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Selected aspects of acoustic treatment of the orchestra pit

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Abstract The orchestra pit is not a friendly workplace for musicians, and the need to ensure their interaction with the stage and audience places very high demands on this interior. The aim of the considerations presented in the article was to analyse the various possibilities of acoustic adaptation of the orchestra pit against the background of obtaining the expected effects. The conducted simulation studies and the use of the results of the experimental studies carried out in the well-equipped orchestra pit of the Krakow Opera allowed for the indication of representative acoustic parameters useful for the assessment of the results of acoustic treatment. Based on the comparison of the reverberation time T20 and EDT for various variants of the orchestra pit interior, the confirmation of the legitimacy of using sound diffusing and absorbing systems was obtained. They spread the energy of the first sound reflections in time and reduce the risk to the musicians' hearing. Reflective elements and sound dispersing within the orchestral will ensure adequate audibility between the musicians.

Keywords: first sound reflections, reverberation time, early decay time, reflective screens, adjustable orchestral barrier.

1. Introduction

The issues related to the acoustic conditions of the stage continue to be present in the scientific discourse. Starting in the 70. with the paper by Meyer [1] through the works of Barron [2], Gade [3], the next generations of the researchers (i.a. [4-7]) focus on finding objective means for the assessment of the acoustic conditions of the stage to be used to aid designing and remodeling of the interiors for performing classical music. The majority of the works include stage area of the philharmonic concert halls, multi-functional halls, and rehearsal rooms. The orchestra pit is basically the combination of the above two, with the main function of transferring the music to the audience, whereas the space for the musicians is more like a rehearsal room. Small volume, the proximity of the reflecting surfaces, together with little area for each musician constitute the working conditions of the artists in the orchestra pit described as difficult. What is more, sound pressure level is high, which additionally causes discomfort, and in some cases poses a threat to the musicians' health.

The parameters used for the assessment of the acoustic conditions of the stage are, among others, EDT, T_{20}, ST_{early}, ST_{late}, C_7, G, G_{80}, G_{late}, or the parameters determining the direction and the arrival time of the sound reflections [7].

Recent works [8] on the data which should be assessed while determining the acoustic quality of an interior but have not been included in the ISO 3382-1 standard [9], show the necessity to investigate early sound reflections more closely. The parameter of early decay time EDT, proposed by Jordan [10] accounts for the early reflections to some degree. It describes the perceived reverberance of the room well, being sensitive to the changes in the time pattern of the early reflections. In the orchestra pit, early sound reflections are caused by the orchestra pit walls, the ceiling (suspended in the rear part), the barrier between the pit and the audience, the frontal part of the stage, and the reflective panel over the stage.

The energy of the early reflections and their time pattern can be shaped by using sound absorbing and sound diffusing structures, as well as by specially designed reflective elements. When sound absorbing materials are used, the acoustic energy is lost and the problem of losing so-called support arises. Decreased acoustic support of an interior stimulates the musicians to play more loudly which in turn increases the total sound pressure level. Using sound diffusers, on the other hand, allows the preservation and even distribution of the acoustic energy. An obvious consequence of this is the decrease of the mirror reflection and sound levels. Designing such structures carefully is especially vital in small rooms, when the distances between the walls and the musicians are small. Sound diffusers of too large thickness may induce comb filters and disturb the uniformity of the sound field even at significant distances (for example in the case of a 10 cm thick QRD Schroeder diffuser, such a distance is around 1 m). In this context, redirecting the sound reflections from the orchestra-pit walls is difficult, and in the case of the barrier between the orchestra-pit and the audience, the frontal part of the stage (see [11]), or the overhead stage panels, we can expect noticeable effectiveness of sound diffusers.

Numerous opinions expressed by directors and musicians indicate that early reflections can significantly affect the assessment of the acoustic conditions of an orchestra pit, both positively and negatively. It is crucial to maintain the balance, since early reflections are the most valuable, and yet they cannot be dominant.

