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ACOUSTICAL TESTING OF AUDITORIUM MODELS WITH THE AID OF THE MIDAS PACKAGE

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1 INTRODUCTION

Acoustic modelling is a valuable technique enabling an auditorium design to be investigated and modified at an early stage of development. The behaviour of sound in the auditorium and the acoustic characteristics of the design can be investigated and predicted by investigation of a scale model of the auditorium. This enables the architect to ensure that no major design faults will be encountered after the auditorium has been built.

Although acoustic modelling is of great value to the architect, current traditional model testing techniques have the disadvantages of relatively high costs and long model preparation and testing times. A recently developed set of computer programs known as the Midas Package enables cheaper models to be used and testing times to be shortened. This paper briefly describes the Midas Package and experience gained by the author in the use of the package for testing 1:50 scale auditorium models.

2 MODELLING PRINCIPLE

The acoustic modelling technique depends on the phenomenon that the behaviour of sound in an enclosure is determined by the ratio of wavelength to surface size, and the sound propagation in the model is usually through the medium of air or nitrogen [5]. Thus, the fundamental equation of acoustic modelling is :

$c = d/t = f.l$ where c is the speed of the sound
d is the distance
t is time
f is frequency
l is wave length of the sound [5].

The speed of sound in air is constant. With a scale factor of 1:50, the wavelength must be reduced by 50; and as a consequence, all frequencies must be multiplied by 50 compared with the full-scale. The distance is reduced by 50, and time is automatically reduced by 50 as well. So, the sound behaviour is reproduced in miniature.

The internal structural surfaces of the model are made of materials which have minimum sound absorption coefficient. The main absorbent area is the seating. It is therefore essential that the absorption coefficient of the model seating is properly scaled to the real auditorium seating [2,3].

The scaling factor requires that all measurements have to be done in a high-frequency range (4-100 KHz). Consequently, the sound attenuation in air must be taken into account, due to the influence of air absorption at high frequencies. Attenuation can be minimized by substituting the oxygen in the model atmosphere by nitrogen gas, or by removing water vapour from the model atmosphere by drying the air [3]. However, this means that the model must be made airtight, and therefore with traditional modelling techniques relatively expensive model methods are required.

A further disadvantage of traditional modelling techniques is that testing is a relatively slow process, involving replacement of the atmosphere in the model.

3 THE MIDAS PACKAGE

The Midas Package was developed recently by Polack, Marshall and Dodd, for evaluating acoustic model characteristics [1]. This package has been used for testing a number of 1:50 scale models of auditoria at the University of Salford.

In this application, a type 9000 series 300 Hewlett Packard computer was used for running the package. This computer can run real time tasks and is equipped with a floating-point processor and firmware for fast calculations. It is therefore suitable for signal processing. It is linked to the user environment by a type AD200 analogue-to-digital converter, a printer and a plotter. The AD200 has a sampling frequency >300 KHz.

An electrical spark used as a sound source is triggered by the computer, and an 1/8" microphone captures the impulse response of the spark and sends it to the analogue-to-digital converter. A FFT is used for direct computation of the impulse responses of the spark in the digital signal processing unit. Also, the frequency response of the spark can be equalized.

The main advantages of the Midas Package are firstly that it speeds up the measurement process, and secondly that it uses digital processing to provide numerical compensation for excessive air attenuation in normal atmospheric conditions. This means that the use of dry air or nitrogen gas, which is required with traditional techniques, can be avoided.

The Midas Package is divided into two levels : management and executive. The management level coordinates the measurement procedures including communication with peripherals. The executive level consists of three divisions : initialization, acquisition, and processing.

All parameters needed for the measurements are read into the initialization, which comprises five sections : 1. Measurement characteristics (model scale, pressure, temperature, relative humidity, source-receiver distance). 2. Measurement references (date, name of hall, source and receiver positions, series number). 3. Analogue-to-digital converter parameters (sampling rate, maximum deflection). 4. Signal characteristics (underflow level, number of averages, length of signal, full scale deviation). 5. Acquisition mode (time or frequency domain) [1].

