CONCERT HALL ACOUSTICS: 25 YEARS OF EXPERIENCE

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Concert hall acoustics became an engineering science at the turn of the century through the pioneering experiments of Wallace C. Sabine of Harvard University. His works led to the well known reverberation equation and to the development of acoustic materials for control of reverberation and noise.

Many concert halls and opera houses were built in the next half-century and a substantial literature accumulated. That literature produced much opinion based on the success or failure of those halls, but no new scientific principles ensued that were useful in guiding design.

The classical halls possessing satisfactory acoustics are Boston's Symphony Hall and Vienna's Grosser Musikvereinssaal. Rectangular in shape, with sound-diffusing interior surfaces, shallow balconies and stages that communicate easily with the main auditorium, they receive the most ardent praise of the world's musicians. Unlike the production of musical instruments, copies of such successful halls are seldom attempted, because each owner and architect seems to prefer a monumental space, new in concept, guided, of course, by current building regulations and materials.

The first large completely-new concert hall built after World War II was London's Royal Festival Hall (1951). The world's acoustical experts were consulted by the acoustical consultants to the architect, and there seemed little possibility that the hall would have any problems that could not be corrected easily. Upon completion, it was found that the reverberation time was unexpectedly low, less than 1.5 sec at mid-frequencies, fully occupied. Complaints were widespread. The desired reverberation time of 1.7 sec which the consultants had hoped to achieve by providing in the design for a cubic volume per person of about 6 m^3 (210 ft^3) was missed by 12 percent. Alternatively stated, the absorption per person was assumed to be about one-half of that actually found in later studies. Instead of attributing the low reverberation time to too small a cubic volume per person, the authors believed that instead the ceiling was highly absorbent.

This mis-diagnosis of the reason for the low reverberation times in Festival Hall unfortunately led later to several large halls having the same problem of unexpectedly low reverberation times. Examples are the Fredric Mann Concert Hall in Tel Aviv (1957), the Alberta Jubilee Halls in Edmonton and Calgary (1957), and the Beethoven Hall in Bonn (1959).

Having received several commissions for consultation on new halls, and desiring to understand why these lower-than-expected reverberation times occurred, I assembled the dimensional drawings and the measured reverberation times for over forty existing halls and studied their interrelations. From that analysis I found that, "The absorbing power of a seated audience, orchestra and chorus in a large hall for music increases in proportion to the floor area occupied, nearly independent of the number of seated persons in those areas (uniform distribution of persons assumed)" (1959). I believe that this is one of two important contributions that I have made to concert hall design.

My next experience of significance came from the design of the orchestra enclosure and acoustical canopy in the Tanglewood Music Shed in Lenox, Massachusetts, which was completed in 1959. This summer hall, seating over 5000 persons and dedicated in 1938, possessed adequate reverberation time, about 2 sec at mid-frequencies, but there were constant complaints about the difficulty of hearing vocal and instrumental soloists by people seated in the front half of the hall. Also, there were complaints from the players about the ability of those of one section of the orchestra to hear another. To the staff at Bolt Beranek and Newman, it appeared that those complaints might be alleviated by placing more sound diffusing walls around the orchestra and by installing a large irregular overhead canopy over the front part of the hall. This canopy is comprised of triangular panels of different sizes, each non-planar. The longest sides of these triangular panels range in length from 2.5 to 8 m and the open spaces between them form triangles of about the same size, so that the suspended array is about fifty percent open.

Upon completion, the improvement in the acoustics was hailed by musicians and music critics alike as "fantastically successful" (Isaac Stern), "the acoustical enclosure is wonderful" (Eugene Ormandy), "fine acoustics" (New York Times) and "total glory and sheer magnificence" (Boston Globe). The success of this design has been difficult to duplicate in other types of halls and canopies, for reasons that I hope to point out later in this paper.

Another hall for which I was consultant was the Arie Crown Theatre in Chicago (now razed). Following its first concert complaints were expressed about its acoustics. The room sounded dead and the performing orchestra sounded remote. The following day I sat in the empty hall and tried to imagine why this hall and the Music Shed in Tanglewood were so different. The problem could not be the reverberation time, because the Arie Crown was only slightly less reverberant (1.7 sec at mid-frequencies) than Boston Symphony Hall (1.8 sec), nor could it be the large seating capacity (about 5000 seats) because Tanglewood had the same capacity. One observable difference from Symphony Hall was that it was not rectangular. Instead, like Tanglewood it fanned out rapidly starting from the proscenium.

It suddenly became clear to me that the characteristic that Tanglewood and Symphony had in common was an early return of the first reflections to the listener after (s)he had received the direct sound. In Symphony Hall, these first reflections are returned laterally to the main-floor audience by the balcony facia while in the revised Tanglewood Shed the reflections are returned by the overhead panels. In each, the difference between the arrival of the first of the early reflections and the arrival the direct sound at about the 15th row was less than 20 msec. Only this fact seemed to separate Arie Crown from the other successful halls.

I named the difference in the time of arrival at a listener's ear of the first of the reflected waves and the direct sound wave, the initial-time-delay gap.

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I then proceeded to collect acoustical and dimensional data on more halls and interviewed about fifty major orchestral conductors and music critics in America, United Kingdom and Europe to learn their judgments of the acoustical qualities of those halls. There were fifty-four concert halls and opera houses in all. I calculated the initial-time-delay gaps, t_I, and found that t_I was the single most important factor correlating with the ratings that the conductors and music critics gave to the halls. The next most critical factors were mid-frequency reverberation times and the ratio of the low-frequency reverberation times to those at mid-frequencies. Other factors of importance included adequacy of diffusion, loudness of the sound, quality (blending) of ensemble at the sending end and freedom from noise and echo.

Identification of the importance of the initial-time-delay gap in concert halls was my second significant contribution to the science of acoustics.

The next section of this paper is devoted to a slide discussion of desirable and undesirable characteristics of overhead panels in several halls, including the Joseph Meyerhoff Symphony in Baltimore, the Roy Thompson Hall in Toronto and the original Philharmonic Hall in New York. This will be followed by a slide discussion of recent movements in design of concert halls where slanted side-panels or surfaces are introduced for the purpose of providing short intitial-time-delay gaps by reflections that arrive at the listeners' ears laterally. Halls considered are New Zealand's Christchurch Town Hall and Wellington Michael Fowler Center, Tokyo Metropolitan Festival Hall, and Orange County California Performing Arts Center. Comparisons will be made between lateral and overhead reflections.

An optical method for use in completed halls for determination and adjustment of the effectiveness of reflecting panels in producing early reflections is described using techniques devised and data provided by T. J. Schultz.

Based on a listening experience in the original New York Philharmonic Hall, a new meaning to sound diffusion in concert halls will be advanced for discussion.

Y. Ando, in a recent book, has advanced four parameters in the sound arriving at a listener's ears which he has found are statistically independent of each other and are of greatest importance in the subjective preference of the sound in concert halls. These are (1) the preferred initial-time-delay gap, (2) the preferred listening level, (3) the preferred reverberation time subsequent to the arrival of early reflections, and (4) the magnitude of the preferred measured interaural cross correlation (IACC). The first three of these are Temporal-Monaural Criteria. The fourth is a Spacial-Binaural Criterion. As different music is performed in a hall, the total preference value changes according to the auto-correlation function of the music. I attempt in this paper to make some early observations of the parameters by comparing my earlier studies with Ando's "Design Study."