A Comparison of Architectural Acoustical Scale Models to Their Prototype Room

Gary W. Siebein and Chandler E. Rozear

Department of Architecture
231 ARCH
University of Florida
Gainesville, Florida 32611
U. S. A.

KEYWORDS

Architectural Acoustics, Acoustics, Acoustical Modeling, Auditorium Design, Scale models

ABSTRACT

The objective of this research is to determine the limits and validity of the acoustical data that can be obtained from architectural study models. A range of psycho-acoustic indices were measured in a 1500 seat multi-purpose theater. The measurements made in the full size room were compared to measurements made in detailed 1:10, 1:40 and 1:100 scale models of the room as well as a series of progressively less refined models at 1:40 scale. The measurements were grouped in 4 general categories: reflectogram interpretations, temporal energy ratios, sound build up measurements and sound decay measurements. A significant amount of information can be obtained from the model studies on a zone by zone basis. Measurements in the 1:10 scale model very closely duplicated the measurements in the full size room especially in the more diffuse zones of the room. The less refined 1:40 scale models showed a close relationship to both the more detailed 1:40 scale model and the full size room so long as the room volume and the relative amount of diffusion in the room were accurately modeled. Some problems with air absorption were evident in the higher frequencies in the smaller models.

Comparaison entre les Résultats Obtenus dans des Expériences Acoustiques Conduites sur des Maquettes d'un Espace et Celles Menées dans l'Espace Prototype Même

Gary W. Siebein and Chandler E. Rozear

Department of Architecture
231 ARCH
University of Florida
Gainesville, Florida 32611
U.S.A.

MOTS CLÉS

Acoustique Architecturale, Acoustique, Maquettes Acoustiques, Conception d'Auditorium, Maquettes

SOMMAIRE

Le but de cette recherche est de déterminer les limites et la validité des résultats d'analyses acoustiques realisées sur des maquettes d'étude. Une série d'indices objectifs psycho-acoustiques ont été mesurés dans un auditorium de 1500 fauteils destiné à diverses fonctions. Les mesures prises dans la salle de l'auditorium même ont été comparés à celles effectuées sur des maquettes construites aux échelles 1:10, 1:40, et 1:100, et aussi a une série de maquettes progressivement moins réfinés à l'échelle 1:40. Les mesures ont été classées en quatres typologies générales: interpretation reflectogrammétriques, rapports d'energie temporelle, mesures de croissance du son, et mesures de décroissance du son. Une somme importante d'information peut être obtenu en se servant des maquettes en etudiant les divers zones de l'espace. Les résultats des analyses pour la maquette à l'échelle 1:10 ont ete tres semblables a ceux obtenus dans l'espace meme, surtout pour les endroits les plus diffus de l'espace. Les maquettes moins refinees a l'echelle 1:40 ont demontrées un rapport proche de la maquette plus détaillé à l'échelle 1:40. On a remarqué également ce même rapport entre les maquettes moins réfinées et l'espace même, dans le cas ou une maquette est construite pour le volume de l'espace et la diffusion relative de la chambre. Pour les hautes fréquences dans les maquettes aux échelles les plus petites, le phénomène d'absorption d'air a causé quelques problemes.

METHODOLOGY

The research consisted of a case study comparison of data recorded in the prototype room and 1:10, 1:40 and 1:100 scale models of Bailey Hall at Broward Community College in Fort Lauderdale, Florida. Figure 1 shows a plan and section of the auditorium. A series of 3 progressively less refined models were constructed at 1:40 scale to determine how much detail should be built into the models in order to yield useful acoustical data. Measurements taken at multiple locations in the room and at comparable locations in each of the successively smaller scale models are the average of 5 bursts.

