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The influence of the stage layout on the acoustics of the auditorium of the Grand Theatre in Poznan

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The paper concerns the influence of the stage layout on the acoustic properties of the auditorium of the Grand Theatre in Poznań. An experimental investigation and a numerical calculation were carried out. During the experimental investigation three cases were analyzed. Firstly, the stage was prepared for a concert (acoustical shell), secondly it had sets for the "Le nozze di Figaro" by W.A. Mozart, and thirdly it was empty. The reverberation time and the acoustic pressure distribution were analyzed. The research was done by the interrupted noise method and by the true impulsive sources (pistol shots). The modified ray method was used in numerical calculations of acoustic field parameters. It turned out that the light weight structures (materials used in construction of stage sets and acoustical shell) had only decorative function and their influence on the acoustics of the auditorium opera theatre is small. Moreover, the investigation proved that the distribution of the sound pressure level in the auditorium is asymmetrical. It is because of the geometrical asymmetry of the stage (only one side wing). An acoustical correction of the stage was suggested i.e. applying of slided acoustics walls to separate the stage from the background and the side wing.

1 Introduction

This paper concerns the influence of the stage and flytower layout on the acoustics of the auditorium opera theatre. This is a very essential problem of the opera theatres architecture and acoustics. The stage constitutes the biggest area in the entire theatre and at the same time the heart around which the life of the theatre is focusing. The literature is dealing mainly with the problems of shaping the audience, while not much has been written about the stage and flytower influences [1,2].

An experimental investigations has been carried out in the Grand Theatre in Poznań.

The cubature of the auditorium is about 5000 m³, the cubature of the stage and the flytower is about 11300 m³. On the ground floor there are 469 seats and on the three balconies together there are 400 seats.

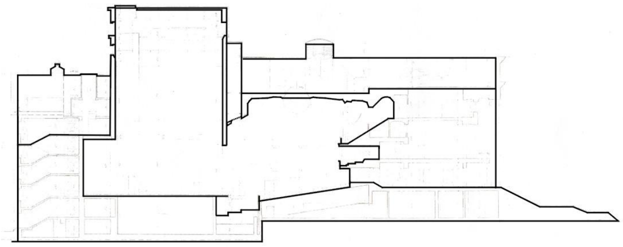

Fig.1 Longitudinal section of the Grand Theatre in Poznań

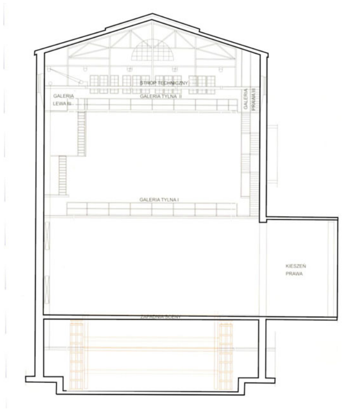

Fig.2 Cross section along the stage and flytower of the Grand Theatre in Poznań

The researches had a practical aspect as they were supposed to give an answer to the question: how the stage sets and the acoustical shell affect the acoustics of the auditorium.

The reverberation time and the acoustics pressure distribution have been analyzed. The research concerning reverberation time was done by the interrupted noise method (omnidirectional sound source) and by the true impulsive sources (pistol shots). Additionally the clarity C_{80} and the center time T_S mean in frequency characteristic were calculated. Average reverberation time was also calculated. The researches by the interrupted noise method was done for each of the octave bands (125-4000 Hz). The Svan 912 AE sound analyzer was used. Sound pressure level and the sound-decay curve were measured.

The linear regression method was applied to calculate reverberation time.

2 The characteristic of the carried-out researches

During the experimental investigations three cycles were analyzed.

a) investigation 1 - the stage was prepared for a concert (acoustical shell),

b) investigation 2 - the stage with sets for the "Le nozze di Figaro" by W.A. Mozart,

c) investigation 3 - the stage was empty, additionally, in the third cycle two other researches were done.

- investigation 3a - the stage alone, separated from the auditorium by the fire curtain
- investigation 3b - the auditorium alone, separated from the stage by the fire curtain

The investigations 3a and 3b are recommended in professional literature [4].

