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ACOUSTIC DESIGN OF THE NEW PRINCESS OF WALES THEATRE IN TORONTO,CANADA

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1. INTRODUCTION

Miss Saigon is amongst a handful of late 20th century productions in genre that has become known as a "mega hit". These musicals have production budgets that can rival the construction costs of the buildings in which they are performed. When the Mirvish family of Toronto won the rights to produce this play in Canada, they agreed to build a 2000 seat theatre specifically for it. The Mirvish's own and operate The Old Vic Theatre, in London and The Royal Alexandra in Toronto. The latter was named for the consort of the day, Queen Alexandra. It seemed appropriate therefore, that in January of 1992, the current Princess of Wales granted the use of her title on the building.

The acoustic design of the theatre is based rather loosely on the nearby Royal Alexandra Theatre. The Royal Alexandra seats 1500 people, the Princess of Wales 2000. Both are located on small tracts of land near a surface rail transit line and both have double balconies. The first concern in fact was to recommend a double balcony in lieu of the single balcony that had been proposed in the conceptual design.

2. DESIGN PHILOSOPHY

This early recommendation was indicative of the design team's approach to the entire project. When we spoke to the architect, Peter Smith, about the subject of the balcony we were pleased to learn he had already been considering such a design change. The design team met in the architect's office, discussed the various options and arrived at the decision together. There are advantages and disadvantages to a double balcony room and in the end there are even some compromises. A good theatre is in many ways a collection of well thought out compromises.

The tacit and in some ways happenstance design philosophy throughout the project was to integrate contemporary thinking with successful precedents from the past. Architecturally, this translates into a traditional English playhouse adorned with abstract sculptures and murals. In terms of acoustical design, decisions were guided by the latest developments in computer modelling and psycho-acoustics but in the end did not steer too far from the much loved Royal Alexandra Theatre located just down the street.

3. ACOUSTICAL CRITERIA

Modern acoustic measurement data are readily available for concert halls. When we began this project however, data on theatres was virtually non-existent in published literature. The author was fortunate enough to participate in Barron's Survey of British Auditoria, [1] and its results formed the basis of our acoustical design criteria. Barron's work has since been published in text book format. Rooms that we were interested in for the Princess of Wales design included Wydham's, a double balcony room, and Theatre Royal, Bristol perhaps the first horseshoe shaped theatre in Britain.

In the twelve British theatres, Reverberation Times range from approximately .7 to 1.0 seconds, The Roundhouse in London being the exception. Acceptable Distinctness coefficients (D50) were about 0.60 or higher. Exceptions were The Roundhouse and The Festival Theatre in Chichester, neither of which are known for good speech intelligibility. Standard deviations are in the range of 0.15 to 0.20 with the exception of The

Arts Theatre in Cambridge which was significantly lower and coincidentally has the highest Distinctness coefficient. The Arts Theatre is a small room with a single balcony seating only 655, the average Distinctness coefficient is 0.69 and the standard deviation across central and lateral measurements is 0.08.

From our own measurements and those of John Bradley [2] we were able to compare some local theatres. Conditions in Canadian theatres are much the same as British theatres although we find slightly higher reverberation times. All but one of the seven theatres we have data for have reverberation times above 1.0 seconds. Unfortunately we do not have D50 data for all of these theatres.

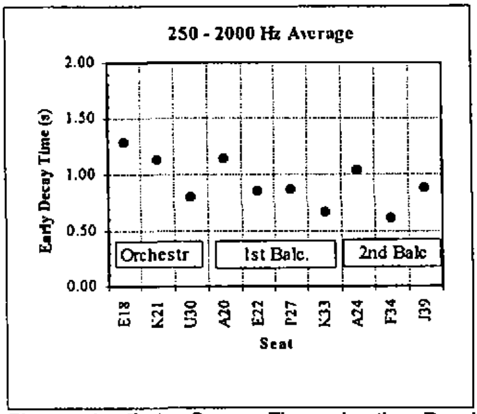

Figure 1. *Early Decay Times in the Royal Alexandra Theatre show the effect of the long balcony overhangs.*

