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REVERBERATION TIME OF WROCŁAW OPERA HOUSE AFTER RESTORATION

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One of the main acoustic goals set prior to restoration work on the Wrocław Opera House in 1997 was to increase the auditorium's reverberation time. Now, after the completion of the restoration work, comprehensive acoustic investigations of the Opera House, including reverberation time, were carried out. Measurements were performed in accordance with the ISO 3382.

The reverberation time measurement results were analysed with regard to the absorption coefficient of seats. After the seats were installed, the effect of acoustic coupling with the stage and also the position of the orchestra pit's movable floor was investigated.

The effect of the location of a sound source (on the stage and in the open and covered part of the orchestra pit) on reverberation time was examined. The differences in reverberation time between the measurement locations were compared with the differences in reverberation time between the sound source locations.

The current and pre-restoration reverberation time values were compared. It was found that the acoustic goal set for the restoration of the Opera House was achieved.

Key words: opera house, reverberation time, restoration, absorption.

1. Introduction

The restoration of the Wrocław Opera House conducted since 1997 was completed in 2006. As part of modernization the orchestra pit has been enlarged and sunk lower below the stage and all the interior finishing materials, the floors, the underbalcony ceilings and the wall plasters have been replaced. But the historic interior layout and the character of its decor have been preserved.

Now there are 244 seats on the ground floor and 147, 133, 68 and 164 seats in respectively the 1st, 2nd, 3rd and 4th balcony. In order to adjust to new regulations, the total number of seats has been reduced from 800 before the renovation to the present 756 seats.

One of the primary acoustic goals set prior to the restoration of the Wrocław Opera House was to increase the auditorium's reverberation time [4]. Therefore the main recommendation concerning the interior finish was to use materials and elements (e.g. seats) with a low sound absorption coefficient.

After the completion of the restoration work comprehensive acoustic investigations (including reverberation time measurements) of the Opera House were carried out.

2. Measurement methods and conditions

The present reverberation time was measured using the Dirac system (Bruel&Kjaer type 7841) and the impulse response integration method [3]. MLS noise (8 averagings), a single MLS cycle time of 5.46 s and 262 143 impulse response samples were used in the measurements. In 1997 measurements the interrupted noise method had been used.

The measurements were performed in the auditorium with the fire curtain down and the orchestra pit's movable floor raised to the level of the stage (A) and also in the auditorium coupled with the stage and the orchestra pit opened (A+O+S).

Table 1. Measurements of reverberation time in Wrocław Opera House auditorium.

No.	Year	Interior layout	Number of seats	Sound source locations	Microphone locations
1	1997	A+O+S	800	orchestra pit; stage (2 locations)	3 points on ground floor
2	1997	A+O+S	0	middle of orchestra pit	3 points on ground floor
3	2005	A	0	proscenium	8 points on ground floor
4	2006	A	353	proscenium	8 points on ground floor
5	2006	A	756	proscenium	8 points on ground floor
6	2006	A+O	756	proscenium	8 points on ground floor
7	2006	A+O+S	756	orchestra pit (A1, A2) stage (A3, A4)	10 points on ground floor, 3 points per balcony 1, 2 and 4

3. Reverberation time and acoustic absorption before and after modernization

Figure 1 shows the reverberation time before (1977) and after the modernization (2005, 2006). The measurements were carried out for the auditorium with the orchestra pit and the stage (A+O+S) and for the auditorium separated from the stage by the fire curtain and the orchestra pit closed (A).

A comparison of reverberation time (RT) after the modernization for the auditorium alone (with seats) – A – with that for the auditorium with the orchestra pit and the stage – A+O+S – shows that the coupling of the auditorium with the empty stage results in an increase in RT. Thus the considerably high RT values measured in the modernized auditorium without seats indicate that the acoustic absorption of the auditorium has been significantly reduced after restoration.

The reverberation time in the modernized auditorium with seats is considerably longer than before the modernization, being even longer (except 4000 Hz) than the RT of the auditorium without seats before the modernization. RT at medium frequencies – T_M (the average for 500 Hz and 1000 Hz) before the modernization had been 1.00 s for the auditorium with the stage. The RT of the auditorium after the modernization with the fire curtain down is $T_M = 1.46$ s while for the auditorium coupled with the (empty) stage and the orchestra pit $T_M = 1.66$ s.

By carrying out an acoustic absorption analysis (Fig. 2) one can identify the principal causes of the changes in reverberation time. The average acoustic absorption in the 500–1000 Hz bands for the empty auditorium before the modernization AT_M had been 495 m^2 and the reduction in absorption after the removal of the seats DA_M had amounted to 272 m^2. After the modernization the AT_M of the empty auditorium was 259 m^2 and an increase in absorption brought about by the seats (DA_M) amounted to 266 m^2.

