all frequencies.

The present study deals with the sound absorption by scale-model seating at the scale of 1/16 as measured in a 1/5 scale-model of the reverberation chamber. The 1/16 scale-model seating was chosen to measure a large number of seating blocks. Tahara and Shimoda [9] demonstrated the effectiveness of using a 1/16 scale-model for room acoustics measurements. A 1/16 scale-model has advantages in observing the physical acoustical parameters at all frequencies from 125 Hz to 4000 Hz and the model size is only 62.5% of the 1/10 scale-model. In this work, firstly the effects of sample size on measurement of the sound absorption by seats were investigated by using the P/A method. The results were then compared with those obtained from the scale-model of a real hall.

## MEASUREMENTS

### Reverberation chamber measurements

A 1/5 scale-model of the reverberation chamber was used for the measurements of the sound absorption by seats. The volume of the reverberation chamber was 1.98 $m^3$ (247.5 $m^3$ in full-scale). The reverberation chamber was built using 20-mm-thick acrylic panels. Figure 1 shows the 1/5 scale-model of a reverberation chamber. Prior to the measurements, the diffusivity of the sound field in the reverberation room was examined according to ISO 354 [4]. A total of 16 diffusers (1.5-mm-thick acryl panels) ranging from 0.8 m² to 5 m² in area, which corresponds to the total surface area of 35 m² (full-scale), were installed on the ceilings and side walls of the reverberation chamber; this was found to be the optimum number of diffusers. As a result, measurements in the corresponding full-scale frequency bands from 125 Hz to 4 kHz were reliable.

In the measurements, a 1.37-s logarithmic sweep from 2 kHz to 100 kHz was used, which corresponds to full-scale frequencies from 125 Hz to 6.3 kHz. The compensation of air absorption in the reverberation chamber was dealt with by substituting the air with nitrogen. The reverberation chamber was kept at a constant temperature of 23 ℃ and a relative humidity of 4%. Table 1 presents the equipment used in the measurements. Six combinations of two source positions and three receiver positions were selected for measuring the absorption coefficients of unoccupied seats. A repeatability test of measurements for the absorption coefficient of seats was carried out to check whether the results were consistent for each measurement. The standard deviations after nine measurements showed that the repeatability of the measurements was considered reliable in the corresponding full-scale frequency bands from 125 Hz to 4 kHz. For this reason, the measurements were repeated three times, and the results were presented as the mean absorption coefficient with its standard deviation.

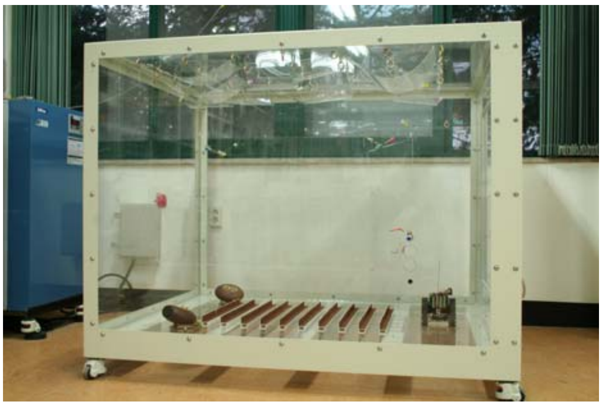

**Figure 1.** A 1/5 scale-model of the reverberation chamber (width: 1.2 m, length: 1.5 m, height: 1.1 m).

Figure 2 shows the 1/16 scale-model of the two seat types (refers to as type-A and-B). The seat was constructed as 175 mm long benches (2.8 m in full-scale), which is equivalent to the size of four seats. The absorption characteristics of type-A and-B seats were varied by adding a single layer of 1-mm-thick felt on the seat and back surfaces. The absorption coefficients of the materials used for the seat construction were measured and plotted in Figure 3. The samples with the edges exposed were measured. The sample size tested was 69.12 $m^2$ (full-scale) and this gave a P/A value of 0.49 $m^{-1}$.