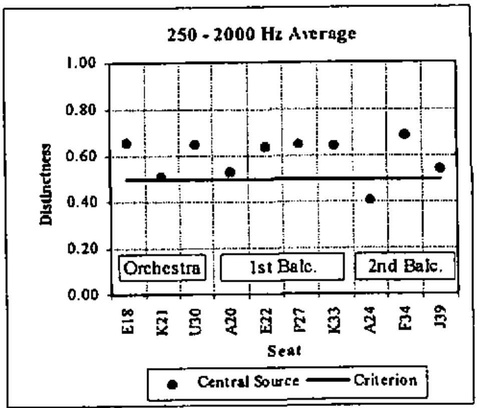

Figure 2. *Distinctness coefficients also show effect of the balcony, though not as clearly as the EDT. Note the low value in the first row of the 2nd balcony.*

Figures 1 and 2 give a better look at the measurements in the Royal Alexandra and are perhaps more germane to the design considerations of a double balcony theatre. Note the pattern of the Early Decay Times and the D50 values in the parts of the room that are covered by a balcony. D50 increases underneath the balcony and close to the ceiling. Early Decay Times show the opposite trend.

4. ARCHITECTURAL DESIGN

The plans and longitudinal section of the finished theatre are shown in Figure 3. One of our big concerns with the architect's original design was a 9 meter diameter opening in the ceiling for lighting. The concerns were with Loudness and Clarity in the front seats of the balconies.

One mitigating proposal we made was to make use of the top corners of the proscenium arch. Our original suggestion was for convex corners but we eventually settled for concave corners. The foci of these concave corners, of course, are not near the audience. It became apparent that if there was a solution to the hole in the ceiling, we would have to find it somewhere else!

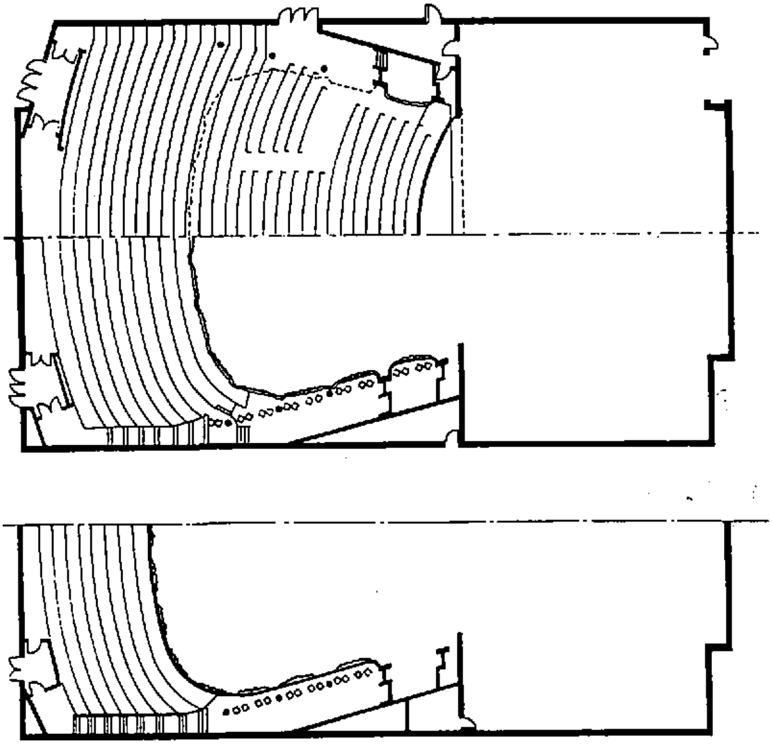

Figure 3a *Orchestra and balcony plans of the completed Princess of Wales Theatre.*

One advantage of a horseshoe shaped room is that the balcony facia can operate as useful reflecting surfaces. Using a specifically designed module of our room acoustics software, we examined the reflected energy coverage from the facia to determine if we could compensate for the opening in the dome. Figure 4 shows reflected sound off the first balcony facia as received on the first and second balconies, on the left and right of the figure respectively.