The acquisition division stores data ready for processing by triggering the spark, checks the validity of the energy responses, converts the analog data into digital format, and ensures coherent averaging.

After acquisition has been completed, processing can then be started. Before processing, all parameters in the initialization and acquisition divisions are converted to full-scale by frequency transposition, so that the calculations are related directly to the full-scale auditorium. The energy responses are calculated by the FFT in a broad-band spectrum as well as in the octave-frequency bands. They are compensated for air attenuation by digital numeric compensation, and the results are finally displayed in the form of graphical and written criteria outputs. The output acoustic characteristics obtained from the measured model are RT, EDT, D_50, C_50 and C_80, and loudness.

4 SOURCE AND RECEIVER DEVICES

The directionality of the sound source is important, and an electrical spark source is suitable due to its omnidirectionality. A spark source with tungsten electrodes is discharged inside the model to generate a loud but extremely short crack. The spark source, built at the University of Salford, has a spectrum reaching up to 100 KHz. It has a small electrode gap (0.5 mm) and the discharge voltage is 600 V [1,3].

An omnidirectional microphone is employed as a receiver. An 1/8" B&K 4138 microphone is sensitive to ultrasonic frequencies up to approximately 160 KHz; and it is therefore suitable for 1:50 scale model. To improve omnidirectionality, a nose cone is fitted on the microphone [1,3].

5 ACOUSTICAL TESTING OF AUDITORIUM MODELS

Two auditorium models have been investigated to determine their acoustic quality using the Midas Package. The first was tested using both the traditional method and the Midas Package for comparison, whilst the second used the Midas Package only. Fig.1 shows the diagram of the measurements. To ensure accuracy, the average of 16 spark impulses was taken, which is assumed to be sufficient. Recorded signal length was set at 30 ms in the model scale.

5.1 MULTI-PURPOSE AUDITORIUM MODEL

The first model design corresponds to a multi-purpose auditorium. It was designed on the Vineyard Step Principle [6], purely as a tool for research work. The basic shape is octagonal and the seating capacity is 1200.

Measurements were taken with empty seating, without added absorbent, and with a configured ceiling (i.e. suitable for musical performances). Three sound source positions on the stage and six receiver positions in the seating area were tested.

The model was first tested by the traditional method, the acoustic quality of the model determined was the RT and loudness. This was done by recording the decays with a B&K 7502 Digital Event Recorder after the model had been filled with nitrogen gas in order to minimize air absorption at high frequencies. The source was a piezo electric tweeter loudspeaker (KSN 1038A) connected to a noise generator, and the receiver was an 1/8" B&K 4138 microphone. Secondly, the model was tested by the Midas Package with the same microphone as a receiver but an electrical spark was used to represent the sound source.

The results in Fig.2 show that Midas gave RT values approximately 0.3 seconds shorter than those obtained with the traditional method. However, the difference is not significant when considering that the accuracy for RT measurements is about 5%, and the two values seem to be in agreement.

As regards total sound level, an accurate comparison could not be made, because of the different methods used with the two techniques. M Barron's method was used in the first test, and the direct sound measured at a distance of 10 m from the source was taken as a reference for comparison with the total sound level in the model [4]. On the other hand, Midas evaluated the total sound level by measuring the direct sound in the first 5 ms at a given receiver position, then comparing it by an inverse square law to the equivalent value at a distance of 10 m from the source [1].