**Table 1.** Measurement equipments used in this study.

| Equipment | Manufacturer | Model |
|---|---|---|
| Loudspeaker | TANNOY | Prestige super tweeter ST200 |
| Loudspeaker Amp. | MARANTZ | Integrated amplifier PM-11S1 |
| Microphone | G.R.A.S | 1/8-inch pressure microphone 40DP |
| Microphone Amp. | B&K | NEXUS conditioning amplifier Type 2690 |
| Sound card | LYNX | LYNX TWO |
| Measurement software | B&K | Dirac V.4.1 |
| Nitrogen generator | CELLFA | CN-M15-04 |
| Thermo-hydrometer | VAISALA | Measurement indicator MI70 |

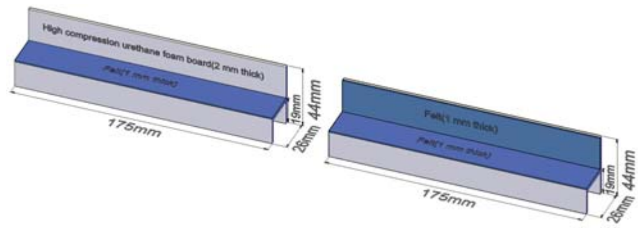


**Figure 2.** A 1/16 scale-model of the two types of seats (left: type-A, right: type-B).

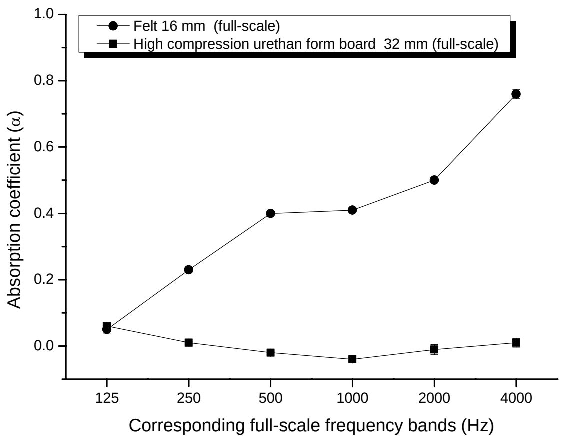


**Figure 3.** Absorption coefficients of materials used for the seat construction, measured with the edges exposed.

6 to 120 seats were arranged in various-sized samples with a row-to-row spacing of 0.90 m (full-scale). The floor area did not include the row-to-row space in front of the first low. The measurements were carried out with the seat edges exposed and the absorption coefficients were calculated using the floor area occupied by the seats. A total of 9 seating configurations were used to give various-sized samples having different P/A values. The seating blocks with the P/A values from 0.4 to 1.37 $m^{-1}$ were measured. The P/A values tested are representative of the larger seating blocks typically found in real auditoria: seating blocks in auditoria have the P/A values of 0.5~1.0 $m^{-1}$ [6]. Table 2 presents 9 seating configurations used in the reverberation chamber measurements along with the number of seats and P/A values. Figure 4 shows an example of the seating configurations.

**Table 2.** 9 seating configurations used in the reverberation chamber measurements.

| Seating configuration | Number of seats | P/A ($m^{-1}$) |
|---|---|---|
| 3r_1bw* | 12 | 1.37 |
| 5r_1bw | 20 | 1.07 |
| 7r_1bw | 28 | 0.96 |
| 9r_1bw | 36 | 0.90 |
| 11r_1bw | 44 | 0.86 |
| 5r_2bw | 40 | 0.71 |
| 7r_2bw | 56 | 0.60 |
| 8r_3bw | 96 | 0.45 |
| 10r_3bw | 120 | 0.40 |

*Note that 3r_1bw indicates the seating configuration for a single block of 3 rows, 1 bench wide.

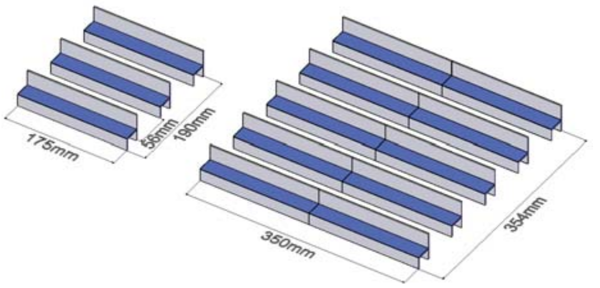


**Figure 4.** Seating configurations for a single block of 3 rows, 1 bench wide (left) and a single block of 5 rows, 2 benches wide (right).

