Sound Fields in Orchestra Pits

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Abstract: The main problem for musicians sitting in opera house orchestra pits is the general loudness of the orchestral sound, which is affected not only by direct sound, early reflections, and reverberation, but also by standing waves. These standing waves are extremely disturbing for seats under the stage, if the musicians' ears are in the neighbourhood of the antinodes. Therefore the standing waves between floor and cover have to be damped by well-tuned absorbers.

INTRODUCTION

The acoustic situation of musicians playing in an opera house is much more difficult than in concert halls. Independently of the problems of synchronicity and dynamic balance between singers and orchestra, the special acoustic situation of the orchestra pit impairs the playing control of the musicians' own instruments as well as the precision of ensemble playing. The sound field occurring at the musicians' ears is not only affected by direct sound, early reflections, and reverberation, but particularly for seats under the stage - by standing waves. Whereas direct sound and more or less diffuse reflections appear to come from comparatively large distances, the sound due to standing waves is localized just around the head. Therefore it seems to be necessary to include the standing waves into the considerations on the musicians' situation in orchestra pits.

DIFFUSE FIELD AND DIRECT SOUND IN THE PIT

The lowered orchestra pit may be considered as a small separate room coupled to the hall by the top opening area. Usually, a pit has a floor area in the order of 90 m², but it may vary between 60 m² and 120 m². As in most cases a part of the pit is under the stage or the first side boxes, the top opening area is smaller than the floor, typically in the order of 60 to 90% of the floor area. Assuming a depth of the pit (measured between pit floor and stage edge) of 2.50 m in its open part and of about 2.0 m under the stage, a 90 m² pit may have a volume in the order of 210 m³.

For the evaluation of the diffuse reverberation time inside the pit, it may be assumed that the top opening area effects like an absorbing area having an absorption coefficient of about 0.6. In case of usual floor and walls (without special absorption) and of an orchestra of 85 players, the reverberation time of the diffuse field inside the pit would lie in the order of 0.3 s for middle frequencies increasing to about 0.7 s at low frequencies. Therefore, the reverberation of the pit is much shorter than that of the whole theatre: for the musicians, the audible reverberance seems to come from above. On the other hand, this diffuse reverberance of the pit effects the level of the statistical field and by this the loudness inside the orchestra. For a typical forte, the sound power level of a romantic opera orchestra is about 114 dB. This generates a sound pressure level of the diffuse field inside the pit of 100 dB.

For the mutual hearing of the musicians, the strength of the direct sound is important. If its level descends more than 10 dB below the level of the statistical sound field, the localisation of the sound source is impaired. For mutual hearing inside the orchestra, the statistical field built up by all instruments has to be compared with the direct sound of the instrument, which a musician wishes to hear. For example, a violin - played forte - produces a sound power level of 89 dB, a clarinet of 93 dB and a trumpet of 101 dB. Furthermore the (energy related) directivity index for the strongest components and horizontal radiation directions is about 4 dB for the violin, 6 dB for the clarinet, and 7.5 dB for the trumpet. According to these values, the sound pressure level occurring in a distance of 1 m in front of the player lies about 87 dB for the violin, 93 dB for the clarinet and 103 dB for the trumpet. In case of violin and clarinet, these values are valid for an angle of approximately 180° in front of the player, in case of the trumpet for an angle of only about 45°.

Therefore sometimes, sound screens reducing the direct sound by about 5 to 10 dB are placed behind the musicians sitting in front of the heavy brass. But the question remains open whether there are coloring effects for sound incidenting from front directions caused by the sound reflection at the screen.

On the basis of a diffuse field sound pressure level of 100 dB, when the whole romantic orchestra is playing forte, a critical distance for audible direct sound may be estimated: it lies in the order of 5 m for the trumpet, 1.5 m for the clarinet and below 1 m for the violin. That means, in a tutti forte of the orchestra, it is nearly impossible for the musicians to localize other instruments except the heavy brass and the next neighbour in the woodwind section.
STANDING WAVES

In orchestra pits, there exist two possibilities for standing waves. One hand, standing waves may occur between the hard floor and the hard underside of the stage if the pit is enlarged under the stage; in these cases, the distance between floor and "ceiling" is mostly little less than 2 m. On the other hand, standing waves may occur between the front and rear wall of the pit; this distance varies from 4.5 m for small theatres to more than 6 m for large opera houses (Vienna State Opera: 7 m, New York Metropolitan Opera: 8 m).

Fig. 1 shows the first three modes of standing waves built up in the space under the stage having a sound pressure maximum at the reflecting surfaces. Such standing waves are disturbing for the musicians, if the region of high levels covers the height of the players' ears (typically 1.15 to 1.20 m above the floor). If the limits of the "range of high levels" are set at 3 dB below the maximum level, this (hatched) range extends by ±λ/8 around the maxima.

Fig. 2 shows the dependence of the frequencies of the first four eigenmodes on the height of space under the stage. The thick parts of the curves represent the ranges in which the 3 dB regions cover the location of the ears. With the typical height of about 2 m, the second mode, and the third or fourth mode occur. It seems to be difficult to avoid the second mode, except by reducing the height to less than 1.80 m. Therefore, well tuned absorbing areas (for the frequency range between 100 and 200 Hz) should be provided for the underside of the stage to improve the musicians' hearing. Additionally the third or fourth mode lying in the frequency range from about 250 to 335 Hz should be damped. Coincidently, the three higher modes occur only in a very small range of the height about 2 m. This should be considered, when designing a pit.

Regarding sound spectra and directivity of the instruments, the frequency range between 100 and 200 Hz is mostly important for the timpani; whereas their harmonic components have a rather small radiation in vertical directions, the unharmonic first ringmode is radiated omnidirectionally, i.e. strongly in vertical directions too. Therefore this mode has best conditions for exciting standing waves. Even if bassoons radiate levels of about 10 dB below their strongest components, they can excite standing waves in this frequency range. In the frequency range between 250 and 335 Hz, oboe, clarinet, trumpet, and trombone radiate omnidirectionally, bassoon and French horn radiate invertical directions only about 3 dB softer, as the main formant (the loudest components) of French horn lies in this frequency range, this instrument group is the most important one for exciting standing waves.

CONCLUSIONS

1. To avoid standing waves, the underside of the stage should be covered by well tuned absorbers in the frequency range between 100 and 200 Hz, the special tuning depends on the height of this space.
2. Front and rear wall of the pit should be covered by low frequency absorbers for reducing the low frequency components of the diffuse sound field inside the pit.
3. High frequency components must not be absorbed by the walls of the pit for preserving at least a small part of the instruments' brillance.
4. Standing waves occurring under the stage are excited in particular by timpany, tuba, and bassoon between 100 and 200 Hz, by French horn, bassoon (and by clarinet in ist lowest part of compass) between 250 and 335 Hz. This has to be considered for the seating arrangement, if there is no absorption under the stage.
5. A transparent front part of the stage may avoid the vertical standing waves too.