The measurement points on the auditorium (points 1, 2, 3, 4 and 5, marked in red) and the location of sound source (points a, b, c, d, e, f, g, marked in blue) are presented on Figs. 3 and 4. Fig. 3 concerns the investigations 1, 2, and 3, while Fig.4 concerns investigations 3a and 3b.

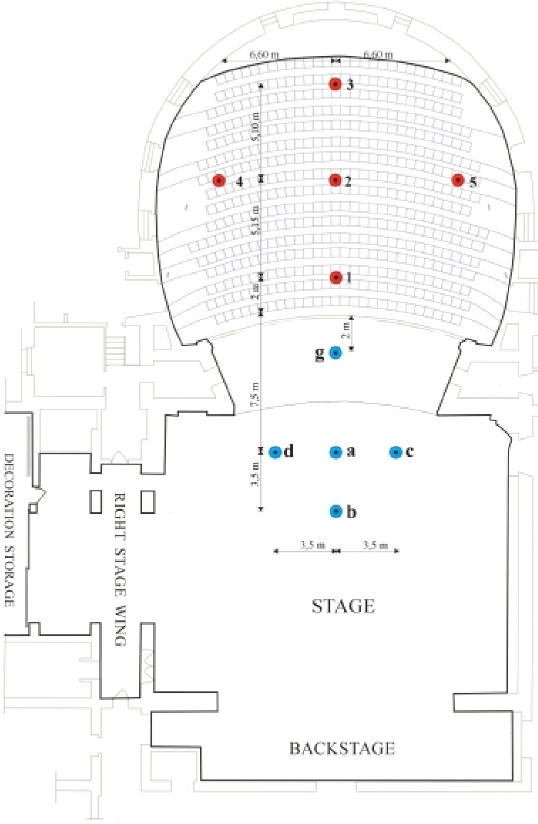

Fig.3. The stage and the auditorium top view, with measurements points marked (red colour) and sound source location (blue colour) - investigation 1, 2 and 3

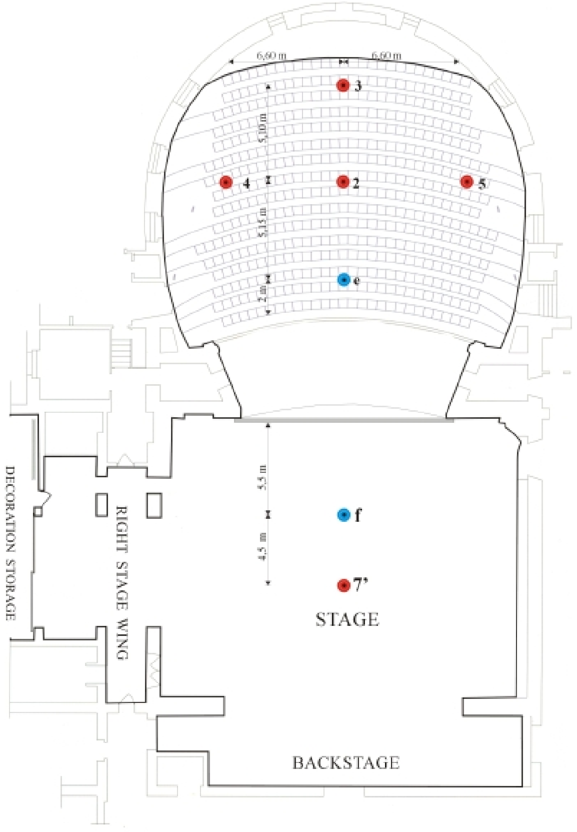

Fig.4. The stage and the auditorium top view, with measurements points marked (red colour) and sound source location (blue colour)- investigations 3a and 3b

In the measurement points the reducing of sound pressure level and reverberation time were calculated. The sound pressure level reducing ΔL_P was calculated by the formula:

$$\Delta L_P = L_{P,Z} - L_P \qquad [\mathrm{dB}] \qquad (1)$$

where:

L_P - sound pressure level in the measurement point

$L_{P,Z}$ - source pressure level (the sound pressure level at the distance of 1 meter away from source)

The level of sound pressure for octave bands (125-4000 Hz) was from about 69 to 86 dB.