### Hall measurements

A 1/16 scale-model of a recital hall was used for measuring the absorption coefficients of the larger seating blocks. Figure 5 shows the 1/16 scale-model of the hall. The hall was constructed using 15-mm-thick varnished MDF panels. Various sized diffuser panels made using 1.5-mm-thick acryl panels were installed on the walls to prevent flutter echoes. The porous absorbers (5-mm-thick polyester fibres) were installed on the ceiling. Table 3 presents the details of the hall. In the hall measurements, a single seating block of 10 rows, 5 benches wide with a row-to-row spacing of 0.90 m (full-scale) was used. This seating block gave a P/A value of 0.35 $m^{-1}$.

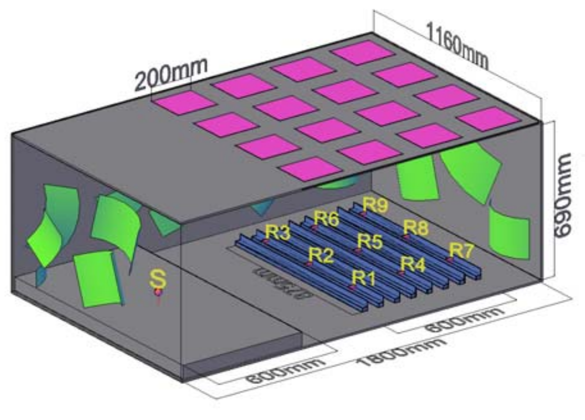


**Figure 5.** A 1/16 scale-model of a hall (S: source, R: receiver).

**Table 3.** Details of the real hall.

| Volume ($m^3$) | Number of seats | P/A ($m^{-1}$) | Rake angle (°) |
|---|---|---|---|
| 5,810 | 160 | 0.35 | 0 |

Reverberation times were measured both with and without the seats in place. Measurements were made at nine locations in the hall for unoccupied conditions. One centre source position was used. The measurements were repeated in three times. The hall was kept at a constant temperature of 23 ℃ and a relative humidity of 40% during the measurements. The compensation of air absorption in the hall was dealt with by applying a numerical method [9]. Figure 6 shows the measured reverberation times both with and without the seats present in the hall. The same equipments were used in the real hall measurements, except for the source (2cm tune-up tweeter SRH290, ADDZEST).

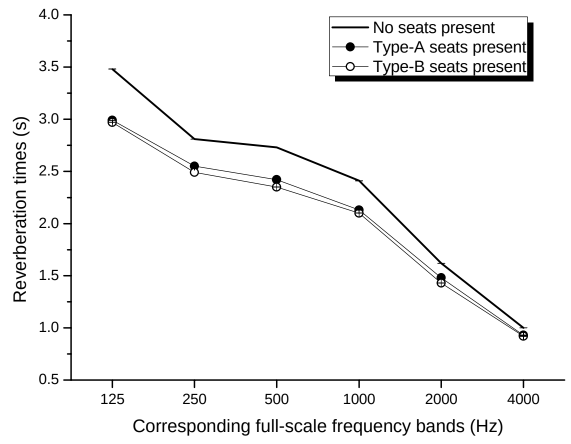


**Figure 6.** The measured reverberation times both with and without the seats present in the hall.

## RESULTS

### The effect of sample size on the measured absorption coefficients of seats

The absorption coefficients for seating blocks of various sizes were measured in the reverberation chamber to determine the effect of sample size on the measured absorption coefficients of the seats. Figures 7 and 8 show the absorption coefficients of unoccupied seats measured with the seating blocks having 9 different P/A values. The results show that type-B seats had slightly higher absorption coefficients than type-A seats. Figure 7 clearly shows that the absorption coefficients of type-A seats varied with sample P/A value and smaller samples with larger P/A values had larger absorption coefficients than larger samples with smaller P/A value. This seems to be obvious at higher frequencies. Figure 8 suggests that the sample P/A has a significant effect on the measured absorption coefficients. As mentioned previously, the variations of the absorption coefficients of seats with P/A value are mainly caused by diffraction effects and the additional absorption of the edges of the small seating blocks.

