FINITE-ELEMENT MODELING OF A REVERBERATION ROOM: EFFECT OF THE ROOM SIZE AND SHAPE ON MEASUREMENT ACCURACY

Md Mehadi Hasan †1 and Murray Hodgson ‡1
[1]Department of Mechanical Engineering, University of British Columbia, Vancouver, BC, Canada.

1 INTRODUCTION

The reverberation-room method, which assumes a diffuse sound field, has long been used for various standardized room-acoustical measurements – i.e. absorption coefficient, source power level, transmission loss, etc. However, unsatisfactory opinions regarding the accuracy of the method, especially at low frequencies, have been reported over the years [1, 2]. This might be due to deviations from the assumed diffuse-field concept, which is very challenging to implement from an application point of view.

To investigate the problem, and find an optimal solution, a number of reverberation rooms of different sizes and shapes have been studied; their capacity to approximate a diffuse sound field is analyzed by means of descriptors like a statistically-based cut-off-frequency definition, spatial uniformity of the reverberant sound field (SPL), prediction accuracy of reverberation times (RT), etc. Results obtained with the help of a numerical finite-element-based modal approach are discussed; in particular, the effect of different room sizes and shapes on the measurement accuracy are explained. Based on these findings, recommendations are proposed regarding the sizes and shapes of reverberation rooms that will give better sound field diffuseness and, hence, better prediction accuracy.

2 THE REVERBERATION ROOMS

Four different shapes of reverberation rooms, all equipped with a number of diffusing panels hanging from the ceilings, were considered, to determine the degree of field diffuseness and, hence, the prediction accuracy. The reverberation rooms considered were: Room #1 – rectangular-shaped with the shortest vertical dimension; Room #2 – rectangular-shaped with the longest vertical dimension; Room #3 – oblique-shaped with the longest vertical dimension; and Room #4 – oblique-shaped with the shortest vertical dimension. For each of the room shapes, three volumes of 150 m^3, 125 m^3 and 82 m^3 were considered.

† mehadi@alumni.ubc.ca
‡ murray.hodgson@ubc.ca

Predictions were performed with 2 sources and 5 receivers in seven third-octave bands ranging from 63 to 250 Hz. Positioning of the sources and receivers was performed based on the standards' prescriptions [3]. A finite impedance value is applied at boundaries to include damping.

3 RESULTS

3.1 Room #1: Rectangular-Shaped with Shortest Vertical Dimension

Predictions done in Room #1 (see Table 1) reveal that the required minimum number of modes of 20, which is the basis for the statistically-based cut-off-frequency definition [4], occurs from the 125-Hz third-octave band for all three room volumes. That means that prediction can be done from this frequency band. However, the standard deviation, which is a measure of the spatial uniformity of the reverberant sound field, yields values smaller than the ISO-prescribed limit of 1.5 dB [3] from the 160-Hz third-octave band for the 150 m^3 and 125 m^3 room volumes. In particular, for the 150 m^3 volume, the band-averaged standard deviation and the RT-prediction accuracy are relatively better than for the two other room volumes.

3.2 Room #2: Rectangular-Shaped with Longest Vertical Dimension

For Room #2, predictions are presented in Table 2. It is clear that the required number of modes 20 occurs from the 125-Hz band. The SPL deviations are also smaller than 1.5 dB from the 160-Hz band. However,

Table 1. Prediction of modal composition, SPL deviation and RT accuracy in Room #1.

Freq. band, Hz	Number of modes			SPL deviation, dB			RT- accuracy, %		
	Volume, m^3			Volume, m^3			Volume, m^3		
	150	125	82	150	125	82	150	125	82
63	5	5	5	3.2	4.2	5.1	27	22	43
80	11	8	6	2.8	1.2	3.6	26	27	48
100	18	17	11	1.7	2.1	2.4	31	32	21
125	35	28	20	2	2.5	4.1	21	15	27
160	61	53	37	1.3	0.9	0.9	12	7	14
200	116	99	69	1.3	1.1	1.5	2	9	3
250	219	188	123	0.6	1.2	1.6	1	4	1

Table 2. Prediction of modal composition, SPL deviation and RT accuracy in Room #2.

