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ACOUSTIC TESTS IN THE BARBICAN CONCERT HALL MODEL

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1. Introduction

The Barbican concert hall is unique in many aspects and as such presents the consultant with many unknowns for which no precedents exist. In plan the hall is roughly octagonal with a stage off one side. The floor is raked with two changes of floor level but with minimal overhang. The length of the hall is relatively short by concert hall standards (rear-most seat 32m (105ft) from the stage front), whilst the hall is very wide at 43m. The ceiling is only 18m above stalls floor level with two pairs of very deep beams, with a depth of 3.7m, running along and across the ceiling to provide structural support. The ceiling has a coffered structure but to further promote diffusion and avoid shadowing effects due to the roof beams an intricate system of about 2000 spheres is being installed above the level of the base of the roof-beams. The spheres are open at both ends and to be constructed of acrylic. They are of three sizes, the largest being 0.76m diameter.

The hall is basically constructed of concrete. The side walls have a series of low frequency absorbers in the form of double-sided panel absorbers. In the front half of the hall these are arranged parallel to the main axis of the hall. The stage area has an absorbent/diffusing wall treatment.

Because of the unconventional nature of the design and in particular the impossibility of predicting the behaviour of the suspended spheres, it was decided to construct and test a 1:8 scale model of the auditorium. The model was installed in Cambridge at the end of 1975 and has been tested in several configurations during the last three years. Both objective and subjective tests have been conducted in the model; this paper will concentrate on the objective test results. All quantities will be quoted as for full-size.

2. Measurement procedures

With good sealing of the model and use of an air lock on the entrance, the model has been successfully dehumidified to 2-3% r.h. by a continuously running plant. With hindsight one is able to assess the accuracy of the acoustic modelling. The principal inaccuracies are excessive absorption in the "empty" shell of the model, particularly at low frequencies, and inaccurate modelling of the seat upholstery. In the case of the latter, there was inadequate time to select a more suitable acoustic foam; regarding the "empty" shell, this is partly because varnished timber at model frequencies is more absorbent than the concrete it is modelling. However shrinkage of the timber has also left gaps which no doubt contribute to absorption but which should ideally have been sealed.

The inaccuracies are however not felt to invalidate the results. The aim of the modelling has not been to reproduce identically the reverberation time but rather to study the effect of the individual components on the acoustic conditions. Results have been corrected, where relevant, to the predicted reverbera-tion time (R.T.) of the hall. In the final configuration the mid-frequency model R.T. (without a model audience) is intermediate between the predicted occupied and unoccupied conditions full-size, though the low frequency (125Hz) model R.T. is 70% of the predicted value.

In addition to reverberation time, objective measurements were made relating to the following subjective characteristics: subjective reverberation time; clarity-reverberance; spatial impression and loudness. Rather than catalogue the suitability of the model auditorium with regard to these attributes, the following discussion will concentrate on the more interesting changes which occured with changes in configuration and on results which indicate the behaviour of sound in the auditorium.

3. Effect of suspended spheres on diffusion

One of the great virtues of model work is that one can measure the absorption coefficient of the model material in diffuse conditions (in a model reverberation chamber) and measure the effective absorption coefficient in the model. If the two differ significantly it is very likely that there has been a change in the state of diffusion in the model.

It is reasonable to assume that diffuse conditions prevailed in the model before any absorbent materials were installed. The upholstery was installed in two batches and the reverberation time in the model was measured after each. With only half the upholstery the R.T. was close to predicted; but with the complete upholstery the R.T. was higher than predicted. This suggested that with absorbent seating and the deep coffering created by the roof beams there was a state of poor diffusion, and that the reverberation time was being dominated by a sound field remote from the seating, presumably in a roughly horizontal plane below the ceiling.

The spheres were tested in the model reverberation chamber and then installed in the roof space of the model. A marked change in the reverberation time occured, again at odds with the predicted change due to the spheres alone. The largest discrepancy occured in the 125Hz octave in which the effective absorption introduced by the spheres was three times the value predicted by the reverberation chamber measurement! However if the situation with upholstery <u>and</u> spheres is compared with the empty situation the agreement between measurement and prediction on the basis of a diffuse field theory is within experimental accuracy.

It would appear then that with upholstered seating alone there is poor diffusion in this auditorium, but that introduction of the spheres in the roof space re-establishes good diffusion, particularly at the lower frequencies. This has been one of the predominant reasons for the spheres being recommended as being acoustically valuable.

