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THE ACOUSTIC DESIGN OF PARTIALLY ENCLOSED ORCHESTRA PITS

Robin K. Mackenzie

Department of Building, Heriot-Watt University, Edinburgh

ABSTRACT

During recent years changes have taken place in connection with the performing arts in the United Kingdom which have placed increasing emphasis upon the need to improve existing theatres throughout the country.

The general economic climate in the country has brought about a steady decline in the number of new theatres which have been commissioned and the emphasis is now clearly on the rehabilitation of existing auditoria. Such improvement often has to be undertaken in theatre designs which impose severe space limitations for the orchestra. In order to accommodate the orchestra, of even a medium sized touring company, it is necessary in the majority of auditoria to create a partially enclosed orchestra pit.

In parallel with the general expansion in touring programmes there is also a tendency now for conductors to require that productions are played to their full score, which reinforces the need for the larger orchestra pit.

This paper describes the findings of a programme of research which was carried out in order to establish the relationship between the acoustic properties of partially enclosed orchestra pits and the subjective response of musicians. Guidelines as to the geometric and functional design are given together with details of the re-design of the pit at the Kings Theatre in Edinburgh which was re-commissioned during August 1985. Details of the scale model tests to establish the optimum shape are given together with a description of the electro-acoustic sound reinforcement system which was installed as an integral part of the re-design exercise.

INTRODUCTION

It is rather unusual in contemporary acoustics research to find a subject which has never been studied before, but despite an exhaustive search, no reference has yet been found to any previous investigations into the problems associated with orchestra pits. Indeed, only one reference (1) has been found relating to design criteria, which is attributed to Paul Veneklasen who referred to his design criteria as follows "It must achieve : musical balance between stage and pit; adjustable size; reflection of sound from pit to stage to pit for cohesive performance; physical and visual tenability for pit performers; musical balance within the pit orchestra". A recommended layout was given as shown overleaf in Fig. 1. The complete absence of research meant that surveys of both the acoustic conditions within pits and the subjective impressions of performers and audience were necessary.

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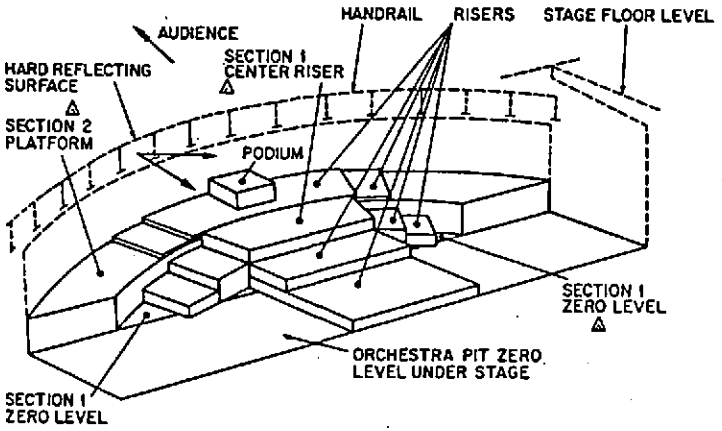

FIG. 1 Modern Orchestra Pit - partially submerged, viewed from under overhanging fore-stage. (After Veneklasen)

ATTITUDE SURVEY AND ACOUSTIC MEASUREMENTS

Opera Audience

The subjective impressions of audiences were sought by carrying out questionnaire surveys in nine theatres, involving a sample of some 5000 persons. The principal findings were as follows:-

(i) The opera-goer is not particularly responsive to minor variations in the acoustic ambience unless he is subjected to a major distraction such as background noise or echoes.

(ii) The opera-goer invariably considers the orchestra to be too loud in terms of musical balance with the singers.

Orchestra

The subjective impressions of 139 musicians were obtained, covering seven professional orchestras. The principal findings involved the following five aspects:-

(i) Stage-Pit Feedback

(ii) Auditorium-Pit Feedback

(iii) Orchestra Ensemble

(iv) Non-Acoustic Considerations

(v) Use of Electro-Acoustic Reinforcement

Stage-Pit Feedback

Almost half of the musicians indicated that they could not hear the singers sufficiently well. Acoustic measurement confirmed that the music level attenuation between the stage and the covered part of the pit was between 25 dB - 30 dB.

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Auditorium-Pit Feedback

Almost all of the musicians who played within the covered part of the pit felt that the lack of feedback from the auditorium affected their tonal quality.

Acoustic measurements confirmed this by showing that whilst the open part of the pit had reverberant properties similar to the auditorium, the covered part typically exhibited double-sloped decay curves. The reverberation characteristics of the covered part are influenced by a number of interacting parameters including:

(i) the depth of stage cover
(ii) the height of the opening
(iii) the width of the open pit
(iv) the damping constants of the pit and the auditorium

Graphical representation of the decay process within the pit is shown in Figure 2 for Auditoria with different reverberation times.