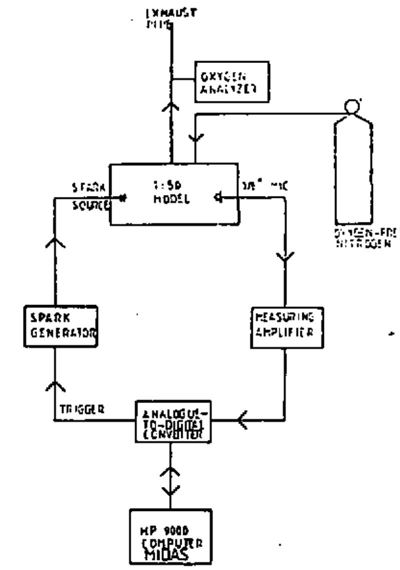

Fig. 1. DIAGRAM OF MEASUREMENT

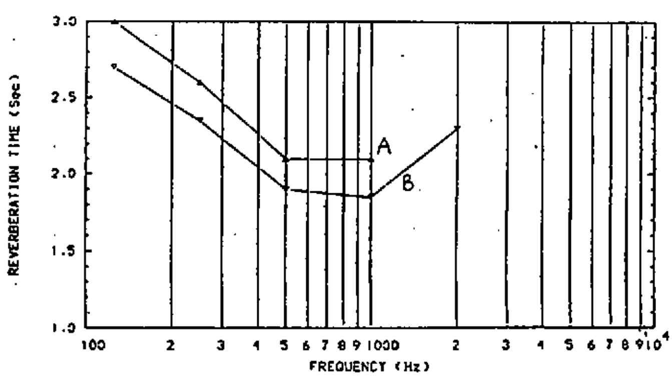

Fig. 2. COMPARISON OF RT MEASUREMENTS
A- by DER, B- by Midas

The main advantage of using the Midas Package is that the values of EDT, D_50, C_50 and C_80 can be computed quickly as well as RT and loudness. The overall results can be seen in Table 1.

Frequency (Hz)	R T (sec)		Loudness (dB)		EDT (sec)	D_50	C_80 (dB)
	DER	Midas	DER	Midas			
125	3.0	2.7	4.8	5.5	1.6	.54	4.9
250	2.6	2.35	4.4	8.0	2.1	.36	-0.4
500	2.1	1.9	5.1	7.5	1.8	.32	-1.2
1000	2.1	1.85	-	-	1.7	.33	-0.9

Table 1. Overall Acoustic Quality of Multi-purpose Auditorium

Two different methods were used to enable a comparison between methods of correcting for air absorption. Measurements were made using numeric compensation on the one hand, and a nitrogen atmosphere on the other. The measurement with nitrogen also involved some numeric compensation but with considerably smaller corrections.

With the first method, the normal relative humidity was estimated at 60% RH for Midas to process the results with numeric compensation. With the second method, 2% RH was set because the 20% oxygen atmosphere in the model was replaced with nitrogen gas. Thus, the numeric compensation was modified by removing the compensation for the absorption due to the oxygen relaxation.

The RT values given by Midas with numeric compensation and with nitrogen gas were not very different, the former were slightly longer up to 1 KHz frequency (Fig.3). On the other hand, the results are not in good agreement for higher frequencies. The reason is because the RH was not measured precisely, but simply estimated at 60% RH, and the RT values at high frequencies are dependant on the RH. When the RH is overestimated or underestimated, the RT could be too long or too short.

5.2 MULTI-PURPOSE THEATRE MODEL

The second model tested is a model of an auditorium which is designed mainly for use as a theatre, and has an orchestra pit, proscenium and fly tower. A fan shape with a curved rear wall was chosen for the basic design, with two balconies to give a total seating capacity of 990. This model was tested only with the Midas Package. In this case the RH of air atmosphere in the model was measured precisely.

The material used for the model seating was pretested to determine its absorption coefficients in the reverberation tank and in the model. Compared with the value given by Beranek [2], the absorption coefficient of the material seems to be a little high in the low frequencies (Fig.4).