4. Variation of subjective clarity/reverberance with source position

The degree of clarity and its antithesis reverberance are felt to be one of the more critical subjective characteristics in concert halls. As a physical measure for this quality we use the ratio of (80ms) early to late sound. This has been measured in 14 seat positions with a forward and rear source position.

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Results have been averaged over five octaves (125Hz–2kHz) and are presented as results on a scale, the ratio is expressed in dB. The results can be compared both with the theoretical value for an exponential decay at the measured reverberation time and criteria recently suggested by Reichardt(1) for music of the classical and romantic periods. In Figure 1 the results for one of the measured configurations is presented for the central source position. The seat positions are labelled according to Stalls (S), circle (C) and upper circle (U); the number following the letter refers to the seat row counting from the front of the block concerned, primes refer to the seat blocks at the side.

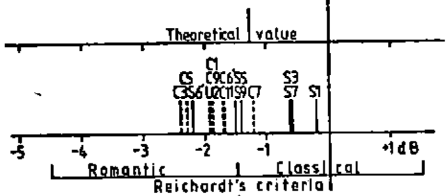

Figure 1. Ratio of early to late energy (in dB) in 14 receiver positions.

In the earlier configurations which were tested, the most serious concern related to the variation in the ratio of early to late energy with source position. As the source moved out to the front of the stage area so the proportion of early sound decreased (though the total sound level was unaffected). This situation exposes the risk of soloists, in particular, when performing from the front of the stage, being heard indistinctly. It had been hoped that the absorbent/diffusing stage wall treatment would rectify this variation with source position, but the improvement was found to be only slight. However the final configuration tested included a model orchestra which was found to reduce the variation with source position to minimal proportions. The inefficiency of the stage wall treatment may have been due to it not extending below 1.2m above the stage floor in the model.

5. Spatial impression

Of the various subjective spatial qualities of which a listener is aware in a concert hall, that associated with early lateral reflections, known as 'spatial impression', is considered by progressively more acousticians as critical for excellent acoustics. An objective measure for spatial impression is the proportion of early energy arriving laterally (2). It has been shown (2) that the lateral energy fraction and hence the degree of spatial impression is a function of hall width for simple rectangular-shaped halls. With a width of 43m we would expect a low degree of spatial impression, particularly at points remote from the side walls.

Curiously the early lateral energy fraction was not found to be especially low in the concert hall model. Mean values were found to be similar to those encountered in three halls in Australasia, which were all significantly narrower than the Barbican hall. A low value was encountered in fact at the front row of the stalls seating area, but this is both typical and of little concern, since listening conditions here are dominated by the proximity of the orchestra. The presumed reason for the satisfactory degree of spatial impression is the highly diffusing treatment in the ceiling, which scatters a significant proportion of the sound laterally. This is an interesting possible virtue of a diffusing ceiling which could be relevant to the design of other halls.

6. Loudness

The steady state sound level is now considered significant both as a component of the experience of spatial impression (3) and as a criterion itself relating to subjective preference (4). In full-size concert halls the louder concert hall is preferred. Measurements of the total sound level were made in 22 measuring source/receiver positions. The results can be compared with measurements made in six German halls during the Berlin group's study (as summarised in (4)). Several interesting observations can be made of the results with this measure.

Firstly, although there were variations with source position of the ratio of early to late energy, there was no significant variation in the total energy with source position, which is an expected result when the acoustic character of the walls and stage area are similar. Secondly, the mean total energy value is less (by 1.6dB) with a reflective stage condition than the theoretical value for a diffuse field - a probable characteristic in many halls. The introduction of absorbent treatment in the stage area and the inclusion of an orchestra reduces the total sound level, again as one would expect.

Perhaps the most interesting aspect is that the total sound level in the stalls is, in almost all cases, greater than in the circle, and the lowest sound level is in the upper circle. The difference between the extremes is about 6dB and therefore not excessive, but this concert hall in this respect is behaving like an extended balcony with a ceiling height which reduces towards the back.

7. Conclusions

This model exercise has demonstrated that the level of understanding of the behaviour of sound in an auditorium is of an order of magnitude greater with an acoustic model, though this produces the risk of being overwhelmed by detail. For a concert hall as original as this one, a 1:8 scale model has been invaluable in determining the value of different forms of acoustic treatment.

References

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