2. Description of the study

During the renovation of the orchestra pit in the Kraków Opera Hall several changes were introduced:

1) Three different sound diffusing structures were introduced; at the rear wall (behind the musicians, under the suspended ceiling) a 3 cm thick diffuser, optimized for its thickness and the frequency range of operation was applied [12]; at the front wall two different structures were applied: a 6 cm thick one up to the height of 1.2 m, and above – a 4 cm thick one.
2) An adjustable reflective barrier was installed to direct the sound partly towards the scene, and partly see-through, enabling the transmission of sound towards the audience.

These changes were aimed at reducing the sound pressure level inside the orchestra pit and the improvement of the contact between the musicians inside the orchestra pit and between the musicians and the actors on the stage. The interview with the director and the musicians indicated significant improvement of the working comfort in the orchestra pit. The possibility of playing more quietly with the maintained support of the room and communication between the instrument groups were indicated.

The examination of the acoustic conditions in the orchestra pit allowed the confrontation of the subjective assessment of the musicians with the obtained values of acoustic parameters.

The analysis was performed based on the in-situ measurements and computer simulations. The measurements taken in the opera hall were used for the calibration of the computer model, with the use of predictive validation based on values of EDT, T_{20} and G. All simulations were made in CATT-Acoustic v9.0 software and TUCT v2. Simulation parameters for all variants were the same: algorithm 1, time trace: 1200 ms, particle/rays number: 435500.

Five arrangements were considered (see scheme in Fig. 1):

A. Initial orchestra pit – sound absorbing ceiling in the rear part of the pit, remaining surfaces reflecting
B. Acoustically treated orchestra pit, the barrier directing sound reflections towards the scene closed
C. As above, the barrier 60 cm lower
D. As above, the barrier open
E. As above, with the corrected arrangement of overhead reflecting panels over the orchestra pit.

All the simulations were performed for a typical equipment of the orchestra pit, following the recommendations by Dammerud [6].

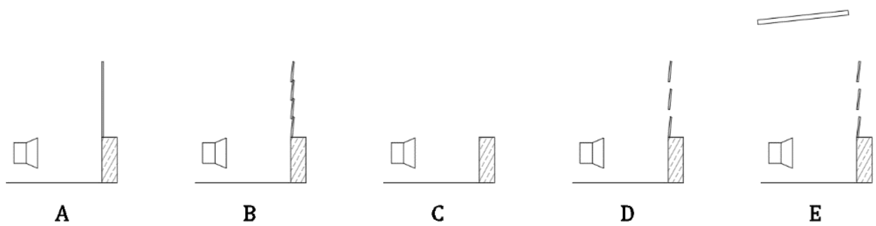

Figure 1. Scheme of the barrier in all variants.

The values of the acoustic parameters were determined for the arrangement of sound sources and receivers as shown in Fig. 2, according to the recommendations of [2]. Receivers were placed in positions R_{p1}-R_{p3} for sources in position P_1 and P_2 (see Fig. 3). All of them were 1 m above floor. This results in six sound source-receiver combinations, two of which are at 1 m (Receivers R_{p1} and R_{p2} were 1 m from sound sources like for the measurement of stage parameters *ST*).

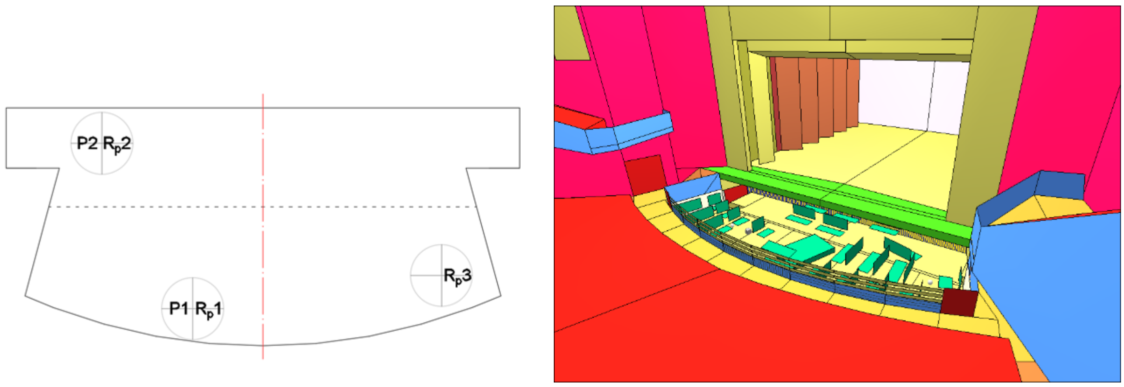

Figure 2. Measurement layout in orchestra pit. P_1, P_2 – sources, R_{p1}, R_{p2}, R_{p3} – receivers, and the view of the 3D model – orchestra pit with chairs and stands inside.