The software we have developed is called TRACES and is a typical hybrid routine using the method of images and particle tracing. In 1990, a new module called SHADOWs was added to the package. It is used to determine the extent of first order reflections cast by individual surfaces such as ceilings, walls, overhead reflectors, etc. For a given reflecting surface, the method of images is used to generate a virtual source. This becomes the centre of a particle tracing source and, in Figure 4, we see the points where this sound is reflected off the front of the balcony and where it intersects the "hearing plane", approximately 1 meter above the floor. One can see that the facia provides good coverage of the hearing plane. The room of course is symmetrical so we would expect almost twice the coverage shown here.

Facia reflections have some advantages over ceiling reflections: (i) they can reach seating underneath the balcony where ceiling reflections cannot; (ii) they are lateral reflections in most seats, which will encourage broadening and envelopment during musical passages and (iii) they arrive at listeners in the middle of the room sooner than similar reflections off the side wall. For example in the Princess of Wales facia reflections arrive at the centre of the first balcony 17 ms after the direct sound. Side wall reflections arrive in the same area after 31 ms.

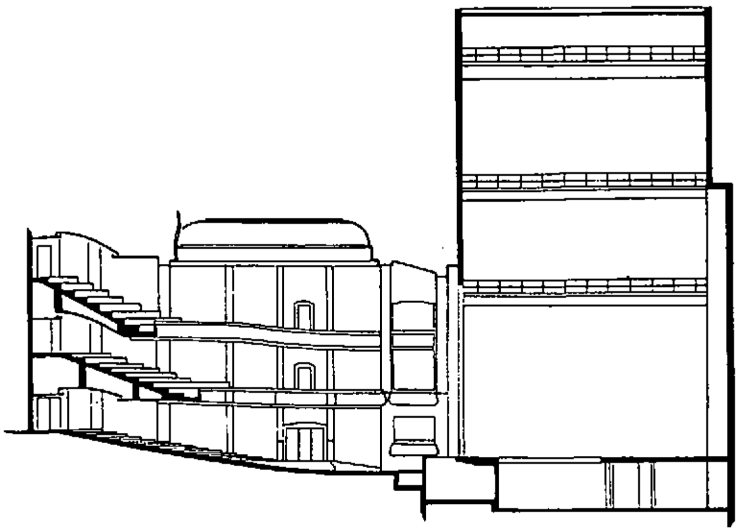

Figure 3a *Longitudinal section of the completed Princess of Wales Theatre.*

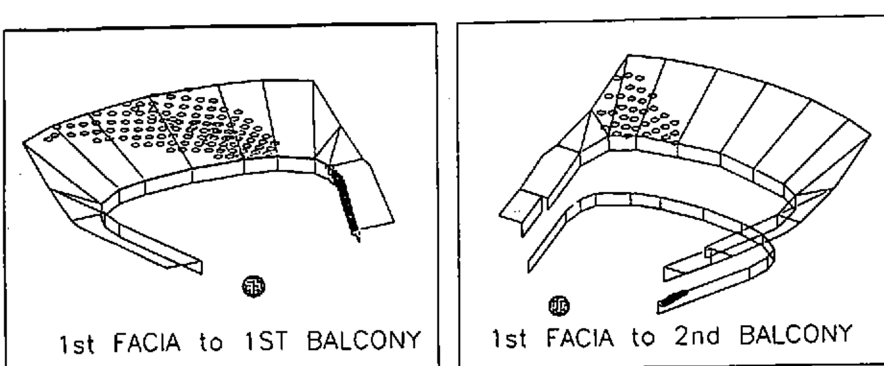

Figure 4 *Reflections cast by the balcony facia onto the "hearing plane" in the balconies.*

ACOUSTIC DESIGN OF THE PRINCESS OF WALES THEATRE

The original design of the theatre called for curved facia. These were later changed to abstract sculptures by the American artist Frank Stella. These of course act as scattering elements and were a welcome addition. Stella also contributed several stunning murals inside and outside the building. It has been estimated that the art work, if it was for sale, would be worth as much as the theatre.