2.1 The stage with acoustic shell - investigation 1

The investigation 1 concerned a stage prepared for the concert (a recital of soprano Barbara Hendriks). The orchestra were on the stage. The area of stage was increased by covering the orchestra pit. The material used for the orchestra shell was 3 mm plywood panels of the following dimensions: height 7.5 m width 1.45 to 2.3 m. The panels were fixed to wooden grid. The arrangement of orchestra shell is presented on Fig.5. Additionally one acoustics screen made of 3 mm plywood was used. The screen was installed at the height of 8.5 m above the stage level with 30º inclination.

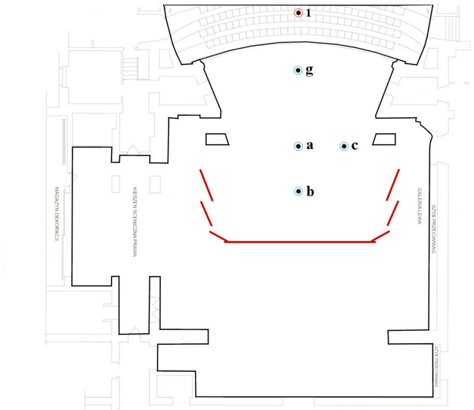

Fig. 5. Top view of the stage with the concert shell

2.2 The stage with sets for „Le nozze di Figaro” - investigation 2

Investigation 2 were carried out with the stage sets for “Le nozze di Figaro” by W. A. Mozart. Both sides of the stage were built up with plywood panels of 3 mm width and 7.5 m height, which were fixed to a wooden grid. The surface of the panels were covered with mirror foil. Additionally the elements made of a painted sponge were distributed on the stage. This elements imitated the pillars of the fence. A tree made of cardboard, sponge and plastic was put at the back of the stage. A metal net which made the stage set elements rigid was mounted above the stage. A large black fabric constituted the cyclorama.

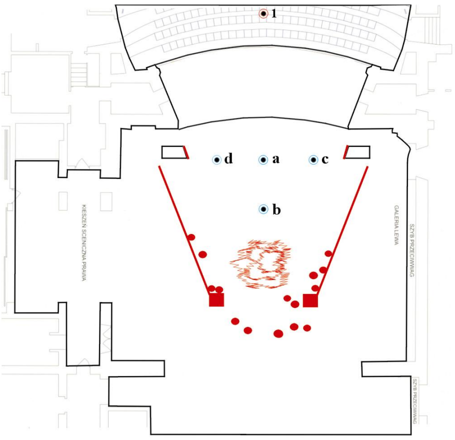

Fig.6. The arrangements of stage sets

2.3 Empty stage - investigation 3

Investigation 3 was carried out for the stage without the stage sets. In the stagehouse black fabric was hung. In this investigation two additional researches were done, marked as 3a and 3b. Using the recommendations given in the paper [4] the stage and auditorium were separated by a fire curtain. In this way two independent rooms were achieved, which allowed researching the acoustics properties of the very stage and the very auditorium. The sound source and the measurements points are marked on Fig.4.

2.4 Numerical calculations

To investigate the above mentioned issue a "RAY MODEL" computer program (author Prof. A. Kulowski) has been used [3]. In this program a modified ray method of analyzing acoustics field was applied. The calculations were done for three variants:

1. Empty stage and auditorium
2. Auditorium with a fire curtain
3. Stage with a fire curtain

Auditorium numerical model consisted in 245 surface elements and 330 nodal points, but the stage and flytower numerical model consisted in 73 surface elements and 137 nodal points.

3 Results of the researches

Frequency characteristic of mean reverberation time on the auditorium for investigation 1, 2 and 3 is presented on Fig.7.

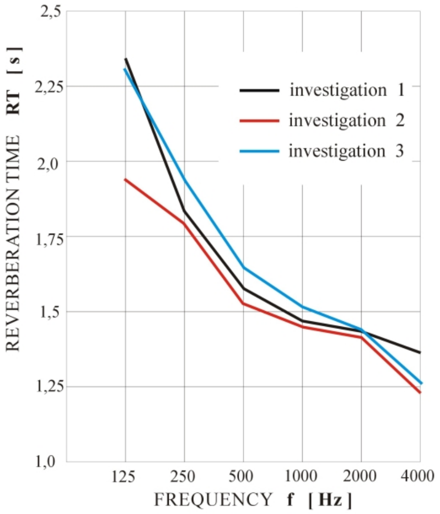

Fig.7. Frequency characteristic of mean reverberation time RT - comparison of investigations 1, 2 and 3

In the range of 250-2000 Hz the highest reverberation time is for an empty stage and the lowest reverberation time is for the stage with the stage sets for "Le nozze di Figaro" (investigation 2).