The acoustic conditions of the orchestra pit were assessed with the use of the ratio of early decay time EDT to the reverberation time T_{20}. Since the resulting value is non-dimensional, it can be used directly for comparing the results for different orchestra pits. This indicator is used for the assessment of the quality of concert halls, and especially for the assessment of the effects caused by the coupled rooms (or the parameters based on the late decay time, LDT [13]). The values of such ratios were determined for average values obtained for the 1/1 octave frequency bands within 500 – 1000 Hz.

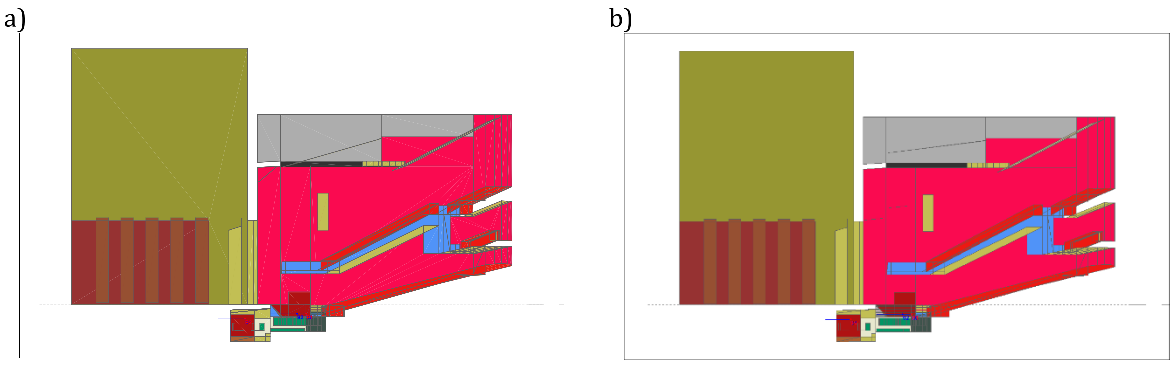

Figure 3. Cross section of the 3D model: a) existing ceiling panels layout, b) corrected ceiling panels layout.

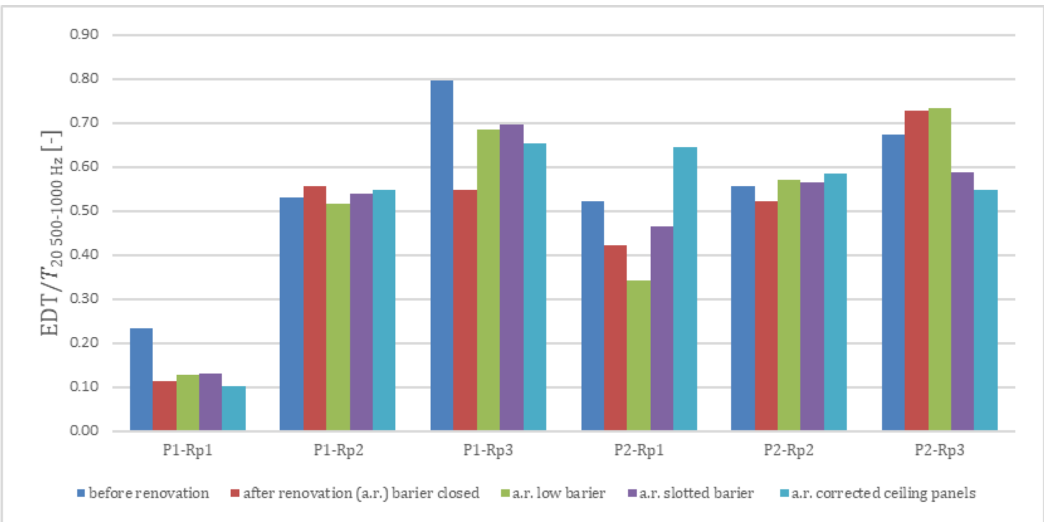

Figure 4. EDT/$T_{20,\ mid}$ for different variants for source-receiver paths.