Other acoustic design elements of interest are:

- The room is 29 m wide, with a volume of 10,500 m^3.
- The seats are fully upholstered including the back of the back rest. This means that there is a minimal difference between the acoustics of a full or empty house.
- The walls are 300 mm poured concrete with 16 mm gypsum board laminated and nailed directly to the wall to prevent absorption of low frequency sound.
- The ceiling is double layer 16 mm gypsum board with a layer of tar paper in between to increase damping. This was done to reduce the effects of frequency selective absorption at low frequencies.
- Primitive root diffusers (PRD) have been designed and installed on the back walls of the theatre and in the orchestra pit. These are one dimensional wooden PRDs, 17 wells, typically 300 mm deep, with 63 mm wells and 2 mm fins.

5. CALCULATIONS AND MEASUREMENTS

Calculated and measured Reverberation Times are shown in Figure 5. Measurements were performed in a similar fashion to those outlined by Barron [3], that is with a directional source on stage pointed first toward the audience then into the wings.

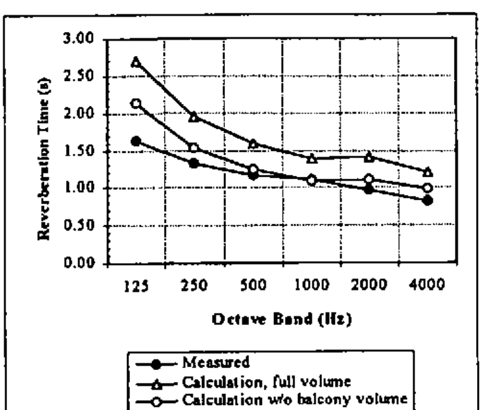

Figure 5. *Calculated and measured reverberation times. Better agreement is found when the volume underneath the balconies is excluded from the calculation.*

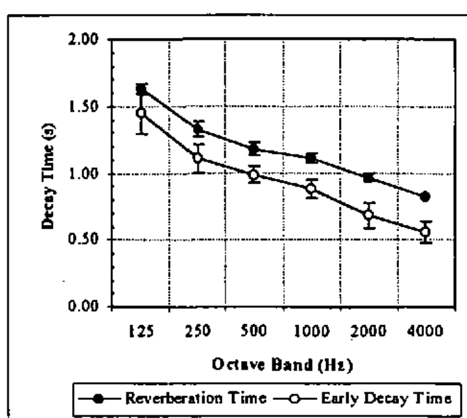

Figure 6. *Measured Reverberation Time and Early Decay Times. Markers indicate standard deviations.*

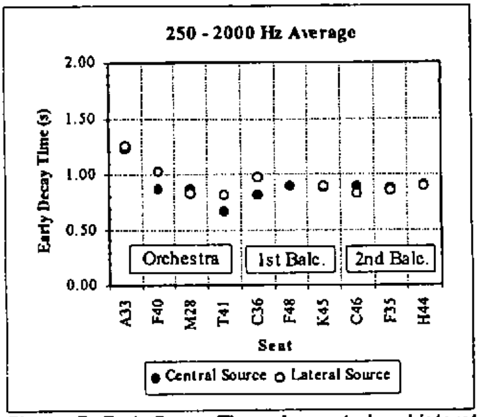

Figure 7. *Early Decay Times for central and lateral sources as a function of seat location. The effect of the reverberant stage house can be seen in the front seats but beyond that EDT is fairly uniform.*