In Figures 9 and 10, the measured absorption coefficients of seats A and B were plotted as a function of nine different P/A values. A linear regression line was fitted to the data to extrapolate to the P/A value of 0 $m^{-1}$, which corresponds to a sample of infinite area. Table 4 presents the regression coefficients and their standard errors. Figure 9 shows that the absorption coefficients of type-A seats are approximately linearly related to the P/A values and there is a large variation of absorption coefficient at higher frequencies. The results in Figure 10 indicate that the absorption coefficients of type-B seats are varied with the P/A values but interestingly, the absorption coefficients at 1000 Hz are inversely related to the P/A values; smaller samples have smaller absorption coefficients. The variations of the absorption coefficients of type-B seats by varying P/A value are relatively smaller than those measured for less absorptive type-A seats. In Table 4, the results indicate that the slopes ($\beta$) vary with frequency and the absorption characteristics of the seats.

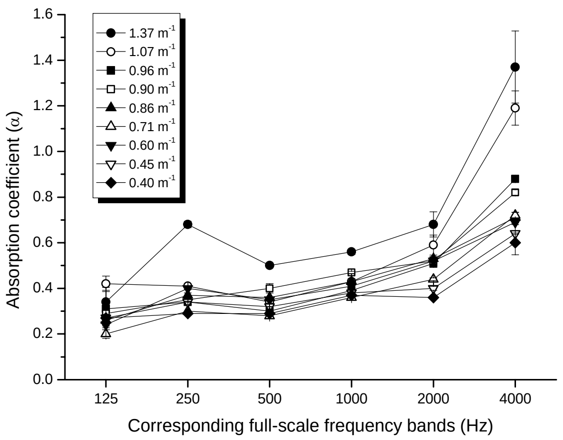


**Figure 7.** Absorption coefficients of type-A seats, measured with nine different P/A values.

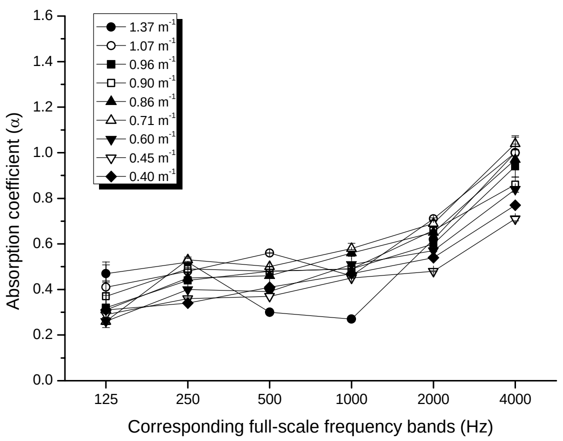


**Figure 8.** Absorption coefficients of type-B seats, measured with nine different P/A values.

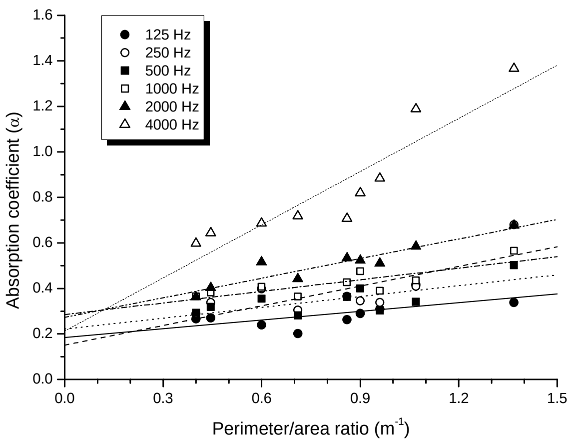


**Figure 9.** Absorption coefficients as a function of nine different P/A values for type-A seats.

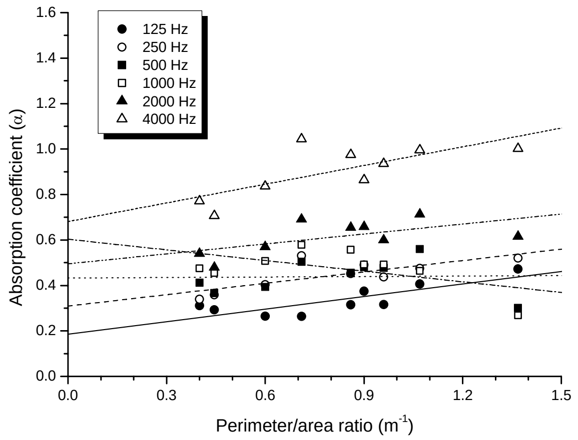


**Figure 10.** Absorption coefficients as a function of nine different P/A values for type-B seats.

**Table 4.** Regression coefficients and their standard errors for type-A and-B seats, edge exposed.

| Frequency (Hz) | β | S.E. | $\alpha_\infty$ | S.E. |
|---|---|---|---|---|
| Type A | | | | |
| 125 | 0.127 | 0.058 | 0.185 | 0.050 |