3. Results

As a result of the simulations, the values of the following parameters were determined: EDT, T_{20}, ST_{early}, ST_{late}, G_{80}, and G_{late}. All the values were averaged for the middle frequencies (average for 1/1 octave bands 500 and 1000 Hz).

In Fig. 4 we can see the values of the ratio EDT/T_{20} for six sound source-receiver paths. The values change in a wide range, mostly for the path in the open area of the orchestra pit (path P_1-R_{p3}). After the renovation and with the barrier closed, we can observe the lowest values. It is because the acoustic treatment provides sound diffusion and some sound absorption, which influence early reflection energy.

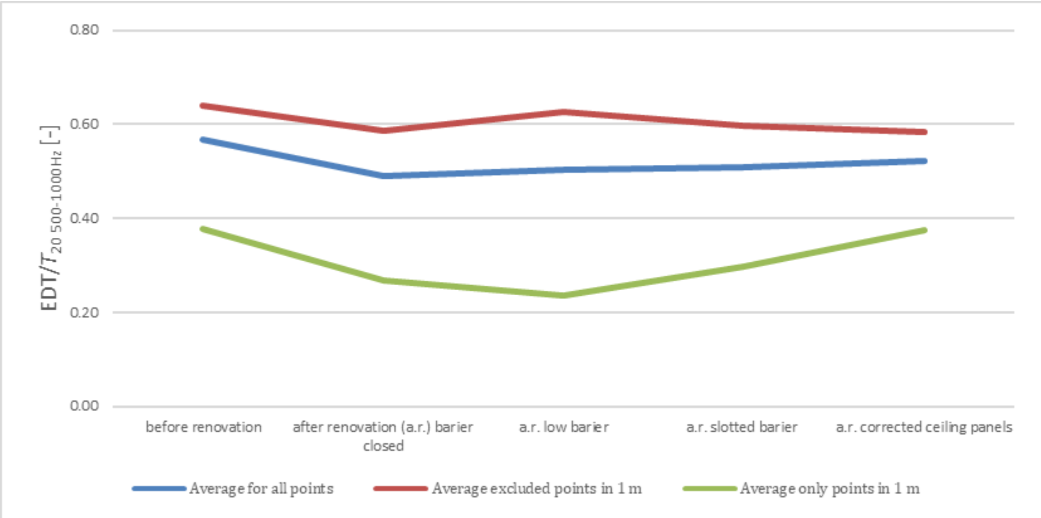

Figure 5. Average values of EDT/$T_{20,\,\mathrm{mid}}$ for all variants.

Averaging values for all paths, and additionally for paths with or without measurements in 1 meter (like for stage parameters measurements) we can observe that values for receivers in 1 m have a wider range of value changes (see Fig. 5 and Tab. 1). In this way we can judge the changes in the early reflections.

Table 1. Average values of EDT/$T_{20,\,\mathrm{mid}}$ and correlation with EDT.

No.	**EDT/T20,** mid	**Average for all Sound receivers combination**	**Average excluded points in 1 m**	**Average only points in 1 m**
1	before renovation	0.57	0.64	0.38
2	after renovation (a.r.) barier closed	0.49	0.59	0.27
3	a.r. low barier	0.50	0.63	0.23
4	a.r. slotted barier	0.51	0.60	0.30
5	a.r. corrected ceiling panels	0.52	0.58	0.37
	Correlation with EDT	**0.95**	**0.82**	**0.83**

The question is by how much the values of EDT/T_{20} differ from EDT and how they are correlated. For the measurements at the distance of 1 m from the sound source we can see that the values are correlated with the correlation value 0.83, and for the remaining points the correlation is 0.82.

Changing the shape of the overhead sound reflecting panels causes a noticeable change of the ratio EDT/T_{20}; for the measurement point at the distance of 1 m an increase is observed, and for the remaining measurement points – a decrease.