Orchestral Ensemble

The majority of players surveyed preferred open pits for ensemble. Almost three quarters of the musicians surveyed and particularly those sitting in the covered part of the pit, indicated that they experienced excessive sound levels, especially from brass and percussion. Ensemble within the orchestra becomes particularly difficult under such conditions, but all aspects of the musician's performance are affected by excessive sound.

Measurements involving musicians confirmed that the levels required to achieve ensemble within the orchestra may well, under the covered section of the pit, cause masking of an adjacent players sound resulting in that musician having to play louder and thus establish the pattern for a reiterative process which extends throughout the orchestra and results in a highly unsatisfactory musical form.

Non-Acoustic Considerations

The survey of musicians indicated that non-acoustic subjects such as access, lighting, safety, and basic facilities were important in maintaining morale and hence performance standard. Particular mention was made of lack of space indicating that the normal allocation of 1.1 m^2 - 1.2 m^2/player was insufficient, whilst 2.0 m^2/player was considered spacious.

Half of those surveyed considered a height (floor to underside of stage) of 1.9 m to be unsatisfactory, whilst 2.0 m was generally considered adequate.

The use of electro-acoustic reinforcement

With the information obtained from the survey and given the situation that a number of existing pits did not comply with what was generally understood to be desirable geometric proportions, an experiement was devised in order to assess the suitability of electro-acoustic reinforcement within the pit.

The Theatre Royal, Glasgow which has an orchestra pit with a 5.7 m stage overhang, was used for the investigation with tests being undertaken during rehearsal periods.

Subjectively, the musicians commented that the singers were more audible thus improving ensemble with the stage, but with little effect on ensemble with the rest of the orchestra. The system proved too loud during chorus passages. A slight improvement in tonal quality was recorded which was encouraging

considering that only one auditorium microphone was used.

KINGS THEATRE, EDINBURGH

Initial Design

The initial re-design of the orchestra pit was based on a plan area of 11.2 m x 10 m (L x B) with a covered section of 6.9 m x 3.0 (L x H). Acoustically, the only satisfactory dimension was the plan area of 112 m^2 which would provide a spacious 2.0 m^2 per player for medium-sized orchestras and easily accommodate the largest opera orchestras when required. Against this was set the problems likely to be encountered with a 6.7 m stage cover, which would certainly result in a total lack of sound feedback from the auditorium for the rear half of the pit.

Design revisions

The rather timeous completion of the research programme allowed the results to be used as a basis in the design revisions.

WIDTH - The only dimension which was fixed by virtue of the proscenium opening was the width which was set at 10 m .

SPACE - The research findings suggested an optimum space allocation of 1.5m^2/ player which for a medium sized opera of 60 players would require an area of 90 m^2.

DEPTH OF COVER - The research findings suggested that wherever possible the depth of the pit covered should be less than that open to the auditorium, and as a maximum limit should not exceed the open dimensions. Acoustical consultants often find themselves to be under considerable pressure from the client over this matter since the further the pit extends into the stalls, the greater the number of seats which are lost. In this case the depth of cover was extended to the maximum recommended, 4.5 m.

HEIGHT OF PIT - The research produced a number of useful guidelines, the first of which established that the minimum acceptable height for the covered part of the pit is 2.0 m. The second rule of thumb is based on the requirement for all the musicians to maintain at least some visual contact with the auditorium. This limits the depth of cover to 2.0 metres for a pit height of 2.0 metres and an additional 0.5 metres depth of cover for each additional 0.1 metre in pit height. Given that the depth of cover was set at 4.5 metres, the pit height was adjusted to 2.5 metres. The resulting ratio of depth/height of 1.8 was clearly in excess of the third criterion viz. that the ratio should not exceed 1.2 if useful reverberant energy is to be returned to the pit. In view of this predicted deficiency, an electro-acoustic sound reinforcement system was recommended for the orchestra pit.

SHAPE OF THE PIT - It was suggested that some benefit might be obtained by orientating the internal surfaces of the pit. For example, by following the rake of the stage, at 3° from the horizontal, additional headroom could be provided for the musicians at the rear of the pit. Alternatively, by creating a rake in the opposite direction i.e. sloping up from the rear of the pit at 3° to the horizontal one may produce a horn effect and thus increase the energy output towards the auditorium. Similarly, by adopting a trapezoidal plan with the side walls spreading out from the rear at 3° from the parallel an increase in energy output may be produced. An 1/8" scale model pit was constructed and filled with 60 model scale musicians.