The reverberation time on the stage (investigation 3a) changes from 2,31 s to 0,94 s appropriately for the frequency of 125 and 4000 Hz.

On the auditorium (investigation 3b) the reverberation time changes from 1,7 to 1,3 s appropriately for the frequency of 125 and 4000 Hz. The sound absorption on the auditorium is practically the same for all the frequencies.(Fig.8)

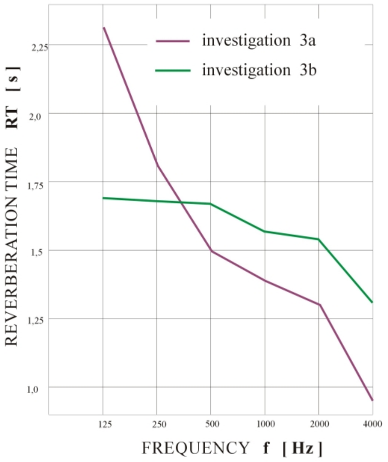

Fig.8. Frequency characteristic of mean reverberation time RT -comparison of investigations 3a and 3b

The comparison of frequency characteristic of mean reverberation time RT measured and calculated in "RAY MODEL" computer program is presented on Fig.9. In the range of middle and high frequencies a good conformity of results was obtained.

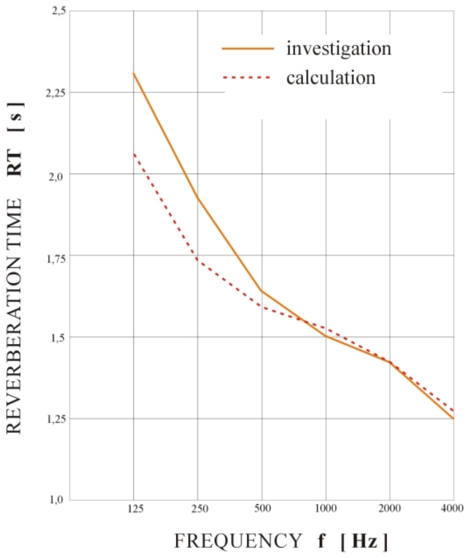

Fig.9. Reverberation time RT(on the auditorium) measured and numerically calculated - empty stage with auditorium

The distribution of sound pressure level on the auditorium for two different positions of sound source is presented on Fig.10 and Fig.11. The comparison concerns investigation 1 - stage with concert shell. When sound source was moved from point *g* to point *b*, the sound pressure level decreased about 6.8 dB.

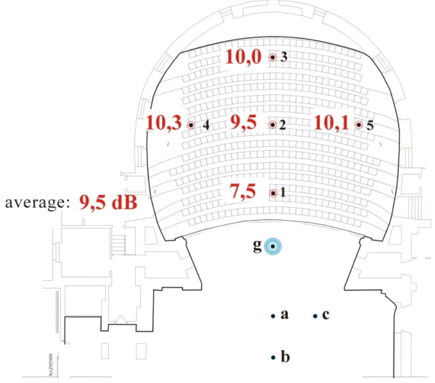

Fig.10. The reducing of sound pressure level ΔL_P for middle octave band, sound source in point *g* investigation 1

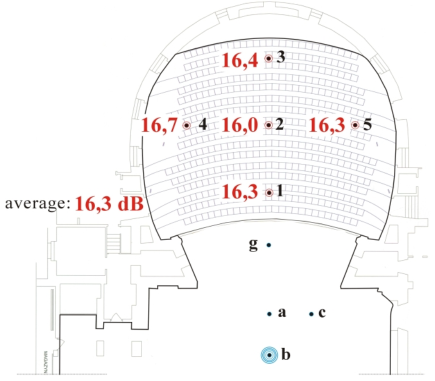

Fig.11. The reducing of sound pressure level ΔL_P for middle octave band, sound source in point *b* investigation 1

The sound pressure level reducing ΔL_P in the range of 125-4000 Hz for investigation 1, 2 and 3 is presented on Fig.12. (the sound source in the *a* point).

