Modern Stage Acoustics Measurements in Orchestra Pits

John O'Keefe
Aercoustics Engineering Ltd.
50 Ronson Drive, Suite 127
Toronto, Canada, M9W 1B3

INTRODUCTION

The subject of performer related acoustics has been briefly introduced in a companion paper[1] The existing literature has concentrated on open stages in concert halls, although Naylor has performed some measurements in orchestra pits[2]. Orchestra pits are not always easy environments to perform in. Noise levels in most pits often exceed safe levels. In fact, most acoustical research in this area has concentrated on hearing loss. With the emerging understanding of performer related acoustics, we thought it might be timely expand the investigation of the acoustical conditions in pits.

MEASUREMENT SYSTEM

The measurements system has been described in the companion paper[1]. Measurements were performed at and between three locations inside the pit and between those three locations and the five standard locations that we measure on stage (Soloist, Violin, Viola, Horn and Bass). We did not use a glass fibre blanket underneath source. Unless stated otherwise, Support measurements have been measured at 0.5 m. Three rooms were measured including the Queen Elizabeth Theatre in Vancouver, the Princess of Wales Theatre and MacMillan Theatre, both in Toronto. Of the three, only the latter pit was empty. The Princess of Wales pit is partially covered while the other two are open, at least in the configurations measured here.

HEARING OF SELF

The 1 m source receiver distance for Support measurements is not entirely practical in the confined quarters of an orchestra pit. Following Naylor's example, a 0.5 m source receiver distance has been chosen. Similar to the previous study[1] on stages, Support measurements were performed at both 0.5 and 1.0 m. The differences between the two are slightly less in pits than they are on stages. At 1000 Hz, the average difference between Support ratios in pits is 3.5 dB, it is 4.4 dB on stages. The reduced difference can be explained by the proximity of the walls and, in the covered pit, by the ceiling.

Average STtotal measurements are higher in the pits than on most stages, again, as expected. A summary of the results is shown in Table 1.

Table 1
1kHz Support and MTF
(ST @ 0.5m)

	STtotal	**STearly**	**MTF**
	Self	Hearing of Other	
QET	-14.0	-14.4	0.84
POW	-10.7	-10.7	0.80
MacM.	-11.3	-12.1	N/A

HEARING OF OTHER.

Gade has found that STearly, measured at 1.0 m, correlates better with Ensemble or Hearing of Other than his Early Ensemble Levels measured across the length and width of the stage. Intuitively this seems a bit odd but when one considers the stage *average* measurements correlated to a group of musician's *average* response, the findings are perhaps not all that surprising.

The reasoning breaks down when one considers the communication between a stage and the orchestra pit however. In this situation, the two groups of musicians are located in significantly dissimilar acoustical environments. In the measurements presented here, STearly was, on average, 8 dB higher in pits than on stages.

Naylor found Modulation Transfer Function (MTF) to be a good descriptor of Hearing of Other[4]. Unlike STearly, the MTF is measured between distant locations. In the pit to stage scenario, the MTF seems the more likely alternative to quantify Hearing of Other. Figure 1 shows some of the MTFs we measured in orchestra pits (heavy lines) and between the pit and the stage above (light lines). At both the Princess of Wales and Queen Elizabeth Theatres, we measured Mean MTFs of 0.56 between the pit and the stage. Inside the pits, the mean MTFs were 0.80 and 0.84 respectively.

STAGE TO PIT BALANCE

The original intention of this paper was to quantify performer related acoustical conditions in orchestra pits. Once in the various rooms however it made sense to extend at least some of our measurements to the audience chamber. In so doing some interesting aspects of the acoustical relationship between orchestra pits and stages as experienced from a audience member's perspective were found.