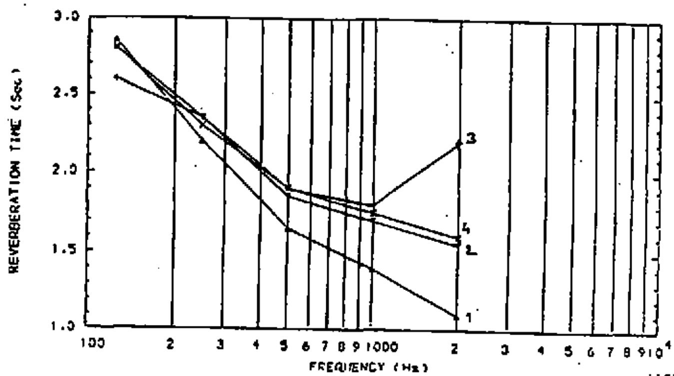

Fig. 3. COMPARISON OF RT MEASUREMENTS
1- Without numeric compensation without N2,
2- With N2, 3- With numeric compensation,
4- With modified numeric compensation and N2

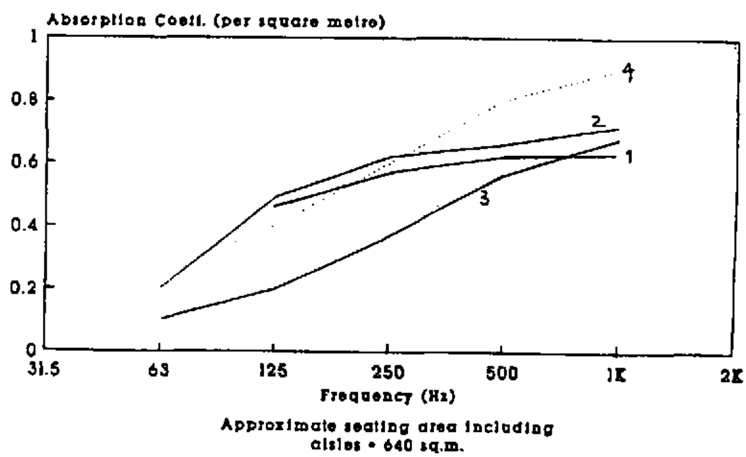

Fig. 4. COMPARISON OF ABSORPTION COEFFICIENTS Of MODEL SEATING
1- Measured in reverberation tank, 2- Measured in model,
3- According to Beranek, 4- Calculated with audience

Four source positions and 10 receiver positions, including one of each in the orchestra pit, were selected. The test results are given in Table 2. The RT proposed was 1-1.15 sec at mid-frequencies to accommodate theatre requirements. The RT values obtained are satisfactory for a theatre, although the values are slightly higher than the predicted values at low frequencies. D_50 values for receivers 7,8 and 9 on the second balcony are good for a theatre (>50%). The ground floor positions (1,2 and 3) are not quite so good due to the values being under 50%. The installation of additional panels improved this. However, the overall value of D_50 is adequate for a theatre.

Frequency (Hz)	R T (sec)	EDT (sec)	Loudness (dB)	D_50	C_50 (dB)	C_80 (dB)
63	3.35	3.27	12.14	.49	1.17	2.54
125	1.4	1.50	10.82	.44	0.09	1.61
250	1.3	1.29	9.13	.50	0.88	2.98
500	1.2	1.09	9.48	.53	0.76	3.59
1000	1.2	1.03	8.39	.57	1.55	4.22
2000	1.3	1.04	9.98	.59	2.00	4.30

Table 2. Overall Acoustic Quality of Multi-purpose Theatre

Before the measurements were taken, it was predicted that significant echo problems would be encountered due to the curved rear wall of the theatre. However, from the impulse responses obtained, only one source-receiver indicated a significant echo between 80-100 ms (source 3 on the side stage to receiver 2 on the ground floor). This was overcome by covering the rear wall of the first balcony with absorbent material.