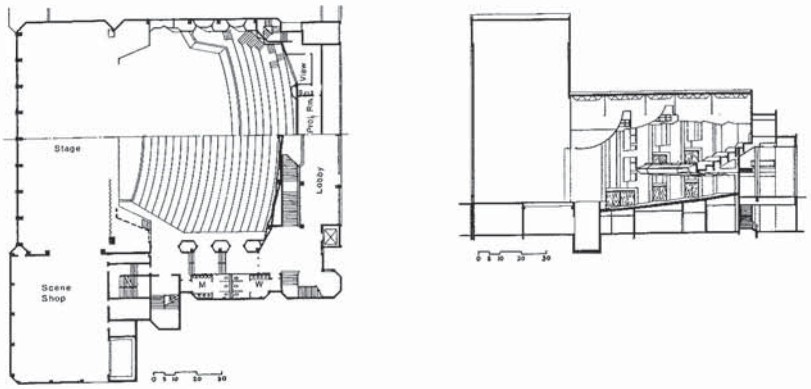

Figure 1. Plan and section of Bailey Hall.

Instrumentation

A Grozier Technical Systems spark source, model GTS-51, was used in the model tests as the sound source. A modified .38 caliber S&W revolver was used as the source in the prototype room (1).

Recordings were made in the prototype room with a GR 0.50" microphone and a Nagra IV-SJ tape recorder. In the models the receiver was a BBN 0.10" microphone with a P-16 power supply. A Grozier Technical Systems scaling amplifier and waveburst processor and a Tektronix T-912 oscilloscope were used to analyze both the prototype and model room data. The data were processed using a computer analysis program adopted from a Lotus 1-2-3 spreadsheet (4).

Absorption coefficients of model building materials at ultrasonic frequencies were based on earlier research by Brebeck (2) and Lyon (3). Typical sound reflecting materials used were heavy chipboard and plywood. Various types and thicknesses of plastic foams and heavy felts were typical of sound absorbing surfaces.

Acoustical Design Criteria

The specific measurements studied were based on an extensive literature search of psycho-acoustic design criteria proposed by various researchers (5). The focus of this study was to evaluate the degree to which these criteria measured in the full size room could be measured in physical models of descending scales and degrees of detail. The measurements were grouped in 4 major categories: 1. reflectograms; 2. temporal energy ratios (both early to total and early to late energy ratios); 3. sound build up measurements; and 4. sound decay measurements.

RESULTS

Reflectogram analysis

Visual analysis of the reflectograms showed that there were several distinct zones in the auditorium in terms of the pattern and intensity of reflections arriving at the listeners including center main floor, side main floor, under balcony and balcony. These observations were consistent through all of the model studies (Refer to figure 2).

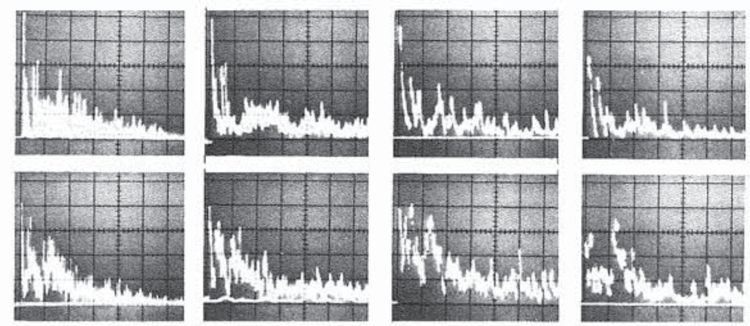

Figure 2. Comparison of reflectograms at center main floor position (top row) and center balcony position (bottom row) for (from left) prototype room, 1:10, 1:40 and simplified 1:40 scale models.

Temporal energy ratios

The temporal energy ratios compare the acoustical energy levels in the sound pulse over discrete periods of time. They are intended to summarize the temporal distribution and intensity of the sound reflections that arrive at a listener's position (6). This category has been sub-divided into the 2 sub-categories listed below.

Early to total energy levels compare the energy level in the early portion of the sound pulse (typically the first 50-80 ms) with the total energy level. Deutlichkeit, clarity, etc., formed the basis for these measurements (6).Early to late energy levels compare the later sound energy level with the early energy level (7).

Figure 3 shows the early to late energy ratios for wide band noise at a center main floor position of the auditorium. Notice how closely the model data (even the 1:100 scale model and the simplified 1:40 scale model) follow the prototype room data. Figure 4 compares the early (0-50 ms.) to the late (50 ms.-infinity) energy levels at the center balcony position on an octave band basis. The models follow the prototype room fairly well. In the 2000 Hz. and 4000 Hz. octave band, the model curves move sharply up indicating the loss of late energy due to air absorption.