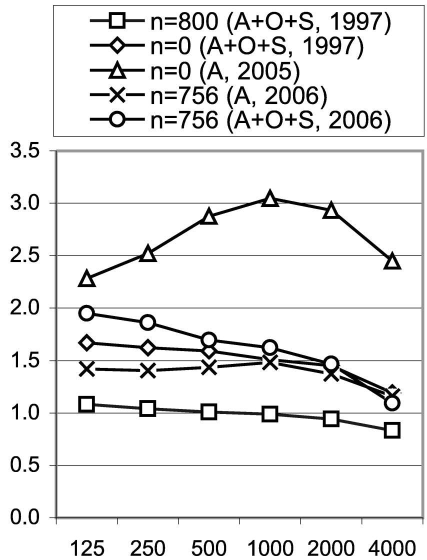

Fig. 1. Reverberation time of auditorium.

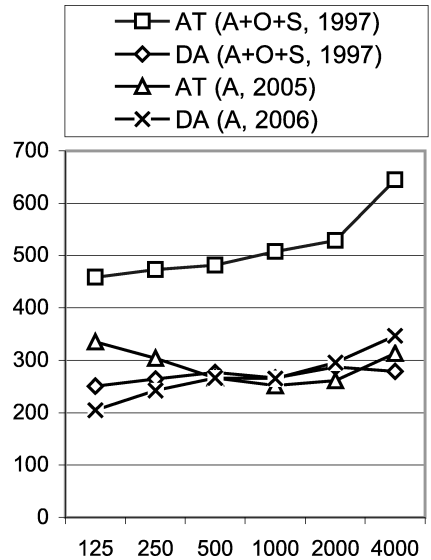

Fig. 2. Acoustic absorption of auditorium without seats (AT) and increase in sound absorption in auditorium with seats (DA).

4. Coefficient of sound absorption by seats

The increase in the auditorium's sound absorption after the installation of seats, related to the surface area occupied by them with an added strip of 0.5 m [1], can be used to estimate seats sound absorption coefficient α. The latter is actually overestimated since no sound absorption by the floor under the seats, although small (parquet glued to the solid foundation), is taken into account. Since the seats were installed and measured in two stages: first, 0.58 m wide seats on the ground floor and in the 1st balcony ($n = 353$, A, 2006) and then 0.54 m wide seats in the other balconies ($n = 756$, A, 2006), α could be calculated for the two cases.

Table 2. Coefficient (α) of sound absorption by seats.

	125	250	500	1000	2000	4000
Ground floor + 1st balcony	0.47	0.55	0.63	0.64	0.73	0.88
2nd, 3rd and 4th balcony	0.44	0.52	0.55	0.54	0.58	0.66

The values of α are similar at low frequencies. As the frequency increases, α of the seats in the 2nd, 3rd and 4th balcony does not increase in the same way as α of the ground-floor and 1st balcony seats. It is highly improbable that the cause was the difference of 4 cm in the width of the seats. The more probable cause is a reduction in the coupling between the balconies and the main interior at higher frequencies as the screening effect of the balustrade and the balcony above it increases.

5. Relation between reverberation time and sound source location

For four different sound source locations the reverberation time was measured at 10 points on the ground floor and in balcony 1, 2 and 4 (3 measuring points per each). The sound source was placed: A1 – in the orchestra pit's open part, A2 – in the orchestra's covered part, A3 – 1.5 m upstage and 1 m from the stage's axis, A4 – 3 m behind A3 upstage.

An analysis of the results showed that the differences in RT on the ground floor and in the balconies are smaller than the ones connected with the sound source locations. Therefore all the results for a sound source location were averaged. RT measurement uncertainties for a single microphone [3] are marked in Fig. 3. The uncertainty values