For a given seat, two sets impulse response functions were measured, one with the source in the pit and the other with the source on the stage. The measurements were performed at a single seat on the orchestra level, a few rows in front of the balcony overhang and a single seat on the first balcony. The following parameter was developed to quantify the ratio of energy received from the stage and pit:

$$SPB = \frac{\int_{t1}^{t2} p^2{}_{stage}(t)dt}{\int_{t1}^{t2} p^2{}_{pit}(t)dt}$$

In this study we have considered three variations of the Stage to Pit Balance (SPB):

	t1 (ms)	t2 (ms)
SPB_{early}	0	50
SPB_{late}	50	∞
SPB_{total}	0	∞

A 50 ms early energy temporal threshold was chosen rather than the 80 ms that has been used by many for musical clarity. This was done in light of the recent work by Julien et al.[5] suggesting a shift in clarity thresholds. It should also be remembered that in a performance that makes use of an orchestra pit, speech intelligibility or diction is, by definition, more important than orchestral reverberance.

Figure 2 shows the results overall ratio of sound emitted from the stage compared to the pit. Measurements on the orchestra level are shown with a heavy line, balcony measurements with a normal line. Not surprisingly, the balance is closer 0 dB for the open pit. It is not clear that an SPB_{total} of 0 dB represents an optimum condition. Given the acoustic energy generated by the orchestra, compared to a singer, it may be greater than 0 dB. Recognising the importance of singers' formants, the optimum SPB_{total} may vary with frequency.

Looking at the total energy, it is surprising how close the orchestra and balcony results are to each other inside the theatres. There does however appear to be a high frequency increase in pit levels compared the stage on the orchestra level of the Queen Elizabeth Theatre.

Figure 3 shows the SPB_{early} curves for the same two theatres. It seems clear that, like so many other aspects of room acoustics, the balance between voice and orchestral sound in a proscenium arch theatre is highly dependant on the nature of early reflected sound in the room. On the orchestra level of both rooms, the low frequency sound emitted from the pit is significantly reduced compared to the balcony. Note that, on the orchestra level, the frequency imbalance is about the same for the open and covered pits.

On the balcony, the advantages of an open pit are a little more obvious. The covered pit still exhibits a frequency imbalance, although not as pronounced as on the orchestra level, The open pit shows an almost flat response, that is the frequency content of sound emanating from the pit is about the same as the sound radiating from the stage.

Looking at the comparatively uniform response of the SPB_{early} curves measured on the balconies, it is not surprising that these seats are traditionally preferred in a proscenium arch theatre.

The results of the SPB_{late} measurements are similar to the SPB_{total} curves, although the variations are slightly less pronounced. It appears that, at least in these theatres, the energy arriving in the first 50 ms dominates the balance between the pit and the stage.

The results of the Stage Pit Balance study show quantifiable differences between an open and partially closed pit. Using this rather simple parameter, SPB, it should be a fairly straightforward exercise to predict balance during building design, just as one might calculate Clarity ratios or Early Lateral Fractions. Clearly there is room for more work, notably in determining an optimum range and developing a database from existing rooms.

SUMMARY

Stage acoustics measurements have been performed in three orchestra pits in an effort to measure performance related acoustical conditions. It was found that Support ratios in the orchestra pits are about 8 higher than on open stages. It has been suggested that using STearly to quantify Hearing of Other between a pit and the stage above is not practical. The Modulation Transfer Function appears to be a more appropriate parameter.

Measurements of the acoustical energy balance between the stage and the pit have been performed in the orchestra and balcony of two proscenium arch theatres. The results indicate that most of the imbalance, both in frequency and overall level, occurs in the first 50 ms of the impulse response. Stage Pit Balance (SPB) is better on the balcony than it is at orchestra level.

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REFERENCES

1. J. O'Keefe. "On the Sensitivity of Stage Acoustics Measurements", Submitted to the Sabine Centennial Proceedings (June 1994)
2. G.M. Naylor, Musical and Acoustical Influences on the Achievement of Ensemble", Ph.D. Thesis, (Herriot Watt University, 1987)
3. Investigations of Musicians' Room Acoustics Conditions in Concert Halls. Part II: Field Measurements and Synthesis of Results", A.C. Gade, *Acustica*, **69**, 249-262 (1989)
4. "Modulation transfer and ensemble music performance", G.M. Naylor, *Acustica*, **65**, 127 (1987)
5. "Some results on the objective characterisation if room acoustical quality in both laboratory and real environments", J.P. Jullien, E. Kahle, S. Winsberg, O. Warusfel, *J. Acoust. Soc. Am.*, **93(S)**, 2281 (1993)