There exists a well documented consensus that the early period of the sound build up process is critical to the perceptual quality of the sound field in a room (4,5). Furthermore, both the frequency content and angle of incidence of these early sound pulses are major contributing factors to the perceived acoustical quality of a room (8).

Sound build up measurements

The sound build up measurements included rise time and initial time delay gap. Rise time (9) was measured at both 5 dB and 3 dB less than the steady state level. The rise times at the center balcony seat are listed in Table I. There was a wider spread of data when analyzed on an octave basis.

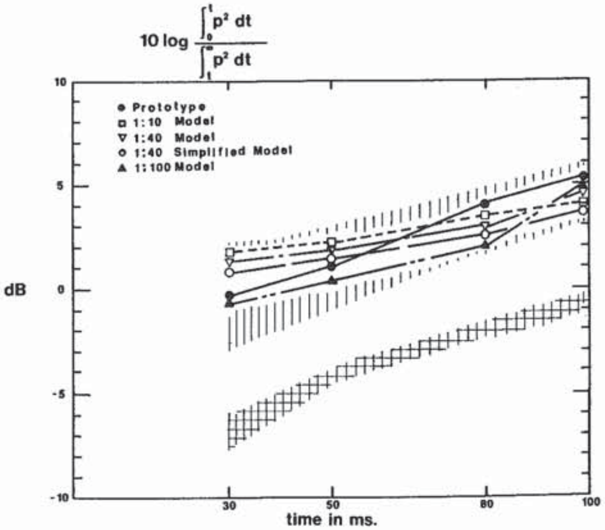

Figure 3. Early to late energy levels in the series of models for wide band noise at the center main floor position. The vertically hatched area shows the range of measurements in multi-purpose proscenium halls at the equivalent position. The cross-hatched area shows the range of the measurements in rectangular concert halls at the equivalent position. The early to total energy ratios showed an even tighter grouping throughout the testing.

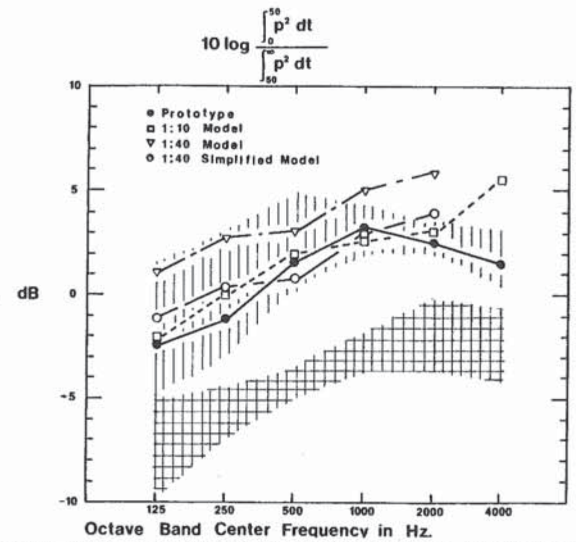

Figure 4. Octave band analysis at the center balcony position for early to late energy at 50 ms. The vertically hatched area shows the range of measured values in multi-purpose proscenium halls at the equivalent position. The cross-hatched area shows the range of measured values in rectangular concert halls at the equivalent position.

The initial time delay gap, considered an indication of intimacy, is the time between the direct sound pulse and the first reflection (10). The initial time delay gap was read off the oscilloscope trace. Once an agreement could be reached as to what the direct sound was and what the first reflection was, this measurement could be made in even the smallest and most crudely built models. Results are summarized in Table I.

Sound decay measurements

The sound energy decay measurement was the dB decay in the first 160 ms (as an indication of early reverberation time) (11). For wide band noise this measurement was reasonably uniform in all of the models. Results are summarized in Table I. Octave band analysis showed that the 1:10 model closely duplicated the prototype room while the smaller scale models showed a greater dB decay which is indicative of the higher frequencies and therefore greater air attenuation present.

