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THE ACOUSTICAL DESIGN OF WELLINGTON TOWN HALL: DESIGN DEVELOPMENT, IMPLEMENTATION AND MODELLING RESULTS.

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INTRODUCTION

In view of the unique nature of the Wellington Town Hall design, and in particular the unknown behavior of the quadratic residue diffusors (QRD), a 1:10 scale acoustic model of the hall was built. Although the QRD scattering behavior is calculable around the design frequency, the behavior at high frequencies was not known when applied as such, and it was feared that high frequency back scattering might produce some undesirable subjective effects. The model was therefore intended to provide a subjective evaluation of all the seating areas plus a full battery of objective tests, the results of which will be presented in this paper.

DEVELOPMENT STAGE ISSUES

Reflected Energy and Diffusion

The need for diffusion of strong early reflections which may be expected from such surfaces as the main reflectors in this design, arises directly from the psycho-acoustical studies made on the perception of lateral reflections during the last 15 years. Reflections from the side of the listener which are too strong or too early relative to the direct sound can cause false localisation and/or colouration. An experimental study we have made comparing a synthetic specular reflection of orchestral music with an equivalent simulated diffuse reflection sequence showed that these adverse effects are avoided in the diffuse case.

Schroeder (1) and his colleagues (2) have recently reported their search for surface features which produce determinate scattering for use in concert halls and have found surfaces based on Quadratic Residue number sequences. These surfaces are periodic phase gratings which diffract the incident sound and produce scattering amplitudes which are, to a first approximation, determinate in direction and uniform in intensity throughout the half space into which the scattering takes place.

The bandwidth, of this scattering phenomenon is determined by the designer by choosing the dimensions of the surface - the step-widths and depths, and the generating prime number.

Our choice of the scattering bandwidth was determined by the following objectives:

a) to compensate for the dip in the direct sound at grazing incidence by a lateral, specular bass reflection, b) to enhance the timbre of the instruments by a specular high frequency reflection above the design bandwith, and c) to provide diffusion in the orchestral power frequencies.

After studying the number of frequency/bandwidth simulations in anechoic conditions, we chose the design frequency of f_o = 500 Hz, and the prime number of 7 which gives a bandwidth of 2 1/2 octaves.

The diffusers are to be realised in timber. 300 mm wide step widths will be separated by 20 mm thick fins. Architecturally, the front of the fins will be in plane. The principal uncertainties which remained arose from unanswered questions in the theory. With practicable surface configurations, backscattering of high frequencies to the vicinity of the orchestra may well occur instead of the specular reflections toward the audience we hoped for.

Marshall wrote to Dr. Hans Werner Strube at Goettingen who studied the effect of fins of non-zero thickness. The results showed that the expected high frequency backscattering does occur, and the question of its audibility required the use of a model.

Reverberation Time Prediction

One of the interesting results of the Christchurch Town Hall was the discrepancy between predicted and measured reverberation time. We concluded that, due to the special characteristics of a directed reflection sequence hall (DRS) with large surfaces independent of the shell which defines the volume, the Beranek lumped audience absorption figures were not applicable.

Using the existing Christchurch data, an extensive calculation (3) into this anomaly was undertaken which took into account the partial decoupling of the volume by the large reflectors, and reflector and gallery masking of the seating areas. The resultant absorption values were then adjusted to allow for the increased reverberant coupling which the Wellington design provides and these final values used in the Wellington RT calculation. Barron's confirmation of these values in the model is discussed below.

MODEL AND MODELLING TECHNIQUES

The model was constructed from timber and was finished with gloss paint. The diffusors were constructed of a sandwich of hardwood and aluminium fins. It was in a polythane bag and connected to a drying plant. The only absortive area in the model was the seating which was made of specially selected acoustic foam which matched the required absorption at the scaled frequencies.

The techniques employed were very close to those used at Cambridge on the Barbican Concert hall model. Objective tests included use of both loudspeaker sources and a spark source. For temporal/frequency transposition, a Nagra T instrumentation tape recorder was used. The principal innovation in these tests were the use of Technics leaf tweeters rather than electrostatic ultrasonic elements. Recordings were made with a pair of 1/4 in. condenser microphones separated by a model head.

ONE TENTH FULL SIZE MODEL STUDY

Objective Programme and Results

Twelve test positions were chosen to be representative of all the seating areas. Sources were either a controlled spark or a filtered noise burst.

A. 80 msec lateral/frontal energy ratio - This is the measure of spatial impression. Our objective was a ratio of at least -7dB. The mean value over 9 seats was -6.4 dB. The other three seats had deficient lateral reflections but these areas have since been improved by the inclusion of additional reflectors, and while objective measurements have not been made since the surfaces were added, the subjective improvement is most marked.

B. 80 msec early/late energy ratio - This is a measure of clarity and definition. Measurements indicated a uniformly high value throughout, rather higher than for Christchurch (4), and clarity is assured. These values with an average of about +2 dB, are significantly higher than those that would be predicted theoretically for a purely statistical space which behaves exponentially. This clearly points out the difference between our DRS hall design and those of a more classical volume.

C. Reverberation time - Barron's tests in the model affirmed the anomaly of the masking of seating areas by galleries and reflectors and confirmed within reasonable error the lumped absorption values previously derived.

D. Impulse responses - These were produced through the gated integrating energy meter designed by Barron and allowed further understanding of the reflection sequences and time/energy distribution.

Subjective Programme and Results

The subjective impressions correlated well with the objective measurements. The high frequency deprivation due to back scattering from the QR surfaces for seats in the back with oblique reflections does occur and is audible. When the surfaces concerned were modified to planes, the effect disappeared.

Subjective differences in spatial impressions, loudness and clarity were easily discernable between different seating areas. The seats with insufficient lateral energy were clearly the worst in the hall, but when reflectors were added, improved to become comparable with the better seats.

SUMMARY

Appropriate modifications have been designed and included in the contract.

The architects Warren & Mahoney of Christchurch must be acknowledged for their unfailing support and willingness in making the project responsive to acoustical needs. We have never before had such access to a concert

hall design prior to its completion and are extremely confident of the results derived from our studies.

REFERENCES

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