| 250 | 0.288 | 0.092 | 0.151 | 0.080 |
| 500 | 0.159 | 0.058 | 0.221 | 0.050 |
| 1000 | 0.169 | 0.045 | 0.290 | 0.039 |
| 2000 | 0.287 | 0.040 | 0.273 | 0.035 |
| 4000 | 0.779 | 0.128 | 0.213 | 0.111 |
| Type B | | | | |
| 125 | 0.184 | 0.048 | 0.185 | 0.041 |
| 250 | 0.167 | 0.053 | 0.309 | 0.046 |
| 500 | 0.007 | 0.096 | 0.433 | 0.083 |
| 1000 | -0.156 | 0.090 | 0.603 | 0.078 |
| 2000 | 0.146 | 0.073 | 0.495 | 0.063 |
| 4000 | 0.274 | 0.096 | 0.680 | 0.083 |

The effectiveness of using screens for eliminating the sound absorption by the exposed edges of seats was investigated for a particular seating block. The absorption coefficients of a single seating block of 8 rows, 3 benches wides were measured both with and without screens around the edges. This seating block gave a P/A value of 0.45 $m^{-1}$. The screens were constructed using 2-mm-thick acryl panels. The height of screens was 56 mm (0.9 m in full-scale) as was both used by Davies et al. [8] and Barron [5]. To eliminate the sound absorption by screens, the reverberation times without the seats present were measured while the screens were in place.

Figures 11 and 12 compares the absorption coefficients of the seating block measured with the edges either being exposed or screened. The variations of the seating absorption coefficients are larger for type-A seats than those values for more absorbent type-B seats and at higher frequencies. No increase of the seating absorption coefficients with the edges screened at lower frequencies was found in the present results. It has been found that the use of screens for eliminating the edge absorption was not successful at lower frequencies [3, 5]. Further, it is known that even with the screens the sample size influences the seat absorption [1, 3, 5]. The verification of this method using various-sized samples was not carried out in the present study.