The determined values of the ration of early decay time of sound EDT to the reverberation time T_{20} indicate that:

1) The change in the value of the ratio depending on the variant was maximum for the P_1-R_{p3} path and was equal to 0.23 (for the open area). After introducing acoustic treatment and with the barrier closed, the values at this direction decreased significantly. Any other change caused the increase of these values.

2) Observing the change of the ratio can be a clue in the assessment of the acoustical quality of the orchestra pit and the designed renovations.
3) The described ratio indicator should be analyzed individually for the measurement paths.

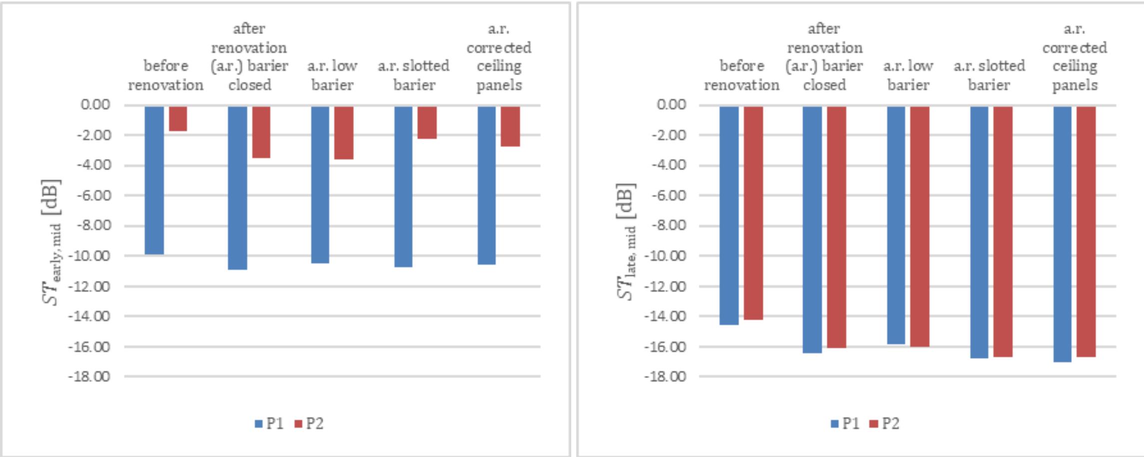

Figure 6. Stage parameters for different variants – P_1, P_2 – sources.

It is natural that the area under overhang has more early reflections, and therefore the values of ST_{early} are high (source P_2). We can observe that the modification of the barrier influences point P_2 which is in the rear part of the orchestra pit even more then point P_1 located near barrier (see Fig. 6).

The introduced changes impact the values of the stage parameters showing the improvement of the acoustic quality of the interior (see [6]). The changes are significant for both *ST* parameters.

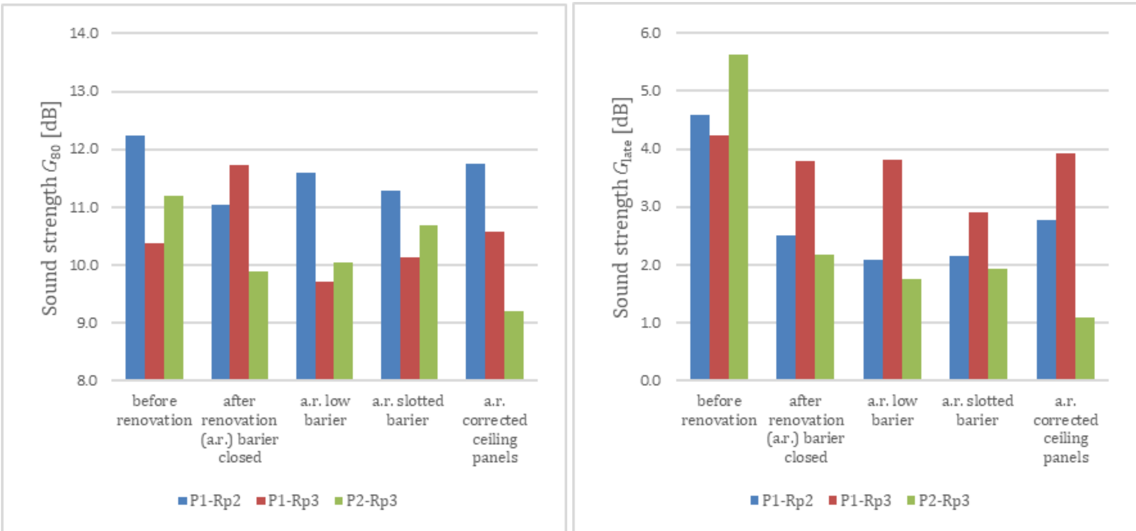

Figure 7. Sound strength G_{80} and G_{late} for different variants.