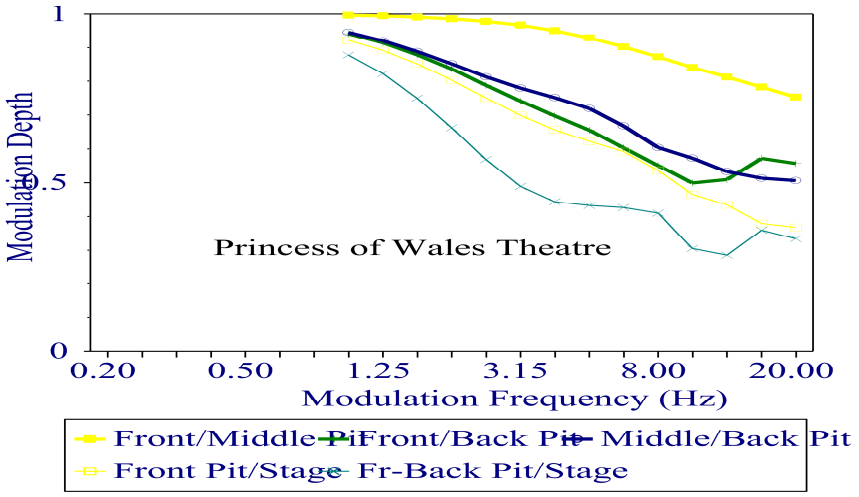

Figure 1 *Modulation Transfer Functions measured inside an orchestra pit (heavy lines)and between the same pit and the stage above*

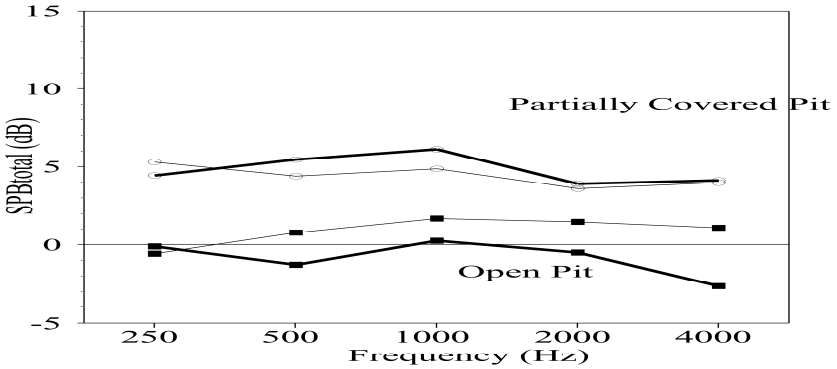

Figure 2*. Stage to Pit Balance (Total) for two types of orchestra pit measured in the orchestra and balconies of the Princess of Wales Theatre (POW) and the Queen Elizabeth Theatre (QET).*

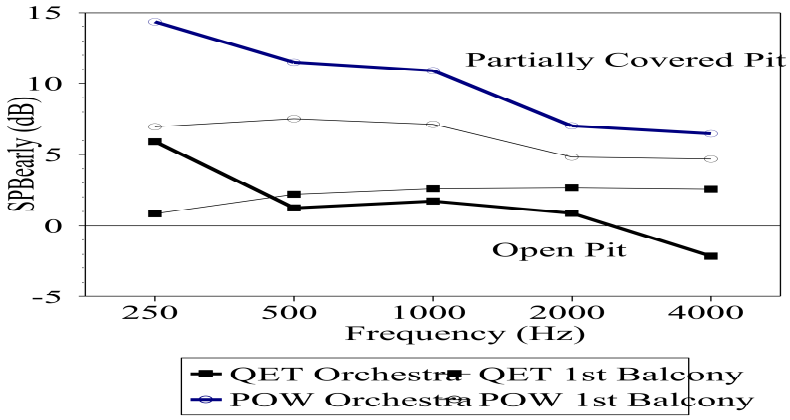

Figure 3 *Stage to Pit Balance (Early) for the same theatres as Figure 2. The effects of the pit rail and cover are most evident in the first 50 ms of the impulse response. Note the high frequency reductions on the orchestra level compared to the relatively uniform response on the balcony.*