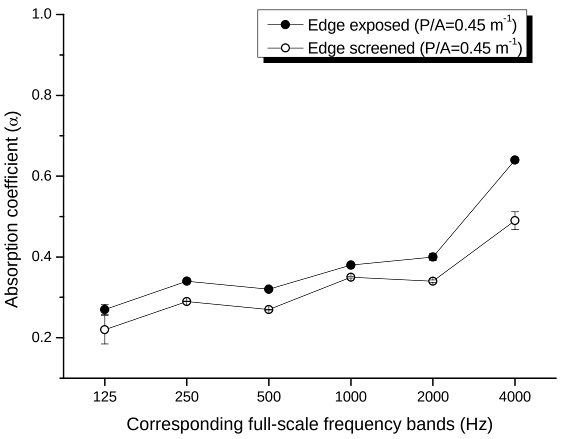


**Figure 11.** Absorption coefficients for type-A seats, measured with the edges both exposed and screened.

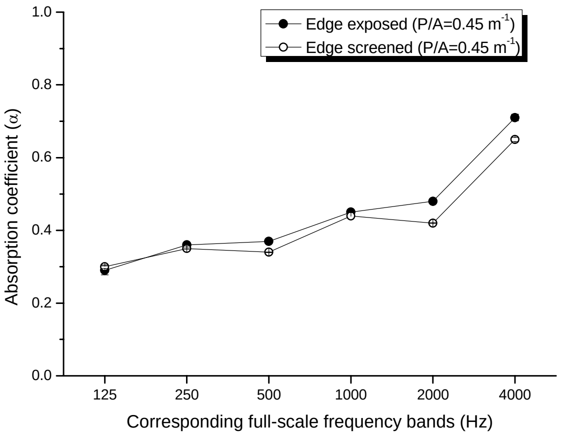


**Figure 12.** Absorption coefficients for type-B seats, measured with the edges both exposed and screened.

### Comparisons with the real hall measurements

The absorption coefficients of the larger seating block in the hall were compared with those predicted from reverberation chamber measurements with various-sized samples having different P/A values to verify the reliability of this method. Figures 13 and 14 show the absorption coefficients measured in the hall with those predicted from reverberation chamber measurements for the seating block (P/A =0.35 $m^{-1}$) with the edges exposed. For type-A seats, the results in Figure 13 show good agreement between values obtained from the hall measurements and those predicted from reverberation chamber measurements. The differences are less than 0.05 in the frequency bands from 250 Hz to 4000 Hz, except for the value at 125 Hz. In Figure 14, the absorption coefficients for type-B seats measured in the hall are in good agreement with the predicted values from reverberation chamber measurements at 250 Hz, 500 Hz and 2000 Hz. Some discrepancies are found for the predicted values at 1000 Hz and 4000 Hz but the differences with the measured values are less than 0.13. For type-B seats, the measured values in the hall are slightly lower than the values predicted from the reverberation chamber.

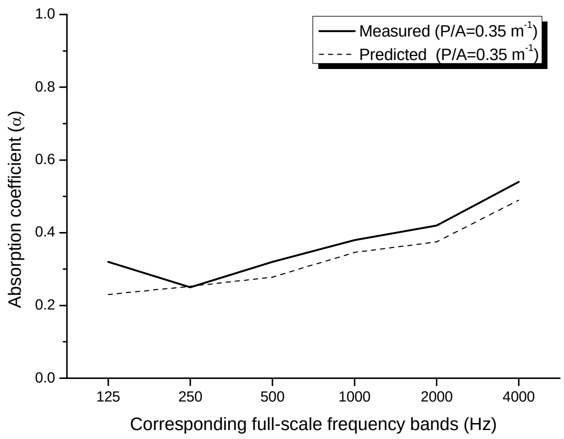


**Figure 13.** Absorption coefficients for type-A seats, measured in the hall and predicted from reverberation chamber measurements for the seating block (P/A=0.35 $m^{-1}$).

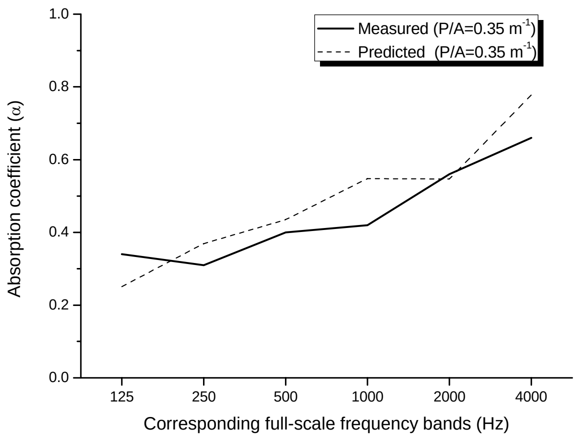


**Figure 14.** Absorption coefficients for type-B seats, measured in the hall and predicted from reverberation chamber measurements for the seating block (P/A=0.35 $m^{-1}$).

## CONCLUSIONS

In general, the preset results show reasonable agreement between the measured and predicted absorption coefficients of the seating block in a scale model. Barron and Coleman [5] showed that the P/A method is appropriate for the measurement of seating absorption in a scale-model of the reverberation chamber but the validation of the results in real auditoria was not carried out. The application of a scale-model for the measurement of the seating absorption is appropriate to measure a larger seating block in real auditoria. Further, the verification process in a scale-model of real auditoria demonstrates that the predicted results from the scale-model of reverberation chamber measurements are reliable and this procedure can be more easily assessed in a scale-model.

Further study needs to be carried out with various seating models having different structure and absorption characteristics. Various seating block configurations that are applied in real auditoria should be investigated. A more complex scale-model of real auditoria needs to be used for the verification process.

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