CONCLUSIONS

The large scale models are very labor intensive to construct, but yield useful results. The upper frequency of interest was limited in the smaller models due to problems with air absorption at ultrasonic frequencies. This trend was clearly shown in figure 4.

The 1:40 scale models have shown reasonable results with the echogram interpretations, initial time delay gap, and temporal energy ratios. Even extremely crudely built models can yield a significant amount of information especially for unfiltered noise studies.

Table I. Comparison of wide band noise signal at center balcony position.

Room	Initial Time Delay	Rise Time 5 dB	Rise Time 3 dB	dB Decay 160 ms
Prototype	0.012s	0.0186s	0.0514s	4.6 dB
1:10 model	0.011	0.0193	0.0492	6.3
1:40 model	0.011	0.0183	0.0524	5.0
1:100 model	0.007	0.0225	0.0565	7.5

REFERENCES

1. Lamothe, M.R. and J.S. Bradley. "Acoustical Characteristics of Guns as Impulse Sources". Canadian Acoustics, Vol. 13, (2), pp.16-24, (1985).
2. Brebeck, D. "Sound and Ultrasound Absorption of Materials in Theory and Practice; Especially in View of Building Acoustic Scale Models in Measure 1:10". Doctoral Thesis, (University of Munich: February, 1971).
3. Lyon, Richard H. Acoustical Modeling Handbook. MIT, (Cambridge, MA, 1975).
4. Rozear, Chandler E . "An Acoustical Comparison of a 1:10 Scale Model to Its Prototype Room" M.Arch. Thesis, (University of Florida, Gainesville, Florida, 1985).
5. Siebein, Gary W. "The Evaluation of Acoustical Modeling Techniques for Use in the Architectural Design Process". M.A.Arch. Thesis, (University of Florida, Gainesville, FL, 1980).
6. Cremer, Lothar. Principles and Practices of Room Acoustics. Theodore Schultz trans. Applied Science Publishers, (London, 1982).
7. Schultz, T.J. "Acoustics of the Concert Hall". IEEE Spectrum, Vol. 2, (6), pp. 5667, (1965).
8. Barron, M. and A.H. Marshall. "Spatial Impression Due to Early Lateral Reflections in Concert Halls: The Derivation of the Physical Measure". JSV, Vol. 77, (2), pp. 211-232, (1981).
9. Jordan, V.L. Music Room Acoustics. Part 1: Acoustical Criteria and Acoustical Qualities of Concert Halls. The Royal Swedish Academy of Music, (Stockholm, 1977).
10. Beranek, L.L. Music, Acoustics and Architecture. John Wiley and Sons, (New York, 1962).
11. Kuttruff, Heinrich. Room Acoustics. John Wiley and Sons, (New York, 1973).

This project was funded by the National Science Foundation.

Computer Program for predicting the Energy Consumption and Operating Costs of Boiler Plants

F.M. van Bergen

TNO-Division of Technology for Society
P.O. Box 342, 7300 AH Apeldoorn, The Netherlands

KEYWORDS

Boiler Plant, Energy Consumption, Space Heating

ABSTRACT

Designing new boiler plants or renovating existing boiler plants for heating buildings will generally mean that a number of alternatives will have to be evaluated. Careful choosing can result in substantial reductions in costs and/or energy consumption. Since this evaluation procedure is extremely labour-intensive, only a few alternatives are usually considered. The aim was to develop a boiler selection program for analysing rapidly and accurately the energy consumption and operating costs of boiler plants.

The principle of the boiler selection program is based on the calculation of the hourly useful output and the energy consumption of the boiler plant. To do this a theoretical model was included in the boiler selection program, containing the ratios between full-load efficiency, standstill-loss and utilization efficiency. Also included in the boiler selection model is an economic evaluation feature. The program simulates the behaviour of the boiler plant based on output data covering not only the boiler plant to be simulated and economic factor, but also the hourly heat demand and outside temperatures.

The boiler selection program developed has been validated by tests in an existing boiler plant. The discrepancies in energy consumption between the actual measurements and the simulation calculations were between 0.1 and 5.7%. It can be concluded from this that the correlation between reality and simulation is good.