The configured ceiling has a void for installing ducting and services. During the tests, vertical absorbent felt pads with an equivalent total area of 175 m2 were placed in the roof void in order to simulate the absorption panels which will be installed in the roof void of the real theatre. This was made with the proscenium blocked off in order to avoid the fly tower obscuring results. Fig.5 gives a comparison of RT values measured in the model with and without the absorption panels. These values coincide, although a slight difference was shown in mid-frequencies. Therefore, extra absorption in the ceiling void did not influence the RT values in the auditorium, presumably due to the shading effect of the ceiling panels.

A test was carried out to investigate the theatre when the fly tower is empty without any absorbent treatment. Then the rear stage was covered with absorbent felt, and some absorbent material was hung in the fly tower. The RT values were reduced by approximately 60% in mid-frequencies by this treatment (Fig.6). In practice, the fly tower contains curtains, stage scenery and other absorbent materials, which will provide considerable absorption although it appeared to be safer to include absorbent treatment on the rear wall of the stage.

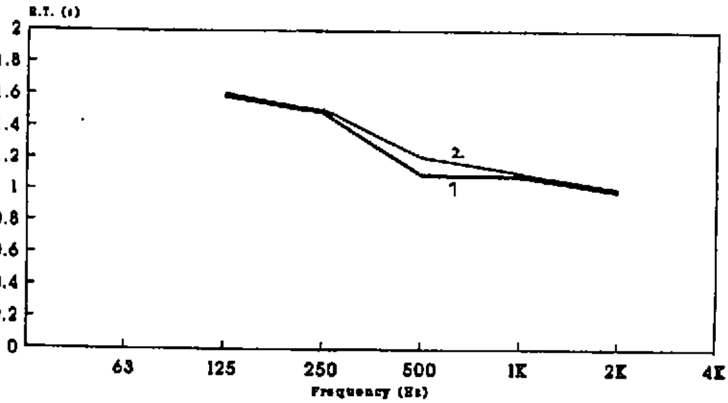

Fig. 5. COMPARISON OF RT MEASUREMENTS
1- With 175 m2 absorbent felt pads, 2- Without absorption

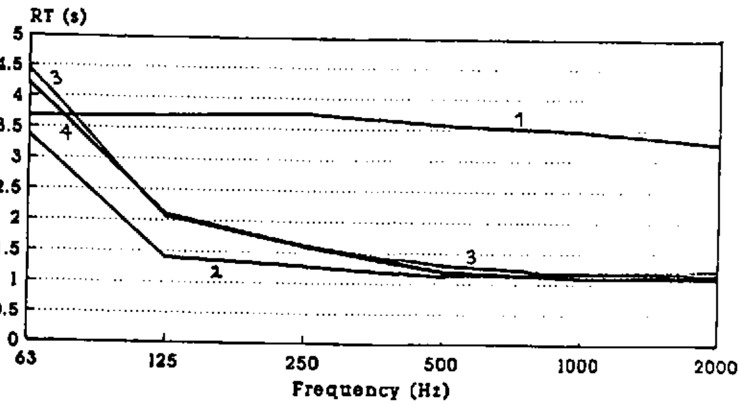

Fig. 6. COMPARISON OF RT MEASUREMENTS
1- Empty fly tower, 2- Fully absorbent fly tower,
3- Unoccupied, 4- Occupied (calculated)

6 CONCLUSION

The Midas Package has been used to investigate two different types of auditorium models under different test conditions. The results obtained so far are satisfactory, especially when compared with results obtained by the traditional method. On the other hand, it is difficult to obtain results below 125 Hz and over 2 KHz due to the limited response of the microphone used and the low spark energy at low frequencies.

Once the initialization procedure is set, it must contain accurate parameters, especially the RH, temperature, and length of signal to be recorded. Otherwise the results achieved will not be appropriate and incorrect conclusions will be drawn.

Experience has shown that the package can make a valuable contribution to the design process, mainly because the tested model does not have to be airtight, and therefore, a simple and inexpensive model may be used. In addition, the time required for processing data from initialization to output of final results relating to the acoustic quality of the model is relatively quick.

7 REFERENCES

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