Both stage parameters *ST* and sound strength *G* reflect the change of the early and late energy. The decrease of G_{80} and G_{late} in comparison with the situation before remodeling indicates the decrease in the acoustic energy in the orchestra pit (Fig. 7), especially for the points under the ceiling in the rear part of the pit, without the sound absorbing materials.

4. Conclusions

The paper shows the results of the research on acoustic conditions of the orchestra pit of Kraków Opera Hall. Based on the parameters described in ISO 3382-1, the acoustic conditions were assessed for different modifications of the orchestra pit. Based on the observations we can conclude that:

1) The changes introduced to the orchestra pit during the renovation caused the decrease of the late energy (ST_{late}, G_{late}), with the simultaneous decrease of the EDT/T_{20} ratio.
2) The barrier (its height and the reflection ratio) has a significant influence on the values of the stage parameter ST for the spots under the ceiling in the rear part of the pit.
3) When the barrier is partially see-through the differences in the values of acoustic parameters are smaller within the whole area of the pit.
4) Correcting the distribution of the overhead reflective panels above the orchestra pit allows the increase of the early reflecions (ST_{early}, G_{80}) and the late energy in the whole orchestra pit (G_{late}) but also decreases the differences between EDT/T_{20} ratio values.

The future work will include determining the preferred values of the parameters described in this paper.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. M. Jürgen; Acoustics and the Performance of Music: Manual for Acousticians, Audio Engineers, Musicians, Architects and Musical Instrument Makers; Springer Science & Business Media, 2009
2. M. Barron; The Gulbenkian Great Hall, Lisbon II: An acoustic study of a concert hall with variable stage; J. Sound. Vib., 1978, 59(4), 481–502
3. A.C. Gade; Investigations of musicians' room acoustic conditions in concert halls ii: Field experiments and synthesis of results; Acta Acust. Acust., 1989, 69(6), 249–262
4. K. Brawata; Akustyczne aspekty konstrukcji fosy orkiestrowej w kontekście interakcji ze sceną; PhD thesis, Akademia Górniczo-Hutnicza, Kraków, Poland, 2019
5. J.J. Dammerud; Stage acoustics for symphony orchestras in concert halls; PhD thesis, University of Bath, UK, 2009; https://stageac.wordpress.com/ (accessed on 2018.07.31)
6. R.H.C. Wenmaekers, C.C.J.M. Hak, M.C.J. Hornikx; How orchestra members influence stage acoustic parameters on five different concert hall stages and orchestra pits; Journal of the Acoustical Society of America, 2016, 140, 4437; DOI: 10.1121/1.4971763
7. L. Panton, M. Yadav, D. Cabrera, D. Holloway; Chamber musicians' acoustic impressions of auditorium stages: Relation to spatial distribution of early reflections and other parameters; The Journal of the Acoustical Society of America, 2019, 145, 3715; DOI: 10.1121/1.5111748
8. T. Halmrast; Acoustical aspects not covered by the common, standardised room acoustic parameters; 2022
9. ISO 3382-1:2009; Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces
10. V. L. Jordan; Acoustical Criteria for Auditoriums and Their Relation to Model Techniques; The Journal of the Acoustical Society of America, 1970, 47(2A), 408–412; DOI: 10.1121/1.1911535
11. T. Kamisiński, M. Burkot, J. Rubacha, K. Brawata; Study of the effect of the orchestra pit on the acoustics of the Kraków Opera Hall; Archives of Acoustic, 2009, 34(4), 481–490
12. Architected Sound OptiDi product sheet; https://www.architected-sound.com/pl/produkty/optidi/
13. M. Meissner; Analysis of non-exponential sound decay in an enclosure composed of two connected rectangular subrooms; Archives of Acoustics, 2007, 32(4(S)), 213–220