Freq. band, Hz	Number of modes			SPL deviation, dB			RT- accuracy, %		
	Volume, m^3			Volume, m^3			Volume, m^3		
	150	125	82	150	125	82	150	125	82
63	5	5	5	3.5	1.7	3.2	30	32	35
80	11	9	6	1.6	1.2	3	29	21	57
100	19	14	12	1.2	2.6	1.1	18	22	42
125	36	31	20	1.7	0.5	2	31	17	31
160	61	54	37	0.9	0.8	0.7	19	15	27
200	116	100	68	1	0.7	2.1	13	9	25
250	219	188	125	0.8	0.6	0.8	12	12	16

the RT-prediction accuracy is not as good as that obtained in Room #1.

3.3 Room #3: Oblique-Shaped with Longest Vertical Dimension

For Room #3, predictions are presented in Table 3. Like Room #2, the required minimum number of modes of 20 occurs from the 125-Hz band, both for the 150 m^3 and 125 m^3 room volumes. SPL deviations smaller than 1.5 dB occur from the 160-Hz band, and the RT-prediction accuracy is also better for these two volumes than for the 82 m^3 volume.

3.4 Room #4: Oblique-Shaped with Shortest Vertical Dimension

For Room #4, the results Room #3 are also true for Room #4, as presented in Table 4. However, the band-averaged SPL deviations, as well as the RT-prediction errors, are smaller in Room #4 than for Room #3.

4 DISCUSSION

Considering all the predictions discussed in section 3,

Table 3. Prediction of modal composition, SPL deviation and RT accuracy in Room #3.

Freq. band, Hz	Number of modes			SPL deviation, dB			RT- accuracy, %		
	Volume, m^3			Volume, m^3			Volume, m^3		
	150	125	82	150	125	82	150	125	82
63	6	6	4	5.6	2.5	5.9	31	29	45
80	11	9	7	3	1.7	4.8	30	28	31
100	19	15	11	1.6	2.4	1.4	21	17	21
125	34	28	19	2.5	2	2.5	17	19	20
160	63	54	37	0.9	0.5	0.7	11	18	20
200	118	99	67	0.7	1	1.9	5	4	16
250	221	187	125	0.8	0.4	1.2	9	11	17

Table 4. Prediction of modal composition, SPL deviation and RT accuracy in Room #4.

Freq. band, Hz	Number of modes			SPL deviation, dB			RT- accuracy, %		
	Volume, m^3			Volume, m^3			Volume, m^3		
	150	125	82	150	125	82	150	125	82
63	5	5	5	3.3	2.2	5.1	35	33	51
80	11	10	9	1.3	2.6	6.4	33	28	62
100	18	15	12	2.9	1.1	1	16	20	43
125	33	28	21	2.7	1.9	0.8	11	12	38
160	64	56	36	1.1	1	0.8	9	11	33
200	118	101	68	0.7	1.1	1.9	2	7	25
250	224	188	123	1.4	0.3	1.1	5	7	26

it is evident that the number of modes of 20 required to start prediction occurs from the 125-Hz third-octave band for all of the reverberation-room shapes and volumes. It is also noticeable that the 150 m^3 room gives better prediction accuracy than the two other room volumes for different room shapes. Comparing results for different reverberation-room shapes make it clear that the oblique-shaped room with the shortest vertical dimension (Room #4) gives better prediction accuracy than the other room shapes for different room volumes.

5 CONCLUSION

Based on the above findings, it can be concluded that prediction from the 160-Hz third-octave band, using the 150 m^3 oblique-shaped reverberation room with the shortest vertical dimension, will give better RT-prediction accuracy and smaller SPL spatial variation than the other reverberation rooms of different volumes and shapes.

REFERENCES

[1] C. W. Kosten, “International comparison measurement in the reverberation room”, *Acustica* 10, 400–411 (1960).

[2] M. Vercammen, “Improving the accuracy of sound absorption measurement according to ISO 354”, *Proceedings of the International Symposium on Room Acoustics*, Melbourne, Australia (2010).

[3] Determination of Sound Power Levels and Sound Energy Levels of Noise Sources Using Sound Pressure - Precision Methods for Reverberation Test Rooms, ISO, Geneva, 2010.

[4] R. Ramakrishnan and A. Grewal, “Reverberation rooms and spatial uniformity”, *Canadian Acoustics*, vol. 36, 2008, pp. 28-31.