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The results were as follows:-

Nature of alteration	Change in Sound Level in Auditorium
(a) 3° rake in ceiling up towards front	+ 0.8 dB(A)
(b) 3° rake in ceiling down towards front	- 0.1 dB(A)
(c) 3° splay in side walls towards front	+ 0.2 dB(A)
(d) (a) and (c) combined	+ 0.9 dB(A)
(e) As (d) but with 6° splay in side walls	+ 1.0 dB(A)

In view of the small improvement likely to be obtained by offsetting the walls and ceiling, it was decided to retain the parallel surfaces originally proposed.

SURFACE FINISHES - The use of absorbent finishes to reduce the early energy level and thus enhance auditorium sound was investigated. Once again model studies were used and measurements of sound level in the auditorium were made for varying applications of absorbent. The results were as follows:-

Pit Surface receiving absorption	Change in Sound Level in Auditorium
Side Walls	- 0.4 dB(A)
Rear Wall	- 0.9 dB(A)
Ceiling	- 2.9 dB(A)
Ceiling and Walls	- 3.3 dB(A)

It was decided to leave the surfaces reflective until further investigations within the actual pit were completed.

ELECTRO-ACOUSTIC REINFORCEMENT

In order to improve ensemble between the musicians and the singers and to return useful auditorium reverberation to the orchestra pit an electro-acoustic reinforcement system was designed and installed.

Microphones

Since the principal requirement by musicians in being able to hear singers is to maintain metrical accuracy during accompaniment it is desirable to place the microphone as near as possible to the performers on stage. Accordingly, two cardiod microphones mounted in anti-vibration mounts, were located at the footlights as shown in Figure 3.

In order to return reverberant sound to the pit, two cardiod microphones were placed at the edge of the 1st and 2nd balconies, facing upwards in order to give more prominence to the reverberant sound and less to the direct components.

Use has been made of the rear lobes of the cardiod microphones which usefully pick up sound from the strings. Due to their location in the pit, the strings do not radiate very effectively back into the covered section, especially to those areas situated obliquely opposite.

Loudspeakers

Ideally each player beneath the covered section should have a loudspeaker directly above his head in order to maintain correct balance. For a variety of reasons, this was not possible at the Kings and a single line of column loudspeakers were installed midway between the rear wall and edge of the stage, with provision made for a second line to be installed further back at

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some time in the future.

Circuits

Following the experience of the trials in the Theatre Royal, it was decided not to apply delays to the auditorium microphone circuits but to mix the signals from the two microphones thus returning direct sound at 40 ms and 50 ms intervals and reverberant sound from 95 ms and 115 ms intervals. This would mix with natural reflections at 80 ms, (1st balcony) 100 ms (2nd balcony) and 130 ms (ceiling). A delay of 10 ms has, however, been applied to the stage microphones in order to maintain temporal accuracy.

A compression circuit has been fitted to the stage channel in order to limit the output during periods involving full chorus.

CONCLUSIONS

The problems experienced by orchestral musicians from playing in partially covered pits have been investigated by measurement and by obtaining the subjective impressions of musicians and audiences. Recommendations have been made for both acoustical and non-acoustical factors and guidelines given for the desired geometry of the partially enclosed pit. These guidelines have been put into effect in the re-design of the Kings Theatre, Edinburgh including a system of electro-acoustic reinforcement which, although still being developed, is already providing encouraging results.

REFERENCE

(1) R.K. Mackenzie, 'Auditorium Acoustics', Applied Science Publishers Ltd., 1975, p.26.

ACKNOWLEDGEMENTS

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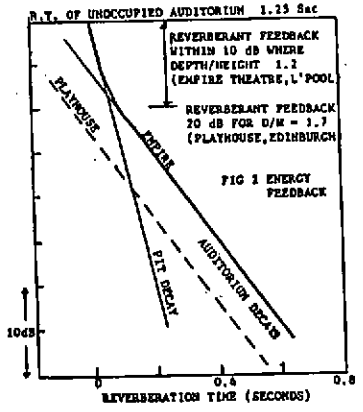

FIG 2 ENERGY FEEDBACK

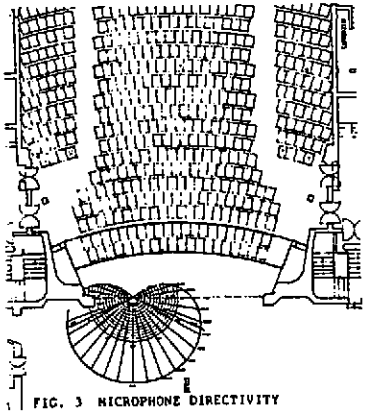

FIG. 3 MICROPHONE DIRECTIVITY