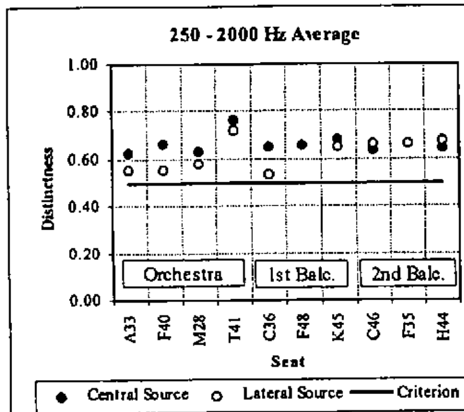

Figure 8. *Distinctness coefficients as a function of seat location for central and lateral sources*

Two predictions of the reverberation time were performed: the first included the entire volume of the house and the latter excluded the volume underneath the balcony overhangs. In neither case was the volume of the stage tower included. The measured data shows a much better agreement with the calculation procedure that omitted the balcony overhangs.

Taking a closer look at the data measured in The Princess of Wales we see the following:

- Early Decay Times are shorter than Reverberation Times. This perhaps explains the good early energy ratios. It also suggests a coupled Reverberation Time, although this is not immediately apparent looking at the decays. The obvious mechanism for the coupled Reverberation Time is the hole in the ceiling. See Figure 5.
- A high bass ratio was measured, in the range of 1.5. It is most likely due to the massive, stiff construction.
- High frequency early energy ratios are high, probably due in part to the upholstered seat backs.
- The average Distinctness coefficient is 0.64 and the standard deviation is 0.06. In terms of uniformity of speech intelligibility, The Princess of Wales compares favourably to the much smaller Arts Theatre in Cambridge.
- Loudness levels vary more than would be acceptable in a concert hall but not so much as to be an issue of complaint.

6. COMPUTER MODEL

Computer based calculations of the impulse response functions were less conclusive than the classical reverberation time formulae. The method of images algorithm proved particularly weak. There were over 200 surfaces in the model some of which were quite small. On more than one occasion we found legitimate reflection paths that the programme had failed to report. The programme was written by the author and, admittedly, other implementations of the method of images routine may have been more successful at finding reflection paths. The fact remains however that for a fourth order reflection sequence, the method of images routine performs over 1 billion validity and visibility checks each one of which is subject to round off error. This experience and others like it have caused us to limit our application of computer based acoustical models. We are now relying more on physical scale models especially for the prediction of impulse response functions and reverberation times. Computer models are used to optimise the size and location of reflection surfaces in three dimensional space using the hybrid SHADOWs routine described above.

7. USER' COMMENTS

Alain Boublil and Claud Michel Schonberg, the composers of *Les Miserables* and *Miss Saigon* said: "The room has a warm generous sound".

David Abell, the music director of *Miss Saigon*, described the sound underneath the balcony as "a bit smaller" than the rest of the room and the loudness measurements would appear to support his opinion.

Greg Connoly, the sound operator for *Miss Saigon*, tells us that the orchestra pit projects well and the house does not need as much amplification as others he has worked in. He also noted that the sound is very crisp, so much so that it is sensitive to humidity conditions. In his subjective estimation, it was "probably a couple of dB above 2000 Hz".

8. ACKNOWLEDGEMENTS

I would like to thank Peter Smith and David Mirvish for their support throughout and beyond this project. Figure 3 is a pen and ink trace of the original Lett/Smith Architects drawing, done by Ms. Iwona Stasiewicz.

9. REFERENCES

[1] O'KEEFE, JOHN 'Objective Measurements Of Speech Intelligibility In British Theatres', M.Sc. Thesis, Institute of Sound and Vibration Research, 1985

[2] BRADLEY, J.S. 'Acoustical comparison of three theatres', J. Acoust. Soc. Am., 79, p 1867-1832 (1986)

[3] BARRON, 'Auditorium Acoustics and Architectural Design', E & F Spon, London, (1993)

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