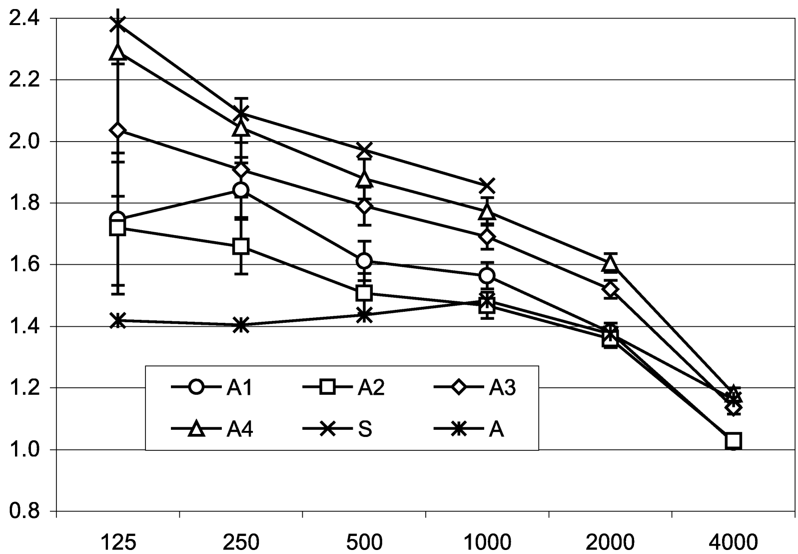

Fig. 3. Auditorium RT versus sound source location: A1 – in orchestra pit, A2 – in orchestra pit below stage, A3 – on stage and A4 – upstage for layout A+O+S as well as RT for auditorium alone (A) and stage (S).

indicate that the differences in the results for the different sound source locations are significant.

Reverberation time is the shortest when the sound source is located in the orchestra pit's covered part and slightly longer when the source is in the pit's open part. RT is considerably longer when the sound source is on the stage (which was completely empty during the measurements). The stage RT and the auditorium RT are bounded from top and bottom by the traces for the different sound source locations. One can expect that when the stage is filled with scenery lifts and scenery, the auditorium reverberation time will decrease to a value registered when the fire curtain is down.

6. Effect of auditorium filling and arrangement

The reverberation time of the auditorium with audience was estimated by the Hidaka method [2]. The RT of the auditorium with audience in a frequency range of 500–1000 Hz is 1.30 s. It increases as frequency decreases: at 125 Hz it is by 9% longer. When frequency increases, RT decreases, which is influenced by sound absorption by air.

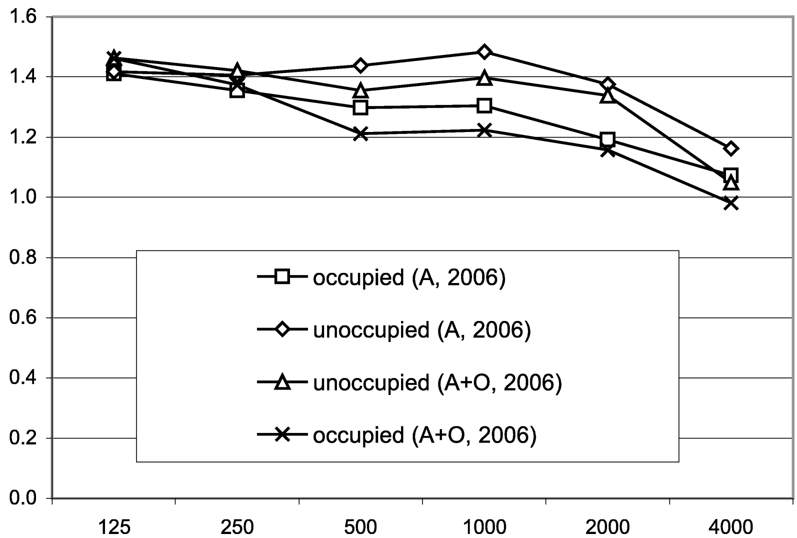

Fig. 4. RT of full and empty auditorium for opened and closed orchestra pit.

The interior can be rearranged thanks to the orchestra pit's movable floor. When the floor is raised to the level of the stage, the orchestra pit is closed and a vast proscenium is formed. When the orchestra pit is closed, reverberation time at medium frequencies T_M increases by 0.08 s relative to the value at the opened orchestra pit. This means that the volume reduction effect at the closed orchestra pit is overcompensated by the reduction in sound absorption.

7. Conclusions

Thanks to the consistent acoustic adaptation of the Wrocław Opera House auditorium the main acoustic goal of the interior renovation – reverberation time elongation – has been achieved. Considering the RT values measured when the fire curtain was down as minimal, the increase in auditorium reverberation time at medium frequencies amounts to not less than 0.46 s which represents a relatively very large change.

An analysis of changes in acoustic absorption showed that the increase in reverberation time was mainly due to the use of proper interior finishing materials.

For the auditorium coupled with the stage reverberation time depends on the sound absorption of the stage. When the stage is empty, the reverberation time can additionally increase by as much as 0.2 s if the sound sources are located on the stage. But as the stage is filled with scenery lifts and scenery, reverberation time will approach the RT values which occur when the fire curtain is down.

The estimation of reverberation time for the auditorium filled with audience showed the RT curve to be monotonic with a slight rise at low frequencies. The reverberation time of the auditorium with audience at medium frequencies is 1.3 s. Thus the reverberation time of the Wrocław Opera House auditorium meets the recommendations [1] both during rehearsals (when it is empty) and when it is filled with listeners.

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