It is seen from diagrams, that in the middle octave bands (500-1000 Hz) the concert shell and the stage sets caused the mean sound pressure level on the auditorium to be about 2 to 4 dB lower than for an empty stage (investigation 3). It turned out that the light structures had only a decorative function. The correction of acoustics parameters is possible to get through the use of massive materials (5 to 10 kg/m²).

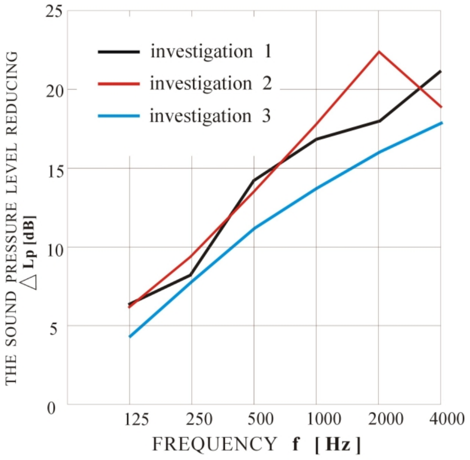

Fig.12. Frequency characteristic of sound pressure reducing ΔL_P on the auditorium, comparison of investigations 1, 2 and 3, sound source in the *a* point

The comparison of average sound pressure level on the auditorium when the sound source was in the points *c* and *d,* lead to the conclusion that the stage is acoustically asymmetric. When the sound source is in the point *d* on the stage, the average sound pressure level on the auditorium is about 1.7÷1.9 dB lower than for the sound source in the point *c*. For the opera singers the place around point *d* (right side of stage- looking from the auditorium) is worse than the place around point *c* (left side of stage). The acoustical asymmetry results from the geometrical asymmetry of the stage. On the right side of the stage, there is side wing with the decoration storage (Fig. 13). An acoustical correction of the stage, i.e. applying slided acoustics walls to separate the stage from the background and the side wing, was suggested. Depending on the requirements it is possible to put the door in the slided walls. These walls are marked in red (Fig.13).

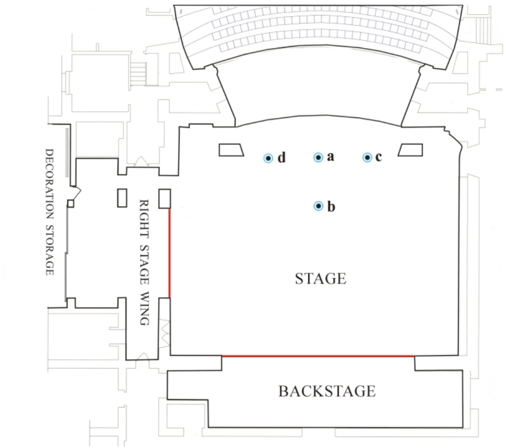

Fig.13. Top view of the stage; slided acoustic walls is marked in red.

4 Conclusion

The problems concerning the acoustics are very important for the reception the of opera. While designing opera houses an emphasis is put on the acoustic and architecture of auditorium. The space of a stage and the flytower is often not considered in an adequate way.

It concerns not only the design, but also using the object. Omitting the material acoustic properties, from which the stage sets and concert shells are made, belong to the basic mistakes. The light weight structures which don't reflect the sound are often used. Too many fabrics which are absorbing sound are also applied. Such solutions are applied because of the low costs and the easiness of the workmanship and the assembly. In order to provide high quality opera performance, it is important to take into account these issues, searching for a reasonable compromise.

References

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[2] L. L. Beranek, "Concert Halls and Opera Houses: Music, Acoustics and Architecture, *Springer, Second Edition* (2004)

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[4] R. Pompoli, N. Prodi, "Guidelines for acoustical measurements inside historical opera houses", *Journal of Sound and Vibration* 232(1), 281-301 (2000)